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Research paper

Online Healthcare Monitor System Based on Optical Wireless and FBG Sensors

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Abstract

In this work, a practical wireless optical communication system has been proposed for the purpose of monitoring the health condition of patients who are in hospital operating on the basis of the wireless communication system and fiber sensors. The suggest practical system employ a diffuse optical broadband link technique based on laser Li-Fi the technology, Fiber Bragg grating (FBG) sensors was investigated. The focused on optical fiber sensors (pressure and temperature) for medical applications because it's small size, immunity to electromagnetic interferences and their suitability for remote monitoring. Fiber Bragg grating (FBG) based (blood pressure, temperature) sensors is designed and implemented using a conventional laser source, Optisystem version 15. The collected data from sensors is transmitted to main unit, the suggested system tested under different operating conditions such as , optical link distance, laser power and transmitter angles, all operating conditions was successively demonstrated.

Keywords: *Light-Fidelity, Laser Li-Fi, Optical wireless channel, diffuse channel, Fiber Bragg Grating.*

1. Introduction

The following sections are to provide the theoretical knowledge related to the Li-Fi technology where the Li-Fi is an alternative of a Wi-Fi technology and it used a light to transmit data. The spectrum of used light located in visible light IR, Ultraviolet [1]. Li fi technology used as carrier visible light coherent (LD) or non coherent (LED). Its very fast ,low cost optical version of Wi-Fi. In this research paper we used laser bulb instead of LED as a carrier . the lase bulb has high on off ratio if we compared with LED on-off ratio. In our work we proposed a fiber Bragg grating (FBG) for on line monitor patient health care . The implemented fiber sensor system based FBG was transmitted data through laser Li-Fi technology. John et al 1995 provide a wireless communication system using non direct optical wireless channel to transmitted 100Mb/s data with carrier power 269mw through a circle with 4 m radius [1]. Rahul et al 2016 introduce optical wireless system to transmit audio signals using Li-Fi technology [2]. Porselvi et al (2017) introduce a health care monitor system using Li-Fi network based on electrical wireless sensor for monitor temperature , heartbeat , and pressure and then convert electric signal into optical signal and transmit it through optical wireless channel, one of the drawback of this method the electrical to optical conversion this process will limit the data rate of optical system [3]. In our proposed system we suggest a patient monitor system completely proses the data in optical domain where all the used sensors work in optical field.

2. FBG Background

In the following section we write the general theorem of propagated light wave in fiber Bragg Grating (FBG) as shown in fig.(1), the mathematical model for FBG included periodic propagation , linear and nonlinear effect . The periodic behavior of FBG given by the waves propagated in this medium [4].

$$\sin(\theta_i) - \sin(\theta_r) = m\lambda = \bar{n}\Lambda \text{ ---} \quad (1)$$

Where: Λ is the grating period , $\bar{n}$ medium index , θ_i incident angle, θ_r reflected angle .

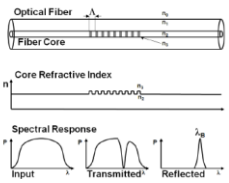


Fig. 1: Illustrate FBG structure [2]

The wave number of grated wave :

$$k_g = 2\pi\Lambda \text{ ----} \quad (2)$$

And the relationship between incident wave number and diffracted wave number

$$mk_g = k_i - k_d \text{ ---} \quad (3)$$

The Bragg condition at wave propagate in fiber optic axis

$$\lambda = 2\bar{n}\Lambda \text{ ----------} \quad (4)$$

The fiber Bragg grating Constructed from short segment of optical fiber [2] .The propagation of the electromagnetic field inside the single mode fiber is governed by the wave equation

$$\nabla^2 E = \frac{\in}{c^2}\frac{\partial^2 E}{\partial^2 t^2} = 0 \text{ ----} \quad (5)$$

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Where; C velocity of light, ∈ dielectric constant of the medium.
Assuming the input light wave is linearly polarized and remain linearly during propagation inside fiber Bragg, the electric field inside the fiber can be written as : [5]

$$E(x,y,z,t) = \hat{x}\frac{1}{2}\{F(x,y)A(z,t)exp^{[j(k_0 z-\omega t)]+c.c}\} \quad (6)$$

Where; $\hat{\mathbf{x}}$ polarization unit vector, $F(x,y)$ waveguide mode dispersion, $\mathbf{A(z,t)}$ slowly varying envelop associated with optical pulse.
The complex amplitude relate to intensity of the signals as shown

$$A(z,t) = S(z,t)exp^{j\emptyset(z,t)} \text{ ----} \quad (7)$$

Sub.(6) into (5)
neglecting the second derivative of A(z,t) with respect to z and t, and integrating over the transverse dimensions, and also take the internal losses into account yields

$$\frac{\partial A}{\partial z}+\frac{1}{v_g}\frac{\partial A}{\partial t} = \frac{j\omega_0}{2nc}x(N)A(z,t) - \frac{1}{2}\alpha_{in}A(z,t) \text{ -------} \quad (8)$$

Where; α_{in} internal loss.
Now we study the behavior of optical pulse in FBG by modified eq. (8) to include the forward and backward direction [6].

$$i\frac{\partial A_f}{\partial z}+\frac{i}{v_g}\frac{\partial A_f}{\partial t}+\delta A_f + KA_b + \gamma\left(|A_f|^2+2|A_b|^2\right)A_f = 0 \text{ --- (9)}$$

$$i\frac{\partial A_b}{\partial z}+\frac{i}{v_g}\frac{\partial A_b}{\partial t}+\delta A_b + KA_f + \gamma\left(|A_f|^2+2|A_b|^2\right)A_b = 0 \text{ -- (10)}$$

Where: γ nonlinear factor, δ detuning factor, K is the coupling coefficient. The nonlinear effect of pulse propagation in optical fiber grating [7]:

$$\gamma = \frac{n_2\omega_0}{cA_{eff}} \text{ -----} \quad (11)$$

Where; n_2 nonlinear coefficient of the fiber medium.
When two optical wave propagate in inverse direction with high power in optical fiber will undergo to nonlinear effect such as cross phase modulation and self-phase modulation . we can use optical back propagation (OBP) to illuminate the linear and non linear effect in fiber Bragg. The refractive index of the fiber depend on frequency of the light wave.
The chromatic dispersion D per unit length is given by: chromatic dispersion

$$D = \frac{1}{L}*\frac{d\tau}{d\lambda} = -\frac{\lambda}{c}\frac{d^2n}{d\lambda^2} \text{ -----} \quad (12)$$

The attenuation of optical power signal can be neglect because short transmission distance few millimeter (FBG length), but the dispersion problem and nonlinear effect specially at high power can't be neglected , therefore we suppose the OBP to compensate this losses. The dispersion compensation fiber (DCF) used with negative dispersion fiber to compensate the fiber dispersion effect according [8];

$$D_{SMF}*L_{SMF}+D_{DCF}*L_{DCF} = 0 \text{ --} \quad (13)$$

$$S_{SMF}*L_{SMF}+S_{DCF}*L_{DCF} = 0 \text{ --} \quad (14)$$

Now travels to nonlinear effects generated from refractive index change from intensity of optical signal and inelastic scattering phenomenon. The highly nonlinear fibers (HNLFs) was used as nonlinear compensator.

3. FBG operating Principle

FBG can be used in different applications, When the laser pulse striking the material acoustic wave generated and impinging the FBG and Bragg wavelength shifted because refractive index change.
The laser intensity pulse from semiconductor laser can be describe as:

$$I_0(r,t) = \frac{2p_0}{\pi^{\frac{1}{2}}w_0^2}\exp\left(-k\frac{2r^2}{w_0^2}-\frac{t^2}{\tau_p^2}\right) \quad (15)$$

Where: I_0 is the light intensity, with distance r from ray axis, τ_p is the time width. When this laser pulse injected into human tissue, the laser energy will absorbed by human tissue, the maximum absorption occur at infrared region (IR) and causing heat up the impinging area as [9].

$$S_t(r,t) = \frac{\partial I_A}{\partial t} = k(1+c)\frac{\partial I_0}{\partial t} \text{ --} \quad (16)$$

Where:$I_A = k(1+c)I_0$, absorption light intensity by tissue. k= a_0b is a constant, a_0 absorption, b is the medium thickness. The wave created by heat source P

$$\left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right)p(r,t) = \frac{\beta}{C_p}S_r(r,t) - \quad (17)$$

Where v: sound velocity in the liquid medium, β isothermal expansion C_p,the specific heat at constant pressure.
Sub. Eq.(16) in (17) we can get.

$$\left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right)p(r,t) = \frac{\beta}{C_p}k(1+c)\frac{\partial I_0}{\partial t} \text{--------} \quad (18)$$

By sub.(15) in(18) we can get

$$\left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right)p(r,t) = \frac{\beta}{C_p}k(1+c)$$

$$\frac{2E}{\pi^{\frac{1}{2}}\tau_p w_0^2}\exp\left(-k\frac{2r^2}{w_0^2}-\frac{t^2}{\tau_p^2}\right) \text{ -----} \quad (19)$$

The resulting intensity wave can be calculated

$$P = \frac{E\beta}{(2\pi\sigma)^{\frac{1}{2}}C_p t^2}k(1+c) \text{ ---} \quad (20)$$

Where:$\sigma = (\tau_p^2+w_0^2/2v^2)^{\frac{1}{2}}$
This wave striking the FBG. Where the Bragg conditions descried as

$$\lambda_B = 2n_{eff}\Lambda \text{ ----} \quad (21)$$

Where this equation represent then core equation of FBG, any refractive index variation, or grating period can detected by FBG. And the period which modulate due to thermal and mechanical effect in the fiber.
First application as temperature measurements where the response of FBG can be expressed as [10]

$$\frac{d\lambda_B}{dT} = \lambda_B(\alpha+\beta) \text{ ----} \quad (22)$$

Where; $\alpha = \frac{1}{\Lambda}\frac{d\Lambda}{dT}$ thermal expansion coefficient, $\beta = \frac{1}{n_{eff}}\frac{d\,n_{eff}}{dT}$ thermo optic coefficient.
Any change in strain produce change in grating period ,refractive index [11] which is given by

$$\Delta(\frac{1}{n^2})_i = \sum_{j=1}^{6}p_{ij}S_j \text{ ----} \quad (23)$$

Where: p_{ij} is the strain optic tensor. The change in refractive index due to applied strain.

$$\Delta n = -\frac{1}{2}n^3[\varepsilon(1-v)p_{12}-v\epsilon p_{11}] \text{-------} \quad (24)$$

While the change in grating period due to strain

$$\Delta\Lambda = \varepsilon\Lambda \text{ ----} \quad (25)$$

The spectral change in FBG $\Delta\lambda_B$ results from any change in grating period $\Delta\Lambda$, or refractive index Δn.

$$\Delta\lambda_B = 2n\Delta\Lambda + 2\Lambda\Delta n - \quad (26)$$

The wavelength of FBG change due to refractive index , grating period written as [12]

$$\Delta\lambda_B = \varepsilon\lambda_B(1 - \frac{n^2}{2}[p_{12} - v(p_{12} + p_{11}] \text{----} \quad (27)$$

3.1 Transmit Reflect Detection System (TRDS) for FBG Sensors.

There are two methods for interrogation the response of FBG, these are edge filter detection methods, and power detection methods.

3.1.1. Power Detection Methods

The spectral shift in FBG ($\Delta\lambda_B$) determine using power detection method shown in figure (2) by detecting the spectral properties of light source. In FBG part from incident power reflect and other part transmitted. Three method for power detection linear edge source [13], narrow bandwidth source , and matched source . All methods depend on Full Width Half Maximum (FWHM) for the detect signal in FBG relative the FWHM of the Light source. With respect to LES power detection, the light source FWHM is larger than the FBG FWHM, means the light source is broader than the FBG and edge of Light source becomes linear to the FBG [14].

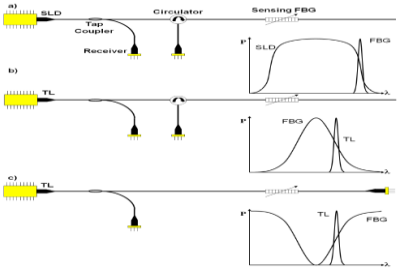


Fig. 2: illustrate the power detection methods [15]

4. Propose Work

The suggested work depend on Li-Fi technology, for wireless communication between devices throughout laser system as shown in figures (3a,b). Li-fi is one of the leading optical communication technologies capable of transmitting data at a very high speed through visible light, infrared and ultraviolet radiation.
Laser works with Li-Fi systems by turning on-off laser system at a very high rate cannot be recognize by the human eye.

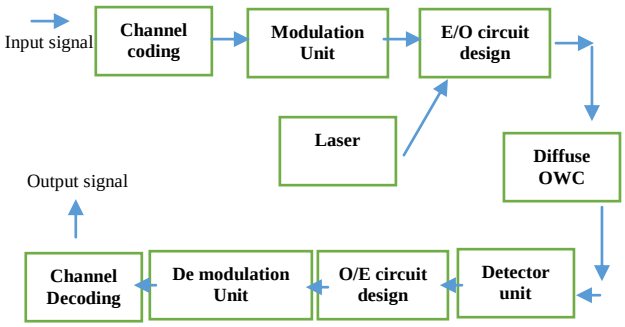


Fig. 3a: Block diagram of the proposed system.

Li-Fi systems are characterized by providing a safe environment for work so can be used in sensitive places such as aircraft, nuclear stations, hospitals and places where electromagnetic interference occurs. The spectrum used for optical communications systems is 10,000 times greater than the radio frequency spectrum.[12].In our work we suggest monitor health care system support 100 Users (Patient) based on FBG sensors (temperature, blood pressure) and laser Li-Fi technology.
The system depend on implementation of laser Li-Fi to collect data from FBG sensors fixed around patient hand, this sensors detect the patient temperature and blood pressure on line and transmit data through laser li-fi system to main monitor unit in the hospital as shown in figures (3,4).

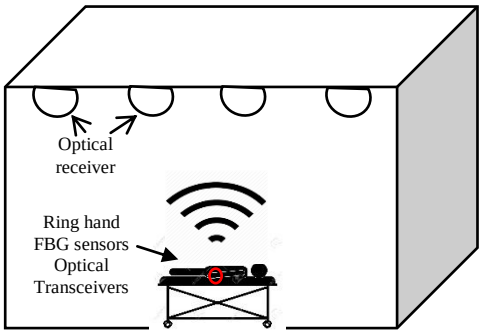
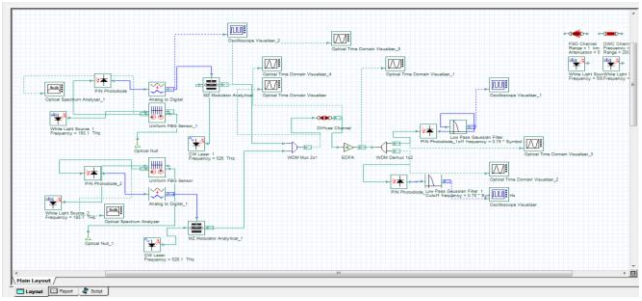
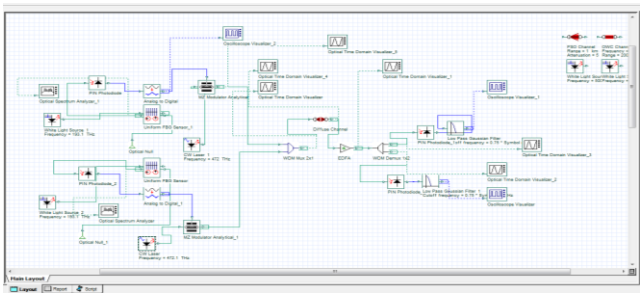


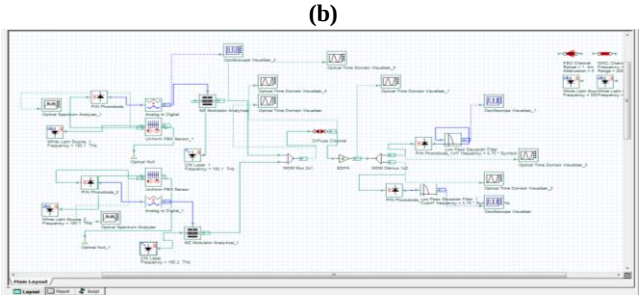
Fig. 3b: block diagram of the proposed system



(a)



(b)



(C)

Fig.4: illustrate the circuit design of the proposed system a) 526 THz b) 472THz c) 193.1THz.

To collect the data from FBG sensors that monitor temperature and blood pressure of the patients. All the collected data will send to doctor via laser Li-Fi wireless to monitor the case of each patient individually. Laser Li-Fi is the future of optical wireless communications, which is characterized by its low cost, license free and its ability to transmit data at a very high bit rate.

4.1 Description of Proposed System

We suppose the room in hospital with dimensions of width, length, high (W=4, L=4, H= 2.5) m. The room ceil divided into n-cells and each cell contain a receiver unit in the center. The divergence angle of all cells assumed equally and also the same area. The optical receiver has FOV ($\emptyset_c$) . the collect power at the detector lens results from LOS, NLOS and multiple reflected paths from transmitter.
The emission spectrum from laser transmitter unit can be modeled by general lamebrain radiant intensity [13].
In our proposed system non-line of sight non direct optical wireless channel was used where the transmitter unit with FBG sensors fixed around patient hand and the receiver is pointing in the room ceil. The Diffuse Channel component can be used to model the free space propagation of indoor optical wireless signals. It assumes the transmit source is a Lambertian disk that is irradiating a detector surface located at an axial distance *h* from the source. based on the transmitter (source) half-angle, the Lambertian order is calculated as follows:

$$m = -log2/\log([costransmitter\ half\ angle]) \quad (28)$$

For Transmitter Half Angle = 60 deg (default), m=1 (Lambertian transmitter). The optical concentrator gain is calculated as follows [11]

$$G = \frac{I^2}{(\sin(CR))^2} \quad (29)$$

where *I* is the internal refractive index of the lens and CR is the field of view. For the case of a hemispherical lens, CR ~ 90 deg. The DC gain (path loss) is then calculated as follows

$$loss = \frac{m+1.A_d}{2\pi h^2}\ Gain.cos\theta^m cos\emptyset \quad (30)$$

Detection surface area (Ad), Optical concentration factor (CR) Amplification factor of lens at receiver [12].

The output power of a Lambertian radiant radiated into a solid angle $d\Omega$ based on the irradiance angle $\emptyset$ can be presented as [11]

$$dpi = \frac{m+1}{2\pi} P_i \cos m(\emptyset) d\Omega \quad (31)$$

The total transmitted power

$$PTx = \int Hemisphere\ dPi \quad (32)$$

The received optical power of the non LOS path given by

$$PRx = PTx * H(f) of\ the\ diffuse\ channel \quad (33)$$

5. Diffuse Channel Model

The core of Li-Fi system, LED bulbs lamps or laser bulbs for data transmission and the transmitter receiver setting.
The channel used in this work (non-direct non LOS (diffuse) channel). As shown in figures (3,4) the diffuse channel provide large coverage area and high mobility but low data rate compared with LOS.

Here we introduce the diffuse optical (Non line of sight (NLOS)) techniques to implement broadband link. Diffuse optical channel is one from link infrared link design. Diffuser link use large spectral width oriented in different directions at power transmitter (1-500 mw) [13].The modulation technology used in the optical communication systems is usually intensity modulation where the output power of the laser is variable according to the data to be transmitted. As for the detection method, the direct detection method is usually used by semiconductor reagents, the current of which is proportional to the intensity of the light falling on the detector lens. The receiver side use PIN detector , the design link can support sensor traffic for health monitor data transfer bidirectional the received power given as [13]:

$$P_R = P_T \frac{(n+1)ACos^n(\theta)Cos^m(\emptyset)}{2\pi d^2} \quad (34)$$

Where : P_T is the transmitted power ,n ,m correspond to source intensity variation proportional to $Cos^n(\theta)Cos^m(\emptyset)$.
A is the detector area and d is the source to detector distance. Assuming R, the detector responsivity ,P_B a background light ,and the receiver bandwidth B the signal to noise ratio is given by :

$$SNR = \left[\frac{RP_T Acos(\theta)\cos(\emptyset)^2}{\pi d^2}\right]\frac{1}{8eP_B RB} \quad (35)$$

For the required SNR [11]

$$d = \sqrt{\frac{R(n+1)P_T ACos^n(\theta)Cos^m(\emptyset)}{4\pi\sqrt{2eRP_B B\ SNR}}} \quad (36)$$

Where: R detector responsivity, P_B back ground light power, B receiver bandwidth, SNR signal to noise ratio. The transmitter and receiver angles 30, the distance around 4 m for power -130 dBm.

6. Results and Discussion

Here we present the simulation results for the proposed system shown in figures (3-9). The data from two sensors FBG1, temperature sensor, and FBG 2 pressure sensor was collected and transmitted over laser Li-Fi system to main monitor room using NLOS diffuse channel. The specification and parameters are given in table 1.

Tab 1: The optical link distance that can be achieve SNR of 13 dB at BER 10^{-10} are plotted as shown in figures (5,6,7 a,b) .

wavelengths	1550 nm, 635nm, 495nm
Input power	1mw-100mw
Room dimensions	4*4*2.5
Active area PIN	30 mm^2
FOV for receiver	60^0
Reflection coefficient (wall, celling, floor)	(0.8,0.8,0.3)
No. of LD per cell	10
Cell size	2*2 m^2
Transmitter half-angle (HA) **At HA= 60 the m=1**	60^0
Incidence half-angle (Theta)	20^0
Channel space	50 GHz

6.1 Influence Power

The received power from NLOS (diffuse channel) for the four cell configuration are shown in figures (5-7), at optical link 2.5 m , 193.1 THz . We observe the received power decreases because multi reflection from wall , ISI and nonlinear channel loss due to increasing transmitter power discussed in mathematical analysis eqs.(28-30), where the optical wireless diffuse channel suffer from many loss such as reflection the signal from the wall and other object in the room which is defined as multipath ray where the transmitted power of the signal suffer from instantaneous effect called temporal dispersion which cause broading which can be modelled as , impulse response, h(t), whose bandwidth ranges usually range from 10 to 30 MHz which causes limit the bit rate because ISI in the transmitted data. The received power increases with increases transmitted power up to threshold limit at which this increasing produce nonlinear losses in optical channel related to carrier power this nonlinearities will limit the received power. That will lead to increases loss of multichannel system as shown in figures (5, 6) . From figure (7) varying the transmitted

power from (1mw up to 60mw) found the optimum transmitted power (40mw) at source detector distance (2.5 m) for detect area 300mm^2.

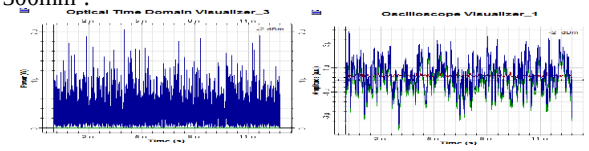


Fig. 5a,b: (a) optical transmitted -2dBm, (b) optical receiver .

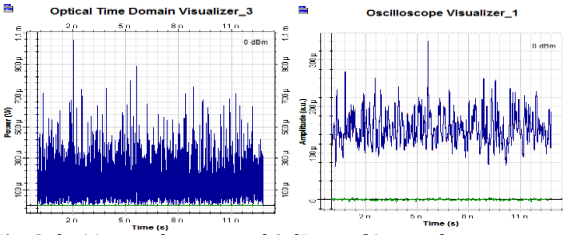


Fig. 6a,b: (a) optical transmitted 0 dBm, (b) optical receiver .

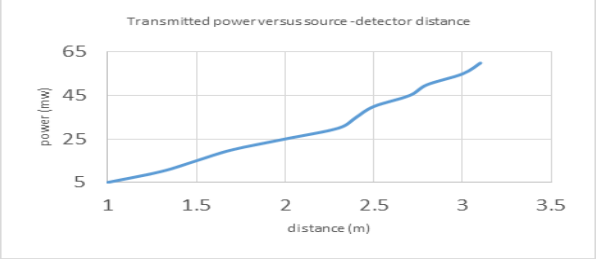


Fig. 7: illustrate the relationship between distance and transmitted power at A=300 mm^2

6.2 Link distance

In order to evaluate the relevance of this effect the layout of the room (distance between FBG transmitter and ceil receiver) is required to investigation. Figures 8 a,b demonstrate effect of optical link influence T-R distance at constant transmitter power (1mw) where the received power. In finite-sized rooms, the walls and floor will allow for multiple reflections to arrive at the receiver, and so we expect to see less path loss in such rooms than that predicted by the one-bounce impulse response.

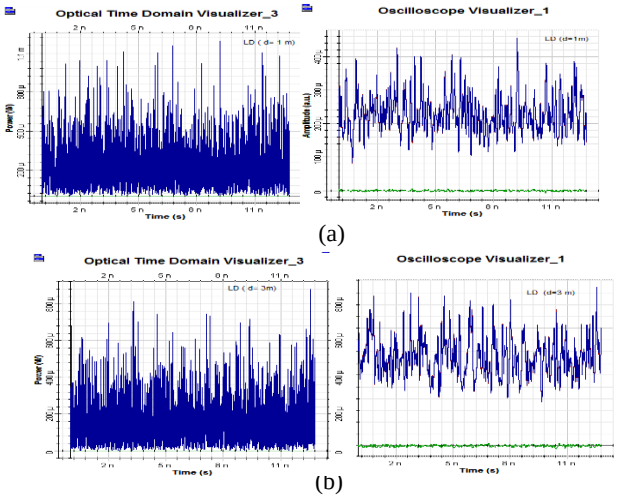


Fig. 8 a,b: Receive power versus different distance 1,3 m respectively

6.3 Transmitter Angle

In this section we take the effect of transmitter angle on the received power. The results of different transmitted angles (50,80) reported here in figures (9a,b). According to mathematical model of the proposed system eqs. (29) to (36) the received power decreases as transmitter angle increases because multipath reflections that cause inter symbol interference and signal fading that limit the performance of a system the increase transmitter angle limit the transmission distance as shown in figure 9,a,b).

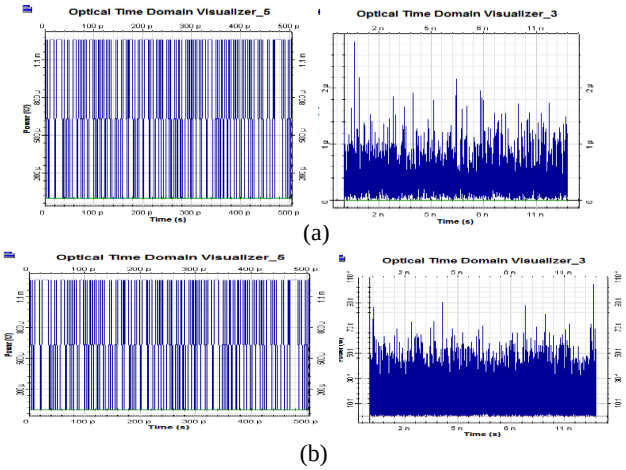


Fig.9a,b illustrate the effect of transmitter angle on received power at constant distance.

6.4 Carrier Frequencies

In this section we talk about use different optical carrier wavelengths (frequencies) to transmit a collected data from optical sensors (temperature, pressure), the selected frequency (wavelength) used here 472 THz at laser power 500 mw , receive distance 2.5 m . Figure (10) shows the transmitted and receive signals. We can note from the figure the received signal attenuated due to high path loss but the received signal maintain the acceptable s/N ratio.

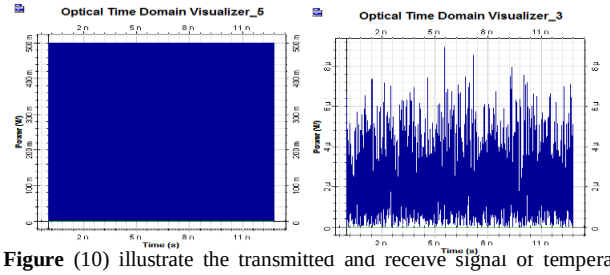


Figure (10) illustrate the transmitted and receive signal of temperature sensor.

The carrier frequencies 193.1, 193.2 THz are used here to transmit the selected data rate in that collect from proposed sensors for receive distance 2.5 m, the received signals for temperature, pressure sensors as shown in figure (11) .this figure illustrate the received signals from different sensors where the figure (a) represent the received signal from temperature sensor at 193.1 THz as carrier frequency while the figure (b) represent the collect data from pressure sensor.

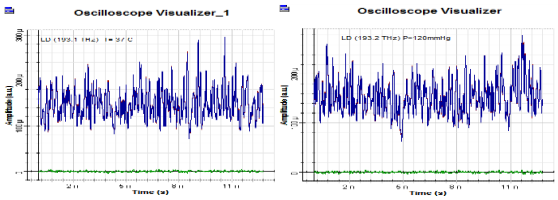


Figure (11) illustrate the received signals a) temperature sensor, b Pressure sensor at 193.1 THz carrier frequency

Now here we use the carrier frequency 526 THz which is equivalent to (495 nm) this optical carrier frequency used to transmit collected data from optical sensors (temperature, pressure), the selected frequency has power 500 mw , receive distance 2.5 m . Figure ( ) shows the transmitted and receive signals

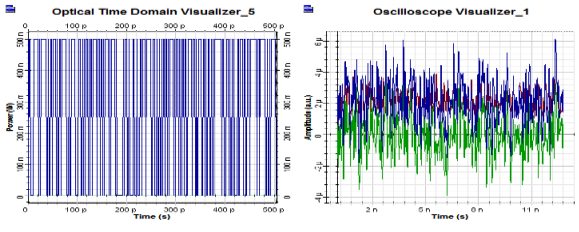
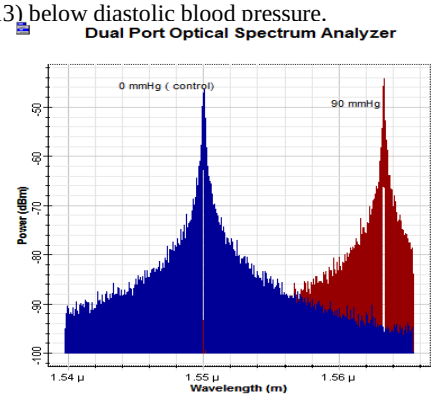


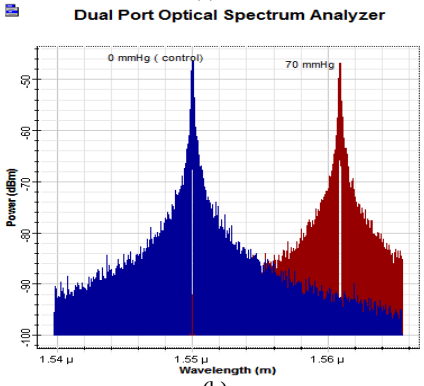
Figure (12) illustrate the a) transmitted b) received signals of temperature sensor at 526 THz carrier frequency

6.5 Blood Pressure Test

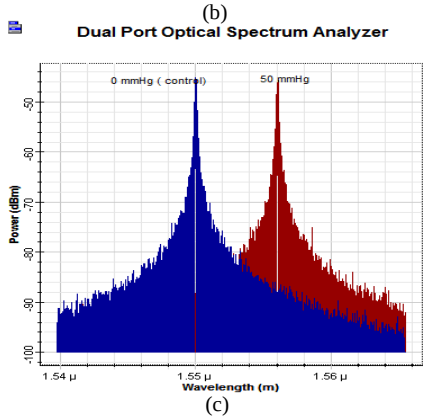
To perform practical test of the suggest work we simulate the proposed system under different operating conditions now the readout of the pressure sensor for patient was recorded a comparison with reference signal was accomplished as shown in figure (13) below diastolic blood pressure.



(a)



(b)



(c)

Figure (13) received signal of diastolic blood pressure sensor a) 90 mmHg b) 70 mmHg c) 50 mmHg

6.6 Temperature Test

In this section we record the readout of the patient temperature sensor, we can see clear shift of wavelength proportional with temperature increase all collected data recorded figure 14 show the received signal of temperature sensor with reference signal.

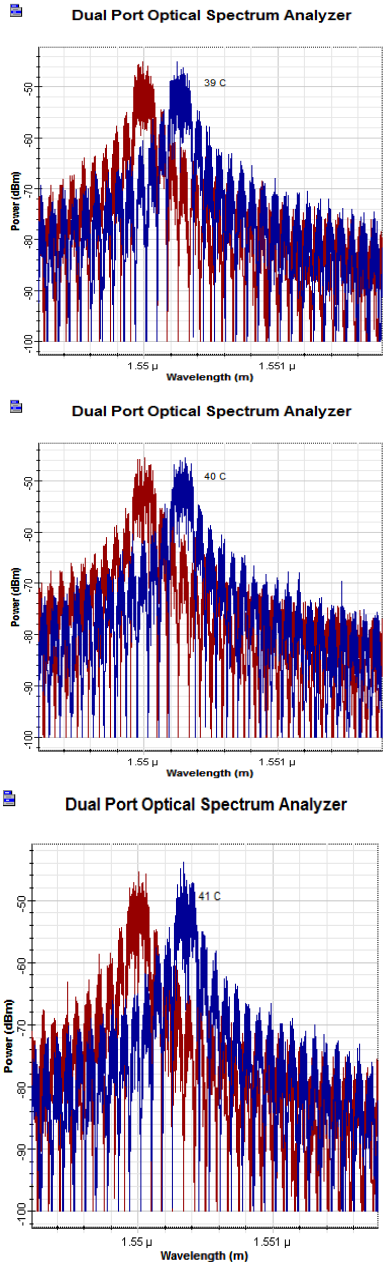


Figure (14) received signal of Temperature sensor a) 39C b) 40C c) 41C

7. Conclusions

In this paper we have introduced a suggested system based on FBG sensors to monitor the patient status (temperature, blood pressure) on line and provide the update information to main monitor room in hospital .Results of the proposed system show that such a scheme can be used to monitor the temperature, blood pressure of the patient. The system tested under different operation conditions such as (distance between transmitter and receiver ,laser power, transmitter angle, carrier frequency) all results indicate good stable performance with optimum transmitted power (40mw) at source detector distance (2.5 m) for detect area 300mm^2.

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