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Analysis of Relative Intensity to Noise Ratio for Lasers at Different Bias Currents

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***Abstract*—In this paper, we have carried out the simulative analysis for averaging out the optimal value of RIN for better performance in high bit rate optical transmission link. We have found that for single mode VCSEL, the bias of 2 mA has the highest Spurious Free Dynamic Range (SFDR) and low RIN. For multimode VCSEL, the bias of 6 mA has the highest SFDR and low RIN.**

***Keywords*—relative intensity to noise ratio, intensity noise.**

PACS: 42.60.-v Laser optical systems: design and operation, 42.15.Eq Optical system design, 42.82.Bq Design and performance testing of integrated-optical systems.

I. Introduction

TODAY'S optical transmission links are targeting a bit rate in T bits/sec, which is possible only if we are able to control various transmission affecting parameters like attenuation, dispersion, fiber non-linearties and relative intensity to noise (RIN). Focus on development of broadband optical communication system is incredible since it offers combination of wide bandwidth and low losses unmatched by any other transmission medium but besides dispersion, fiber non-linearities and RIN remain inherent limitations to such systems thereby degrading the performance [1]–[3]. Therefore, in order to realize broadband optical communication systems and networks, it is imperative to study and analyse the impact of RIN. In the present scope of our work, we have focused mainly on RIN. It has been shown that RIN induced by dispersion at first-order dispersion wavelength in single mode fiber transmission lines and small signal frequency response of a linear dispersive single-mode fiber near zero first-order dispersion wavelengths was observed [4], [5]. Laser diode modulation and noise, which may be intensity noise or phase noise, limits the system's performance [6]. A considerable FM-AM noise conversion occurs in dispersive fiber-link, which must be taken into account when designing analogue sub carrier distribution systems [7]. DBF laser RIN degradation occurs in CATV light wave transmission system [8]. For a link-length of 10km at $\lambda = 1.55\mu$m, RIN values between -125 and -145 db/HZ are expected for frequencies between 1 and 10 GHZ. These RIN values can be reduced either for laser diodes with narrower linewidth or for fiber links with lower dispersion [9]. However, in addition to the FM-AM noise conversion, nonlinear distortion caused by FM-AM conversion must be accounted for in analogue systems. The Influence of fiber nonlinearity on the conversion of laser and optical amplifier phase noise, intensity noise by fiber transmission was investigated in [9]. A very good agreement of RIN spectra at the output of a standard single mode fiber between experimental data and theoretical prediction was achieved. Results reveals that the fiber nonlinearity and dispersion can enhance the RIN magnitude significantly and lead to the shift of RIN dips towards higher frequencies and consequently to a broader RIN spectrum at the fiber output. The theory presented provides a tool in order to reduce RIN in cascaded optical amplifiers systems, by suitable choice of system parameters. It may provide basic information to minimize detrimental RIN effects in future communication systems. Further, the expression for RIN including higher order dispersion term was derived using small signal analysis [10]. It was shown that the second order dispersion term was having negligible effect on RIN. Later on Large signal Analysis of FM-AM conversion in Dispersive optical fibers for PCM systems including Second order dispersion was carried out [11]. However none of the researchers have evaluated RIN for another important parameter laser linewidth with pre-distortion compensation.

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In this Paper, pre-distortion method for UWB signal is proposed; limitations are identified to optimize RoF system. With the proposed pre-distortion method and optimized single mode VCSEL, for 500m optical link, SFDR of 80 – 90 dB $Hz^{2/3}$, the RoF system achieved the performance of 1.54302e-4 for the BER at SNR 30 dB. The low cost RoF system with optimized single mode VCSEL and pre-distortion method is found to satisfy the requirements to distribute UWB RF signal.

II. Simulation Setup

The optical system design consists of VCSEL diode transmitter, single/multimode fiber, attenuator, PIN diode receiver.

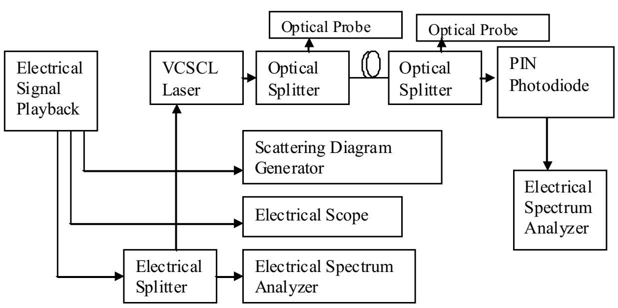

Fig. 1. VCSCL optical system design.

TABLE I
VCSEL LASER EMITTER

Honeywell VCSEL Laser Emitter
Honeywell High Speed Fiber Optic VCSEL (HFE4080-32X/XBA)
Threshold current I_{Th}=3.5 mA
Slope Efficiency η 0.3 mW/mA
Peak Wavelength λ_p= 820 850 860 nm
Spectral Bandwidth $\Delta\lambda$ 0.5 nm

TABLE II
SINGLE MODE FIBER

Corning SMF-28
850 nm LED source minimum overfilled launch bandwidth 200 MHz* km
Laser based source 385 MHz* km
Attenuation: $<$ 0.35/0.22 dB/km @ 1310/1350 nm
Chromatic Dispersion:
Zero Dispersion Wavelength (λ0) 1302 nm $\leq$ λ0 $\leq$ 1322 nm
Zero Dispersion Slope (S0) $\leq$ 0.092 ps/(nm^2*km)
Dispersion = D(λ) = $S_0 \frac{S_0}{4}\left[\lambda - \frac{\lambda_0^4}{\lambda^3}\right]$ ps/(nm*km)
Mode-Field Diameter:
9.2 $\pm$ 0.4μm at 1210 nm, 10.4 $\pm$ 0.8μm at 1550 nm
Length: 0.5 km

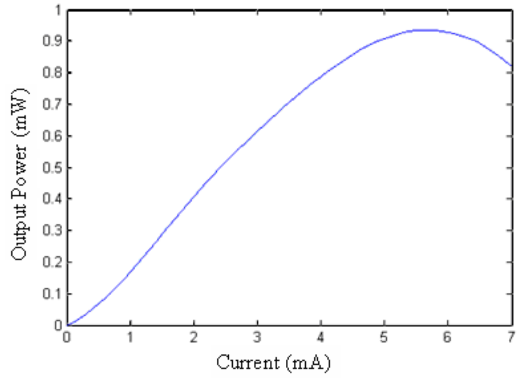

Fig. 2. Output power vs. current for 2μm single mode VCSEL.

Optsim 5.0 optical simulation tool from Rsoft Design Group is used for the design. Figure 1 shows the VCSEL optical system design. UWB RF signal is fed in to the optical system through a test data file reader block. Electrical and optical spectrum analyzers are attached to the input and output electrical and optical signals. Test data file writer collects electrical system after optical transmission for simulation in Matlab Simulink.

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All the parameters for the simulation are taken from commercial products. Honeywell HFE4080-32X/XBA VCSEL is used as laser emitter (Table 1). Corning SMF-28 is used as single mode fiber (Table 2). Corning Infinicor 1000 is used as multimode fiber (Table 3).

TABLE III
MULTIMODE FIBER

Corning Infinicor 1000 multimode fiber
850 nm LED source minimum overfilled launch bandwidth 200 MHz * km
Laser based source 385 MHz* km
Attenuation: $<$ 3.0/0.7 dB/km @ 850/1300 nm
Chromatic Dispersion:
Zero Dispersion Wavelength (λ0) 1332 nm $\leq$ λ0 $\leq$ 1354 nm
Zero Dispersio Slope (S0) $\leq$ 0.0097 ps/(nm^2*km)
Dispersion = D(λ) = $S_0 \frac{S_0}{4}\left[\lambda - \frac{\lambda_0^4}{\lambda^3}\right]$ ps/(nm*km)
Core Diameter: 63.5 +/- μm
Numerical Aperture: 0.275 +/- 0.015
Length: 0.5 km

III. VCSEL OPTICAL SIMULATION

This section presents the simulation of VCSEL transmits in single and multimode fiber. Oxide aperture diameter of 2μm is simulated for single mode and oxide aperture diameter of 10μm is simulated for multimode.

A. *Output Power Response*

The single mode power versus current characteristics is shown in Fig. 2. The multi mode power versus current characteristics is shown in Fig. 3. We can see that, the 2μm single-mode VCSEL has better slope efficiency than the 10μm multimode VCSEL (0.2 versus 0.35WA – 1), and lower maximum power (0.9 versus 4 mW).

B. *Modulation Response and Bandwidth*

Single mode and multi mode small signal modulation at difference bias currents are simulated and shown in Fig. 4 and Fig. 5 respectively. Performing the analysis, we find that the modulation bandwidth of the 10μm multimode VCSEL is limited to 12 GHz at 8 mA by a combination of damping and parasitic effects. From the same analysis see can see that, the modulation bandwidth of the 2μm single-mode VCSEL is limited to 9 GHz at 2 mA by a considerably higher damping due to strong gain compression. This is the result of the high photon density.

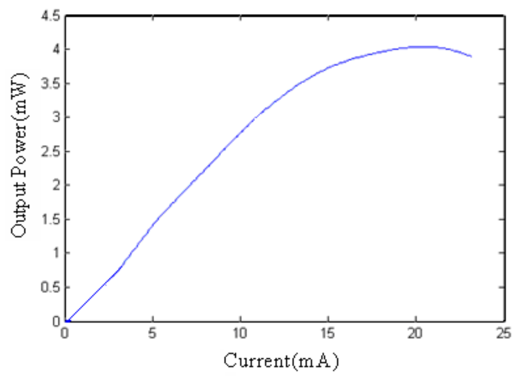

Fig. 3. Output power for 10μm multi mode VCSEL.

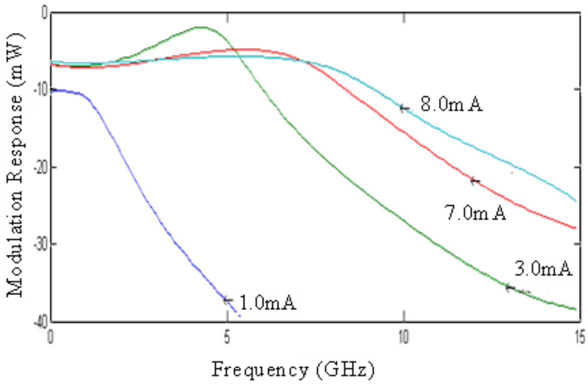

Fig. 4. Small signal modulation response for 2μm single mode VCSEL at different bias currents.

Performing the D-factor analysis, we find that the 10μm multimode VCSEL has a D-factor of 4.2 GHz . However performing the same analysis the 2μm single-mode VCSEL has a D-factor of 11.5 GHz . The high value of the D-factor for the single-mode VCSEL is a result of the small cavity and gain volumes and the high photon density.

Multimode VCSEL has a modulation response at frequencies below the resonance frequency, which is about 10-15 dB higher. This is due to the lower parasitic RF loss and also due to the higher slope efficiency. In this case, single-mode VCSEL is favored by a high D-factor.

C. Relative Intensity Noise (RIN)

Simulation is carried out to analyze RIN for single and multi mode VCSEL at different bias currents. Figure 6 shows RIN spectra for VCSELs at different bias currents for 2μm single mode. Figure 7 shows RIN spectra for VCSELs at different bias currents for 10μm multi mode.

We can see from the simulation, at high bias current, the noise of the single-mode VCSEL saturates at the shot noise floor. However the noise of the multimode VCSEL is higher due to mode competition or mode partition noise, and because of unavoidable mode-selective coupling. So we can see that single-mode is more favorable because the single-mode VCSEL has the lowest intensity noise.

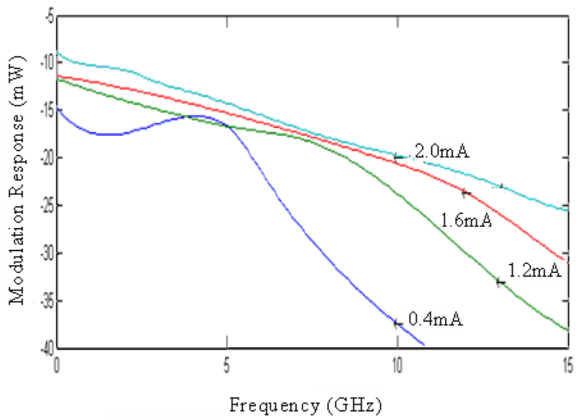

Fig. 5. Small signal modulation response for 10μm multi mode VCSEL at different bias currents.

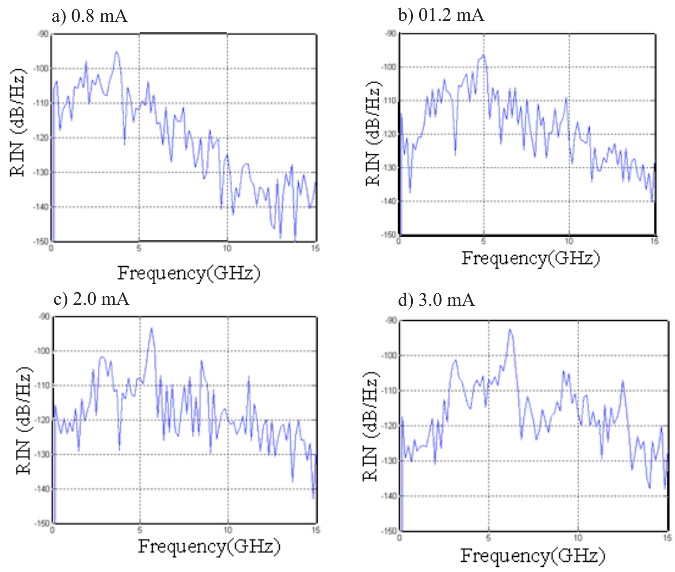

Fig. 6. RIN spectra for 2μm single mode VCSELs at different bias currents.

D. Dynamic Range

Second order harmonic distortion of signal and multimode VCSEL at different bias currents are simulated. Figure 8 shows single mode VCSEL second order harmonic distortion. Figure 9 shows multi mode VCSEL second order harmonic distortion. At lower frequencies (<1.5 GHz for single mode, < 2.0 GHz for multi mode), spatial hole-burning-induced distortion dominates. At intermediate frequencies, the two effects from relaxation oscillation and spatial hole burning cancel each other, resulting in a significantly lower distortion. Spectral hole burning effect, which is accounted for by the

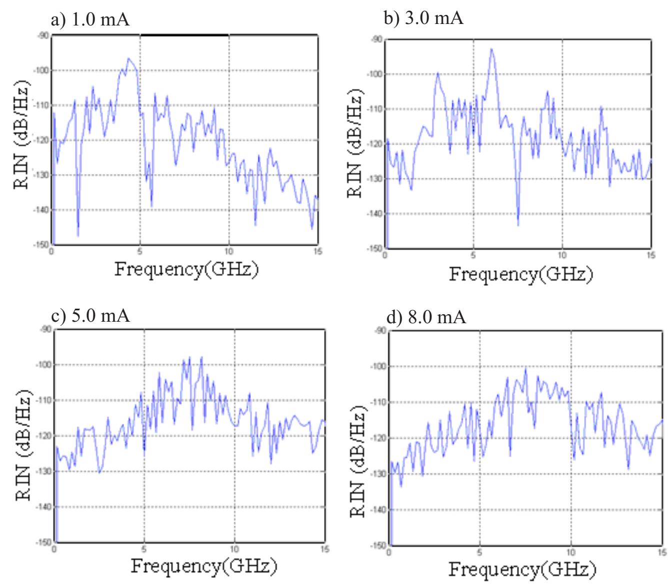

Fig. 7. RIN spectra for 10μm multi mode VCSELs at different bias currents.

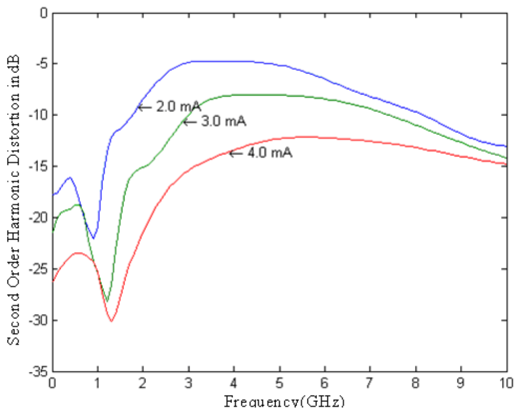

Fig. 8. Single mode VCSEL second order harmonic distortion.

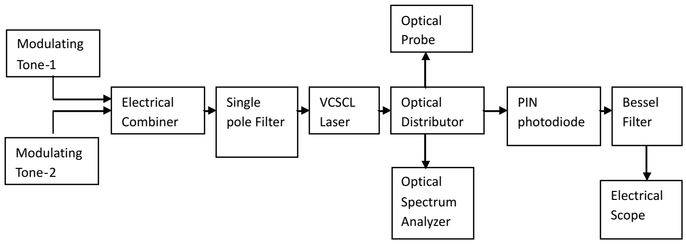

Fig. 10. Conceptual diagram for system setup for two tone tester.

gain compression factor were found to have a small effect on the relative distortion levels.

Spurious Free Dynamic Range (SFDR) is calculated from two-tone inter-modulation distortion (IMD) simulation. Two-tone signal separated in frequency by 1 MHz was fed to VCSEL with different bias current. See Fig. 10 for the setup of SFDR simulation.

The simulation results are shown in Fig. 11 from single mode and Fig. 12 for multimode VCSEL. The SFDR of the multimode VCSEL at 6 mA bias current is 84-95 dB. And the SFDR of the single mode VCSEL at 2 mA bias current is 82-85 dB. The SFDR of Single mode VCSEL is about 10 dB lower than multimode VCSEL. This is because of lower modulation response of the single mode VCSEL. We can see that RF transfer efficiency of multimode is greater than single mode VCSEL.

IV. Discussion and Conclusions

Desirable characteristics of a VCSEL (or any laser) used in a directly modulated fiber optic RF link include:

- Small parasitic RF loss,
- Low relative intensity noise (RIN),
- Low distortion,
- High fiber-coupling efficiency.

Low RIN levels and high coupling efficiency suggest the use of a single mode VCSEL. Because single mode VCSEL has no mode partition noise and low beam divergence. Major sources of distortion are the intrinsic non-linearity associated with the relaxation oscillations and spatial hole-burning-induced distortion. From the above it shows that the performance under direct high frequency modulation should depend on the modal characteristics of the VCSEL. VCSEL has a high resonance frequency and a strongly clamped carrier density because of the high photon density. So the use of a single mode VCSEL is more favorable over multimode VCSEL in analog signal transmission.

From simulation under different bias currencies we found: For single mode VCSEL, the bias of 2 mA has the highest SFDR and low RIN. For multimode VCSEL, the bias of 6 mA has the highest SFDR and low RIN. Since single mode VCSEL is more favorable in analog signal transmission, we chose single mode VCSEL with bias of 2 mA as optical link in the UWB RoF system.

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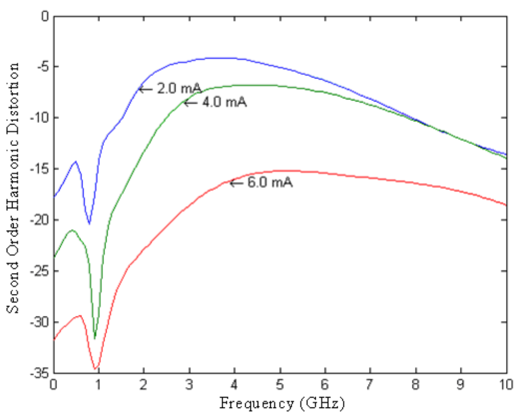

Fig. 9. Multi mode VCSEL second order harmonic distortion.

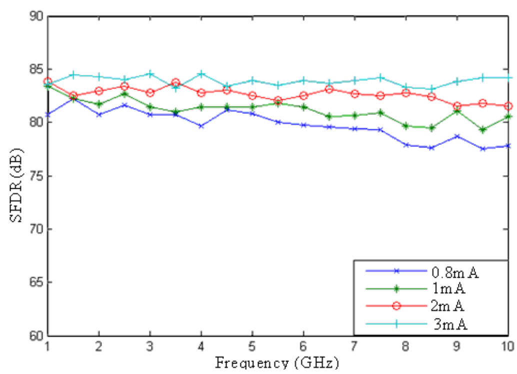

Fig. 11. SFDR(dB) for 2mm single mode VCSEL.

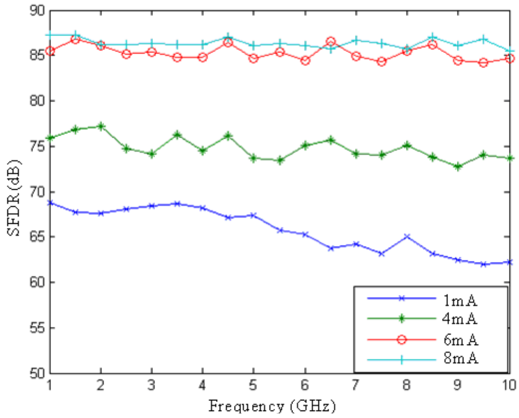

Fig. 12. SFDR(dB) for 10mm multi mode VCSEL.

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