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Implementation of Optical Coherent Communication System between Two Computers

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Abstract

This work represents implementation and investigation of optical coherent communication system between two computers. A single mode optical fiber is selected as transmission medium. The data are sent via the RS-232 standard interface with a bit rate of 9.6 kbps from personal computer (PC1) by line receive to convert the data from electrical levels (-12/+12 V) into TTL level (0/5 V). The modulation of this data was accomplished by internal modulation using laser diode type (HFCT-5208M) 1310 nm wavelength. The optical D-coupler was used to combine the optical signal that come from laser source with optical signal of laser local oscillator (OTS-304XI) at 1310/1550 nm wavelength to obtain coherent (homodyne and heterodyne) detection respectively. A PIN photodetector (HFCT-5208M) is used.

Calculations of Signal to Noise Ratio (SNR) and Bit Error Rate (BER) for coherent detection were measured at different length of the optical fiber. Result show that high SNR and low BER for heterodyne detection than for homodyne detection.

Key Words: Coherent Communication, Local Oscillator, Optical Fiber, Signal to Noise Ratio, Bit Error Rate.

Introduction:

Coherent optical communication is one of the most promising ways to achieve highest receiver sensitivity, excellent spectral efficiency and longest transmission distance for the next generation of optical communication systems [1]. In coherent detection systems, the received light is first combined with the beam of *a local Oscillator* (LO) laser then the photocurrent induced by the sum of these two lights is reduced in frequency to the radio domain [2]. Coherent detection generally results in higher sensitivity in optical communication links. Coherent detection also results is better channel selectivity in wavelength-division multiplexed optical networks. The best sensitivity is achieved when homodyne detection is used. However, in this case both the transmitter and LO lasers need to have narrow linewidths (LWs) and be phase-locked [3]. A most important challenge at such high speed transmission is the spectral efficiency required to increase the transmission capacity over existing transmission links. New approaches based on coherent detection appear as the most promising. They enable polarization multiplexing and the mitigation of transmission impairments through digital signal processing in the electrical domain. In coherent detection, the optical signal is demodulated by mixing with a reference, the ensuing beats being detected by photodiodes [4].

One of the advantages of coherent optical communication is the potential to compensate fiber chromatic dispersion and polarization-mode dispersion in the digital domain [5]. In coherent detection other parameters of the received electrical field can be

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modulated, such as, its amplitude, pulse, frequency, or phase. Coherent detection can be performed using two different techniques: *heterodyne*, i.e., different signal and local oscillator frequencies, or *homodyne* detection, where the signal and local oscillator frequencies are equal. [6]. In optical coherent detection, a single detector configuration can be used, however, a balanced configuration is preferred in order to reduce the local oscillator excess noise and for a more efficient use of the local oscillator and signal power [7]. The principle of the coherent detection technique is to provide gain to the incoming optical signal by combining or mixing it with a locally generated *continuous wave (CW)* optical field [8].

Experiment Work

The system was implement in our work is show as a block diagram in figure1.

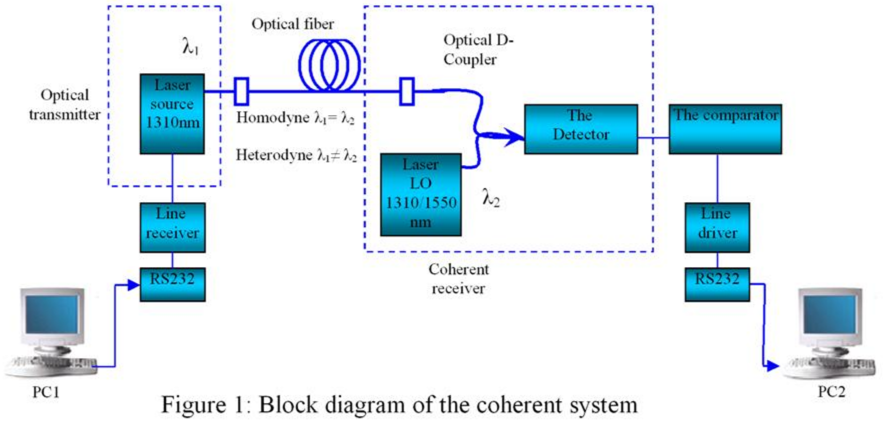

Figure 1: Block diagram of the coherent system

The transmitting computer is used to perform a sequence of processes, which are collectively named the *transmitting process*. The setting process is achieved by using the Microsoft communication control 6 (MS Comm) components. The MS Comm control provides serial communications for an application by allowing the transmission and reception of data through a serial port. The serial port of the computer has been chosen as an output and input port in this work. The output signals (data) from the serial port RS-232 of the PC1 is a voltage level of ±12V while the drive circuit of the laser, which is the next stage of the system, works with a voltage level into TTL level (0/5V). This conversion was achieved by using line receiver MC1489. These data, which are converted to TTL level, are then passed to the optical transmitter. The optical transmitter consists of laser source and its drive circuit. In this work the HFCT-5208M laser source is used. This laser diode module operated at 1310 nm wavelength of high stability with the single mode optical fiber. This laser has spectral line width (RMS) is 2.5nm and have minimum output optical power -15dBm and maximum 8dBm and optical rise time 0.5nsec and private single mod fiber interconnections at 622Mb/s.The optical source used in the transmitter unit is a multiple quantum well laser HFCT-5208M.

The optical fiber was used in this system is a step index single mode fiber. The optical fiber is connected between laser source and optical fiber D-coupler by a connector of FC type. Optical coupler is used for combining optical signals that come from laser source and local oscillator laser. In this work the product single mode fiber coupler 1×2 is used (two port of input signal and one port of output signal).

The coherent receiver consists of a laser local oscillator, optical detector. The local oscillator laser used for creating the CW signal is a narrow line width laser. In this work the OTS-304XI45 laser source is used. This laser diode module operated at 1310/1550 nm dual wavelength of high stability with the single mode optical fiber. When laser local oscillator wavelength 1310nm is mixed by D-coupler with laser transmitted with 1310nm and detect by optical detector that is homodyne detection and if laser local oscillator wavelength 1550nm is used that is called heterodyne detection. The result of this mixing procedure is that the dominant noise in the receiver is the shot noise coming from the laser local oscillator. A PIN detector (HFCT-5208M) is used to convert the detected optical data into electrical signal. The signal power is measured by using optical power meter OTS-310 product, with a responsivity of 0.36A/W at a wavelength of 1310 nm. The reshape of the electrical signal in the receiver unit is done by IC 741 comparator. The data that comes from the optical detector and has to pass to the computer throughout the serial port have a TTL voltage level that must be converted to a voltage level of ±12V. This conversion is achieved by using line driver MC 1488. The MC1488 meet this voltage requirement by converting TTL logic levels into RS 232 levels. These data are then passed to the PC2 through the serial port. The data were received by this computer will be submitted to a sequence of software processing, collectively named receiving process.

Results and discussion

The coherent optical system performance is represented by calculations of the SNR and BER. In the presented work, the transmitted signal is obtained by the optical fiber coupler from optical source 1310nm (HFCT-5208M) and this signal is detected by using optical detector HFCT-5208M. The signal power is measured by using optical power meter OTS-310. The generated signal current of the detected signal in the optical detector depends on the received optical power. To compute the BER, the SNR ratio of the received optical signal should be computed as follows, one supposes an incident optical power Prec(μw) at a specific fiber length L that detects by the detector PIN photodiode of OTS-310 optical power meter with responsivity $\mathcal{R}$ 0.36 A/W. The signal current (Is) generated in the detector is compute by eq.1 [9]:

$$I_S = P_{rec} \times \mathcal{R} \quad \ldots (1)$$

Where *Prec* is the received optical power by the detector. The noise originating in the detector are thermal noise current (i_{th}), shot noise current (i_{shot}) and dark current (I_d). The thermal noise current is given by eq. 2 [10].

$$i_{th} = \sqrt{\frac{4kT\Delta f}{R_L}} \quad \ldots (2)$$

Where K is the Boltzmann constant (1.3805×10^{-23} J/k), T is the temperature in Kelvin (300 k), Δf is the signal bandwidth (9.6 KHz), R_L is photodetector load resistor (1 kΩ).

While the values of the shot noise current are compute by eq.3 [10].

$$i_{shot} = [2 q \Delta f (I_S + I_d)]^{\frac{1}{2}} \quad ...(3)$$

Where *Is* is the signal current, *Id* is the dark current of the detector (4 nA).

The SNR value of the optical communication is [8].

$$SNR(dB) = 20 \log \left(\frac{I_S}{I_N}\right) \quad ...(4)$$

Where I_N is the total noise current, to get BER from eq.5 [9]:

$$BER = \frac{1}{\sqrt{2\pi SNR}} \exp\left(\frac{-SNR}{2}\right) \quad ..(5)$$

Calculations of BER based on a practical measurements of the received optical power at different values of the single mode optical fiber length of coherent (homodyne, heterodyne) detection are shown in tables 1. The calculated results of the single mode optical fiber channel, which total noise current value, SNR and BER are included in this table.

Table 1: The calculated results of the coherent (homodyne, heterodyne) detection

L(Km)	P(μw) Homo	P(μw) Hetero	I_N (nA) Homo	I_N(nA) Hetero	SNR(dB) Homo	SNR(dB) Hetero	BER Homo	BER Hetero
1	265.46	334.19	0.94	1.006	100.137	101.547	7.17E-24	3.52E-24
3.37	210.37	283.13	0.881	0.958	98.684	100.535	1.49E-23	5.81E-24
7.09	169.43	241.54	0.831	0.915	97.306	99.551	2.99E-23	9.65E-24
13.88	132.73	204.17	0.781	0.873	95.722	98.495	6.67E-23	1.64E-23
18.47	123.02	193.19	0.767	0.861	95.222	98.145	8.59E-23	1.96E-23
23.71	115.34	186.63	0.755	0.853	94.795	97.925	1.06E-22	2.19E-23
30.24	111.42	182.81	0.749	0.848	94.565	97.793	1.19E-22	2.34E-23
35.69	109.9	181.55	0.747	0.846	94.474	97.749	1.25E-22	2.39E-23
41.87	108.89	181.13	0.745	0.846	94.413	97.734	1.29E-22	2.41E-23
50.45	108.14	180.71	0.744	0.845	94.366	97.719	1.32E-22	2.43E-23
54.15	108.14	180.71	0.744	0.845	94.366	97.719	1.32E-22	2.43E-23
58.41	108.14	180.71	0.744	0.845	94.366	97.719	1.32E-22	2.43E-23
62.11	108.14	180.71	0.744	0.845	94.366	97.719	1.32E-22	2.43E-23

The last value of the BER at optical fiber length 62.11 km of (homodyne, heterodyne) coherent detection is acceptable because this value less than the acceptable order value of the BER in optical digital transmission is 10^{-9}.

The coherent detection is offer increase selectivity of the receiver. The received optical power after this length is not need to amplify in coherent detection. The value of the SNR in our coherent (homodyne, heterodyne) system is acceptable for 62.11 km fiber length. The relationship between the P_{rec}, I_N, SNR and BER as function of the fiber length are shown in set of figure 2, 3, 4 and 5 respectivel

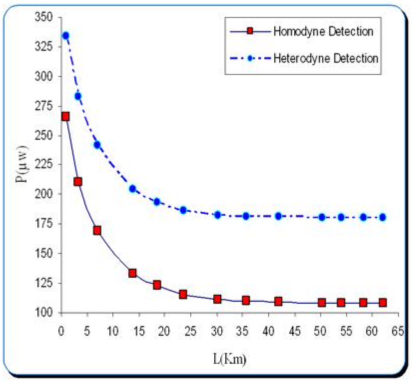

Figure 2: The variation of received optical power with optical fiber length

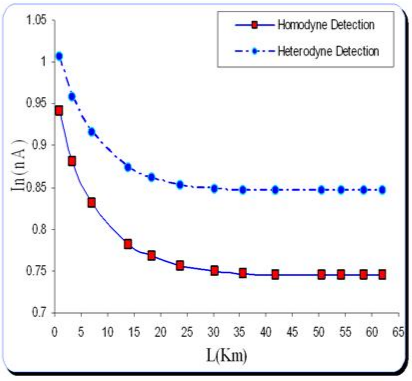

Figure 3: The variation of the noise current with the optical fiber length

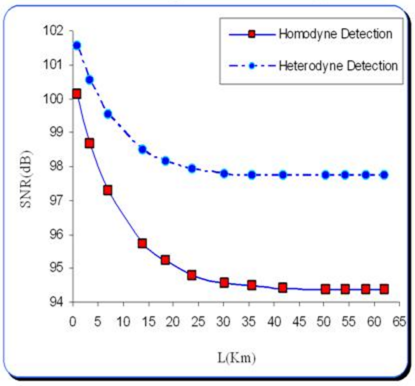

Figure 4: The variation of SNR with the optical fiber length

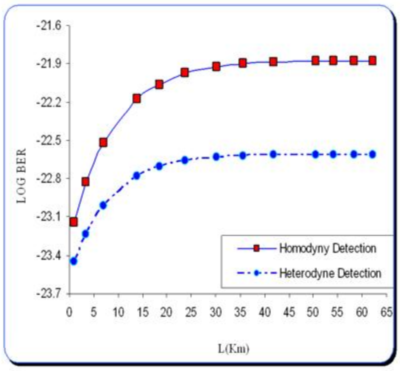

Figure 5: The variation of the logarithm of BER with the optical fiber length.

Figure 2 shows the change of the received optical power with different fiber lengths to show the attenuation effects of coherent detection. From this figure the received optical power decreases with the increase of the optical fiber length exponentially, we can notes the received optical power received decreasing, and the decrease is stop at homodyne and heterodyne detection. This means that the local oscillator is work as amplifier to amplify the weak signals comes from the transmitter medium (fiber). It can be showed from figure 3 the total noise current for coherent detection is high due to the high power incident at the detector which leads to increase the shot noise current.

From figure 4 the SNR is decreased rapidly with increasing the optical fiber length in homodyne detection because the optical power decrease result the attenuation effects and chromatic dispersion in optical fiber while in heterodyne detection the SNR is semi constant in each fiber lengths. This means that the system is acceptable for 62.11Km.

It's cleared from figure 5 that BER increased with increasing the optical fiber length because the BER depended on the SNR that duo to the BER decreased with increasing the optical power received because increased receiver sensitivity. It can see from this figure the variation of BER is very small in coherent system with increasing of the fiber length. The BER it has at heterodyne detection less than value from homodyne detection.

Conclusions

The performance of the coherent optical communication system offers a method to enhance information security of the optical communication system with high quality and low BER over long distance optical fiber length. Both homodyne and heterodyne detection are better suited for optical communication because of the large output SNR and low BER of the received signal. It is clear from results that a BER increases when the fiber length increased due to received optical power decreasing. From the measured and calculated values of the BER of both homodyne and heterodyne detection with fiber length at 62.11 km are acceptable because the BER values are less than 10^{-9}. This system uses a simple and low cost interface circuit to connect between two PC using a fiber optic link.

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بناء نظام أتصال متشاكه ضوئيا بين حاسبتين

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الخلاصة:

هذا البحث يمثل تنفيذ واختبار نظام اتصال متشاكه ضوئيا بين حاسبتين. اختير الليف الضوئي من نوع احادي النمط كوسط ناقل. ارسلت البيانات عبر السطح البيني القياسي (RS-232) بمعدل ارسال (9.6 kbps) من الحاسبة الشخصية(PC1) بواسطة خط الاستقبال لتحويل البيانات من اشارات الالكترونية (-12/+12V) الى منطق ترانزستور- ترانزستور(TTL) بـ0/5V. تم تضمين هذه البيانات بطريقة تضمين الداخلي وبواسطة ليزر دايود نوع (HFCT-5208M) ذو الطول الموجي 1310 nm، الروابط الضوئية من نوع D استخدمت لدمج الاشارة البصرية القادمة من المصدر الليزري المرسل مع الاشارة البصرية لليزر المذبذب المحلي -OTS) (304XIذو الطول الموجي 1310 nm و 1550 nm للحصول على الكشف المتشاكه (المتجانس والغير متجانس) بالتتابع. استخدم مستقبل الاشارة البصرية من نوع الكاشف الضوئي PIN (HFCT-5208M). تم حساب كل من نسبة الاشارة الى الضوضاء(SNR) و معدل الخطأ في نقل البيانات (BER) لمنظومة الكشف المتشاكه(المتجانس والغير متجانس) عند اطوال مختلفة من الليف البصري . أظهرت النتائج ان الكشف المتشاكه الغير متجانس فيه نسبة الأشارة الى الضوضاء أعلى و معدل الخطأ للأشارة اقل مقارنة بالكشف المتشاكه المتجانس.