International Journal of Electronics and Communication Engineering.
ISSN 0974-2166 Volume 4, Number 1 (2011), pp.29-36

http://www.irphouse.com

Simulation Analysis of an Optical Phase Locked Loop Demodulator

G.M. Helaluddin

Department of Physics, Durgapur Government College,
J.N. Avenue, P.O.: Durgapur, Dist: Burdwan, West Bengal, India
E-mail: helaluddindgc@gmail.com

Abstract

Computer simulation analysis of a coherent receiver using optical phase locking technique has been presented in this study. The system is so designed particularly with the help of double balanced phase detector and linear optical phase modulator (OPM) to minimize phase error of the carrier. It is found that, frequency tunable laser sources with low power and higher line width are much effective than previously proposed OPLL for direct or coherent detections. So, it may be suggested that the system will be cost-effective in future light wave networks.

Indexing Terms: Optical phase modulator (OPM), Voltage controlled oscillator (VCO), Balanced phase detector (BPD), phase shift keying (PSK), optical phase lock loop (OPLL), binary phase shift keying (BPSK), quadrature phase shift keying (QPSK).

Introduction

Demand for higher data rate communication systems continues to grow and to stretch the limit of current technology. Of particular interest are coherent receivers in which the carrier phase information is transmitted as a part of the modulated signal and used at the receiver for phase alignment [1]. The synchronous down conversion of an optical signal is critically affected by phase noise of the lasers, and this problem is addressed in many publications on synchronous binary PSK (BPSK) and QPSK optical transmission mostly by the use of external cavity lasers [2-7].

The novel phase-locked coherent demodulator, based on a sampling phase-locked loop, is presented and investigated theoretically. The demodulator is capable of operating at high-frequencies, by using optical sampling to down convert the high-frequency input RF signal to the frequency range of the base band loop. A detailed theoretical model of the (sampling) phase-locked coherent demodulator has been developed and perform detailed numerical simulations [8-11].

However, stringent laser linewidth requirements and power penalty of system make OPLL difficult to implement with available semiconductor lasers. Commercially these are costly but DFB lasers having linewidth (10-50 MHz) are preferable for cost-effective system design. So, the present study is concentrated on the focus of the power sensitivity budget and linewidth requirement of optical sources of the demodulator. The system bit error rate is highly dependent on power sensitivity and spontaneous emission of laser action is the inevitable phenomena which responsible for phase noise and consequently both the phenomena affect the receiver system performance to a large extent with the result of poor detection. In view of this, a novel system has been designed for simulation analysis in which an additional optical phase modulator (OPM) having linear phase modulation characteristic is incorporated at VCO laser output. To obtain the lock-in state the output of the VCO laser modulates the reference input signal from the source laser through the balanced phase detector (BPD) by automatic phase and frequency control loop. The main objective of this paper is to improve the power sensitivity budget requirement and the stringent linewidth requirement of the optical sources, as a result of which receiver performance will improve.

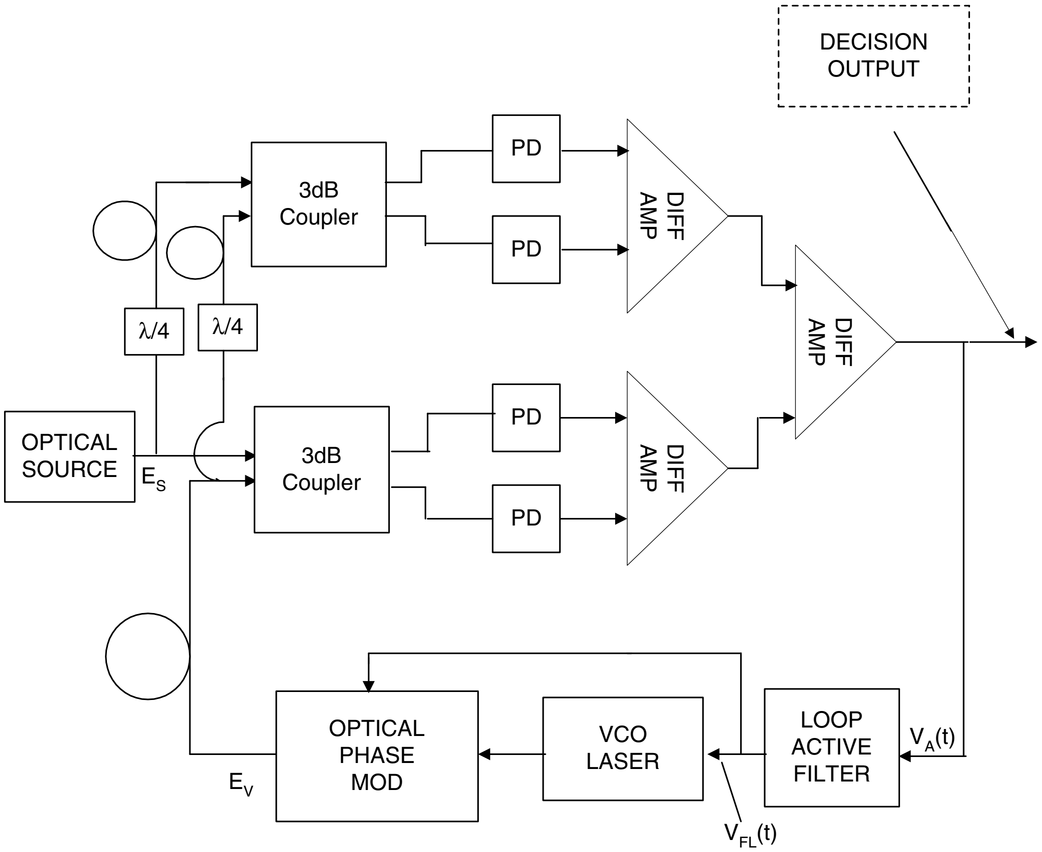

Figure 1: Concept schematic of a simulated optical phase lock loop demodulator.

System Description

For simulation experiment of optical PLL, the system has been designed with optical source, VCO laser, loop active filter and balanced phased detector (BPD) which comprises with following components: 3dB couplers, photo detectors and differential amplifiers. An optical phase modulator at VCO laser output has been incorporated to compensate the phase difference between the incoming optical field and VCO laser field and also to improve the better loop delay performance of the system [Fig.1]. The source laser and VCO laser fields are expressed as,

$$E_S = \sqrt{(2P_S)}\, m(t)\, \mathrm{Sin}[\omega_S t+\theta_S(t)] \qquad (1)$$

$$E_V = \sqrt{(2P_V)}\, \mathrm{Cos}[\omega_V t+\theta_V(t)+ \phi(t)+ \psi(t)] \qquad (2)$$

The balanced phase detector output is expressed as:

$$V_A(t) = K_G \{R\{(r[(E_{S1}+E_{V1})/ \sqrt{2}]^2 - r[(E_{S1}-E_{V1})/\sqrt{2}]^2)$$
$$-(r[(E_{S2}+E_{V2})/\sqrt{2}]^2 - r[(E_{S2}-E_{V2})/ \sqrt{2}]^2)\}+ n_I(t)\} \qquad (3)$$

Where,

Parameters	Symbols
Source laser power	P_S
VCO laser power	P_V
Phase modulation of source laser	$\theta_S(t)$
Phase modulation of VCO laser	$\theta_V(t)$
Phase modulation of OPM	$\psi(t)$
Power splitting of source laser	E_{S1}, E_{S2}
Power splitting of VCO laser	E_{V1}, E_{V2}
Shot noise contribution due to photo detection process	n(t)

Considering the time domain analysis for loop filter transfer function $[F(s)=(1+s\tau_1)/s\tau_2]$ the output of the active LPF is described as:

$$V_{FL}(t+\Delta t) = V_{FL}(t) - V_A(t)\, [\tau_1/ \tau_2] - V_A(t+\Delta t)\, [(\tau_1+\Delta t)/ \tau_2] \qquad (4)$$

Now, the phase contribution $\phi(t)$ due to feed back control of the loop at the frequency modulating port of VCO laser is given by,

$$\phi(t) 2\pi k_v \int_{-x}^{t} V_{FL}\left(t' - \tau_D\right) dt' \qquad (5)$$

The phase modulation due to OPM at VCO laser output is

$$\psi(t) = SV_{FL}(t-\tau_D) \qquad (6)$$

Where, V_A (t) & V_{FL} (t)are loop amplifier output and LPF filter output respectively, Δt is sampling interval.

Parameters	Numerical values
Frequency of carrier signal (f)	100 THz
Source laser power sensitivity (P_S)	-53.0 dBm
Filter time constants (τ_1,τ_2)	0.1 μs, 0.16ns
VCO laser sensitivity (K_V)	300 MHz/Volt
Loop amplifier gain (K_G)	4.47×10^2
Power division factor (K_I)	0.707
Photo detector sensitivity (R)	1 A/W
Detector Trans impedance (r)	2.74 KΩ
Loop delay (τ_D)	20ns
OPM sensitivity (S)	12.0 rad/V

The System Noises

Generally noise corrupts the transmitted signal in a fibre optic system. This means that noise sets a lower limit on the amount of optical power required for proper receiver operation. There are many sources of fibre optic systems like, noise from light source, noise from interaction of light with optical fibre, noise from detector etc.. The noise from light source is due to the spontaneous emission of laser, though stimulated emission is the inevitable phenomena of laser action. This particular noise is known as white phase noise. Other noises are thermal noise, dark current noise and quantum noise. Thus, both signal dependent and signal independent noise limits the receiver sensitivity. In optical frequency domain the only white frequency noise, i.e., phase noise and the quantum detection noise, i.e., shot noise is effective.

Phase Noise of Laser

In OPLL systems, phase noise of the lasers is very much important on loop performance. For commercially available distributed feed back (DFB) lasers the phase noise is large and a wide control band width is required for the system. In most of the cases phase noise consists of following components: random-walk frequency noise, flicker frequency noise and white frequency noise etc. But in optical domain the first two components are negligible compare to white frequency noise due to large frequency (~200THz) of the lasers. The one-sided power spectral density of white frequency noise is given by:

$$S_{PH}(f) = \delta\nu/\pi f^2 \text{ rad/Volt} \tag{7}$$

Where,

$$\delta\nu = \delta\nu_S + \delta\nu_V \tag{8}$$

$\delta\nu_S$ & $\delta\nu_V$: Source & VCO laser linewidth respectively.

Shot Noise of Photo detectors

This noise is the additive in the optical systems, originated due to the quantum detection process. The terms n(t) in equations (3) represents the shot noise contribution of photo detectors. The spectral density of shot noise term is expressed as,

$$S(f)= 2eR[(1-K_I^2)^2P_S+K_I^2P_V]r^2\ V^2/\text{rad} \qquad (9)$$

Where, photo detector sensitivity is R given by,

$$R = e\eta/hf \qquad (10)$$

η : Quantum efficiency of the photo detectors, e: electronic charge and h: Planck's constant.

In the investigation of simulation experiment both phase noise and shot noise are assumed to be White Gaussian noise. To generate these noises a commonly used method, called Polar Marsaglia [9] is utilized. The generated shot noise is incorporated to BPD output and phase noise to the phase part of both lasers signal.

Results and Discussions

The optical phase locked loops (OPLLs) are expected to have a wide range of applications in future light wave networks. One such is the reconstruction of carrier for PSK receiver. The OPLLs performance is unlike that of an ordinary PLL, depends on various noises out of which the laser phase noise, shot noise due to quantum nature of optical signal and the inevitable effect of loop delay are key factors affecting the system performance. The simulation analysis have been done to study the dynamic performance of the loop in terms of loop acquisition time, lock-in range, loop band width etc.. In the delay limited system the absolute stability is not possible. So, stability of the loop is examined through the variation of loop delay with OPM sensitivity (S) at zero phase error condition. This is found that the loop may accommodate larger loop delay in presence of OPM and the optimum value of OPM sensitivity is 12.0 rad/V at which 98ns maximum delay may be allowed within stable boundary of the loop.

The noise performance is studied by the variation of RMS phase error with laser linewidth which indicates that the RMS phase error reduces and stringent linewidth requirement is relaxed in the proposed system [Ref. Fig.2]. Also, the requirement of laser power sensitivity is realized in terms of the variation of RMS phase error with power sensitivity as shown in Fig.3 & Fig.4. The important finding is the improvement in power sensitivity, i.e., the proposed system may allow the optical sources with low power sensitivity to achieve same system penalty as presented in Table-1. Also, the present system can be hooked up with 53.0MHz linewith laser sources than 25.0 MHz source at the same system performance (OPM sensitivity=12.0rad/V). That is the linewidth requirement has been relaxed from 25MHz to 53.0MHZ as presented in Table-2.

Table 1: Laser power sensitivity requirements $\delta\nu_S$ =5.0 MHz & $\delta\nu_V$ =5.0MHz.

RMS phase error	Incoming power sensitivity (P_S) (µWatt) (Consider P_V=1.033 µWatt)		VCO laser power sensitivity (P_V) (µWatt) (Consider P_S=0.005 µWatt)	
14.5^0	Without OPM	With OPM S=12.0 rad/V	Without OPM	With OPM S=12.0 rad/V
	0.0039	0.0043	1.041	0.9901

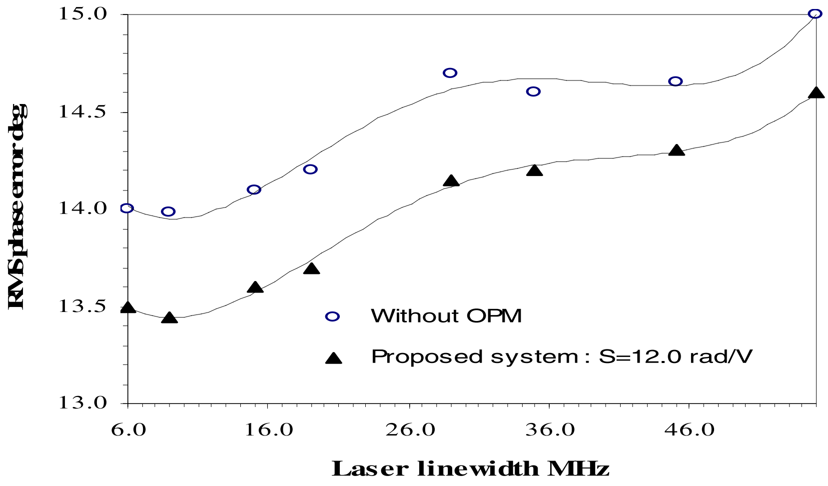

Figure 2: The dependence of RMS phase error on laser linewidth with t_1=0.1us, t_2=0.16ns, t_D=20ns, P_s=53.0dBm, P_v=0.33dBm.

Conclusions

A computer simulation on a new OPLL is presented in this paper. The attention has been focused to wards the search of a cost-effective system design for future light wave system. The proposed system is tolerant with larger loop delay for improved loop gain and locking time reduces to a large extent with greater lock-in range. Thus, system band width enhances for the reception of large volume of information gathering, which is the most interesting achievement. The key components of the system are the optical sources whose spontaneous random emission is the serious disadvantage because of offering stringent linewidth requirement. Also, the signal power budget is another important limitation in respect of system penalty and cost design. It is reported that the low signal power lasers are preferable for the present system with the expense of same phase error. Therefore, commercially available DFB lasers with available linewidth ~10-50 MHz may be hooked up for cost-effective system design (Ref. Table-2).

Table 2: Laser line width requirements Ps=0.005 μWatt, Pv=1.033 μWatt.

RMS phase error	Laser linewidth (MHz)	
14.5^0	Without OPM	With OPM S=12.0 rad/V
	25.0	53.0

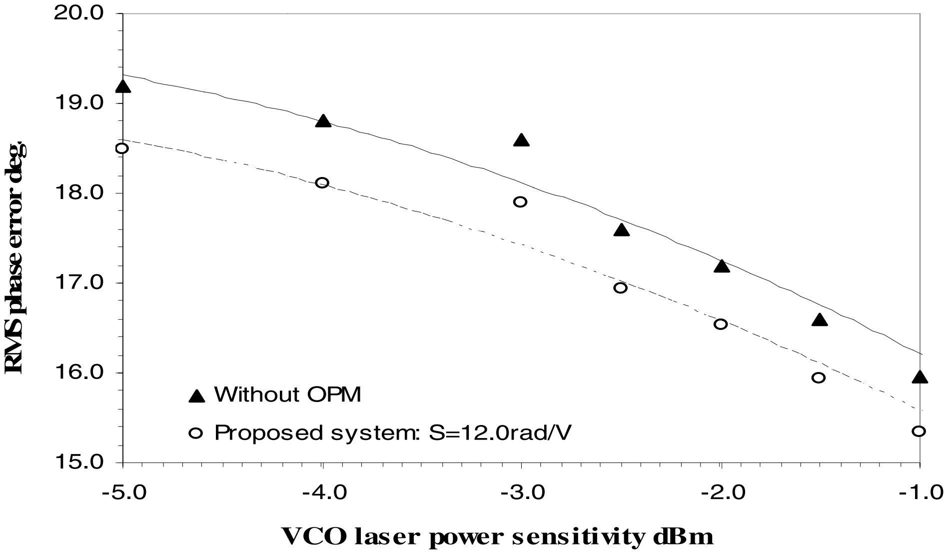

Figure 3: Dependence of RMS phase error on VCO laser power sensitivity with τ_1=0.1μs, τ_2=0.16ns, τ_D=20ns , Ps =-53.0dBm, dns=5.0MHz, δv_V=5.0MHz

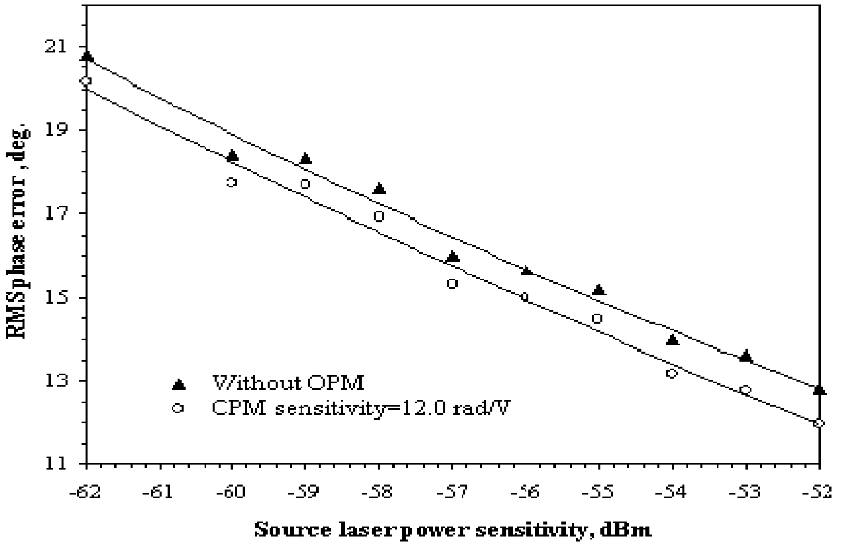

Figure 4: Dependence of RMS phase error on incoming power sensitivity with τ_1=0.1μs, τ_2=0.16ns, τ_D=20ns , Pv = 0.33 dBm, δv_S=5.0MHz , δv_V=5.0MHz

Acknowledgement

Author thankful acknowledge UGC, Govt. of India for financial assistance.

References

[1] Reinhold, Noé, 2005, "Phase noise-tolerant synchronous QPSK/BPSK baseband-type intradyne receiver concept with feedforward carrier recovery," J Light Wave Tech., 23, pp. 802-808.

[2] Kazovsky, L. G., 1986, "Balanced phase locked loops for optical homodyne receivers: Performance analysis, design considerations and laser line width requirements," J Light wave Tech., 4, pp.182-195.

[3] Kazovsky, L. G., Atlas, D. A., 1983, "A 1320 nm experimental optical phase locked loop: Performance investigation and PSK homodyne experiment at 140Mb/s and 2Mb/s," J Light Wave Tech., 8, pp.1414-1424.

[4] Ramos, R. T., and Seed, A. J., 1990, "Delay, linewidth and bandwidth limitation in optical phase-locked loop design," J Elecron. Lett., 26, pp. 389-390.

[5] Hongsheng, G., Smith, P. J., 1998, "Shafi M., 'Improved receivers for coherent PSK systems," J Light wave Tech., 16, pp.1973-1980.

[6] Gagnon, D. S., Tsukamoto, S., Katoh, K., Kikuchi, K., 2006, "Coherent detection of optical quadrature phase-shift keying signals with carrier phase estimation", J Light Wave Tech., 24, pp.12-21.

[7] Djordjivic, I. B., Stefanovic, M. C., 1999, "Performance of optical heterodyne PSK system with costas loop in multichannel environment for nonlinear second order PLL model", J Light wave Tech., 17, pp. 2476-2479.

[8] Ramos, R. T., and Seed, A. J., 1994, "Comparison between first-order and second-order optical phase-locked loops", J Microwave & Guided wave Lett., 4, pp. 6-8.

[9] Kazovsky, L. G., 1986, "Performance analysis and laser linewidth requirements for optical PSK heterodyne communication systems", J Light wave Tech., 4, pp.415-425.

[10] Camatel, S., Ferrero, V., Gaudino, R. and Poggiolini, P, 1994, "Optical phase lock loop for coherent detection optical receiver", J Electron. Letts, .40(6), pp.384-385.

[11] Johansson, L. A., Zibar, D., Ramaswamy, A., Colden, L., Rodwell, M., and Bowers, J.E., 2007, "Analysis of sampled optical phase-lock loops", JIEEE Microwave Photon. Tech. Letts., 3-5, pp.153-156.