Analog Modulation Characteristics of Multimode Fiber Links based on Commercial VCSELs

Executive Summary

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Abstract

This report examines the use of commercial 850 nm Vertical Cavity Surface Emitting Lasers (VCSEL) and multimode optical fiber for analog RF communication applications. Research in low cost and low Size-Weight-and-Power (SWAP) components is relatively new in the field in RF photonics [1-5]. Previous work has targeted high-end performance, but at high SWAP/cost [6]. The combination of VCSELs and multi-mode fiber provides performance that meets the needs of a wide range of RF photonic applications, but with more than 10X reduction in Swap/Cost. The clearest applications are those requiring extreme isolation, compact size, low power consumption, and flexible cabling. These applications arise in both military and commercial markets.

As a starting point for the development of VCSEL/Multimode fiber components, we have completed a survey of commercially available VCSELs and have characterized the gain, bandwidth, noise, linearity, dynamic range, and phase noise of prototypical RF photonic links made with these devices.

1. Introduction

We have carried out laboratory characterization of commercial VCSEL and GaAs PIN photodetector devices in conjunction with 50 and 62.5 µm core multi-mode fibers. The VCSEL and PIN devices may be purchased as bare die, but are more commonly found packaged as a Transmitter Optical Sub-Assembly (TOSA) or a Receiver Optical Sub-Assembly (ROSA). Figure 1 shows an example of one of these components. The TOSA/ROSA components consist of a windowed TO can containing the optoelectronic device and a molded plastic element consisting of a coupling lens and a sleeve to receive a fiber ferrule. The plastic element is actively aligned to the optoelectronic device and glued to the TO can. The TOSA/ROSA is assembled into a module with a housing that provides a retention mechanism for the fiber termination. In TOSAs, the VCSEL device is directly wire bonded to the pins of the TO can. In ROSAs, an amplifier IC is also included inside the TO can.

Figure 1: Example of a TOSA/ROSA component.

TOSAs and ROSAs are used ubiquitously in low cost commercial data communication modules. TOSA/ROSA components are generally not appropriate for applications in harsh environments or those requiring very high isolation or small size. However, they allow for rapid fixturing and characterization in a laboratory environment and were thus used throughout the present survey. Table 1 is a list of the VCSEL devices that were characterized. The PIN used was rated for 10 Gb/s operation and its responsivity was measured to be 0.45 A/W.

To complete the link between the VCSEL and PIN detector, we used 1 meter lengths of 50 and 62.5 µm core optical fiber. We found no significant difference between the two types of fiber over this short link.

The most basic RF photonic link is shown schematically in Figure 2(a). The VCSEL and PIN are directly connected to controlled impedance transmission lines. The characteristics reported in this survey apply directly to this type of link. A more evolved design is shown in Figure 2(b). In this case, specialized circuitry is used to interface to the VCSEL and PIN. On the receive side, superior performance is generally attained by using a low noise trans-impedance amplifier to which the PIN is directly wire bonded or flip-chip bonded. On the transmit side, a direct connection to a 50 Ω transmission line, or the use of a passive matching network, may be acceptable. However, a VCSEL driver, typically having a high impedance output, may provide an opportunity to improve noise and linearity. It is common in RF photonic links to use a laser driver that provides a controlled pre-distortion function to improve the linearity of the link [7-8]. The issue of interface electronics will not be considered further in this report, but the reader is reminded that the use of this type of circuitry is likely in practice and can be expected to provide some performance improvement relative to what is reported here.

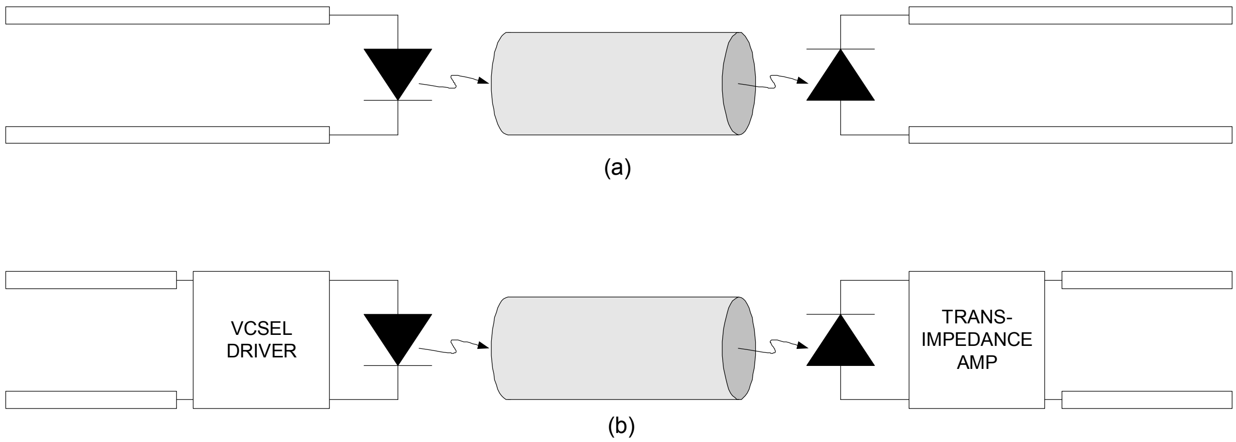

Figure 2: Simplified RF photonic links. (a) Represents the most basic case in which the VCSEL and PIN are directly interfaced to transmission lines. (b) Is a more evolved design in which specialized circuits drive the VCSEL and amplify the PIN signal.

Part Number	Package (# Pins)	Connector	Data Rate (Gb/s)	Max I_{ave} (mA)
1	TO (3)	LC	4.25	10
2	TO (6)	LC	10	9
3	Flex	SC	10	10
4	TO (4)	LC	4.25	12
5	TO (3)	SC	2.5	12
6	TO (5)	LC	8	12

Table 1: List of commercial VCSELs characterized in Phase I

		1	2	3	4	5	6
Intended Data Rate	(Gb/s)	4.25	10	10	4.25	2.5	8
Max Ave Current	(mA)	10	9	10	12	12	12
Threshold Current	(mA)	1.7	0.9	1	1.9	1.8	0.9
Slope Effeciency	(W/A)	0.08	0.15	0.13	0.075	0.13	0.1
Forward Voltage	(V)	1.6-1.9	1.5-2.2	1.6-2.1	1.7-2	1.6-2	1.6-2.2
DC Resistance	(Ohms)	37-55	47-95	40-85	40-63	36-65	57-90
Link Current Gain @ 1.2 GHz, 8 mA	(dB)	-29	-24	-24	-30	-25	-27
Link Power Gain @ 1.2 GHz, 8 mA	(dB)	-28	-25	-15	-30	-24	-29
Bandwidth	(GHz)	5.7	6.9	6	5.1	5.6	4.2
Phase Noise @ 112.5 MHz, 10 kHz offset	(dBc/Hz)	-126	-128	<-130	-126	<-130	-124
Phase Noise @ 1 GHz, 10 kHz offset	(dBc/Hz)			-126		-125	
Phase Noise @ 2 GHz, 10 kHz offset	(dBc/Hz)			-122		-123	
Phase Noise @ 5 GHz, 10 kHz offset	(dBc/Hz)			-122		-121	
RIN @ 1.2 GHz, 8 mA	(dBc/Hz)	-148	-151	-151	-147	-148	-150
NF @ 1.2 GHz, 8 mA	(dB)	28	29	17	31	29	29
Link OIP3	(dBm)	-9	-9	-25	-9	-15	-6
SFDR @ 1.2 GHz, 8 mA	($dB\cdot Hz^{2/3}$)	106	103	94	105	99	108

Table 2: Summary of key measurement results. Note that the power gain and noise figure of part 3 are atypical due to fixture effects which were not de-embedded.

2. Results and Conclusion

We have carried out a survey of six different VCSELs from the two dominant commercial providers of these devices. Typical RF performance metrics of multimode fiber optic links made using these devices were examined. The key measurement results are summarized in Table 2. This cursory data is intended to provide a starting point for the evaluation of this approach for specific applications. The full version of this report describes the measurement methodology and provides detailed data. Overall, we see relatively consistent characteristics across the different devices, at a performance level that would support many typical RF applications. Examination of the two key metrics of phase noise and SFDR allow us to assess the potential of this technology.

Phase Noise: The results suggest that VCSEL/multimode fiber based RF photonic links are very well suited to application in which phase noise performance is paramount. Across a wide range of frequencies, the phase noise performance of the link was near or beyond the measurement ability of the laboratory instrumentation. Additional work is needed to understand the subtleties of VCSEL modulation for optimal phase noise performance. The phase noise measurements in this study were carried out using sinusoidal VCSEL drive. However, phase noise was minimized by driving the device in a large signal operating mode between a sub-threshold state and a peak current limited by reliability. It is likely that superior phase noise performance will result from a switched mode VCSEL driver, rather than an analog RF source.

SFDR: The measured gain, noise, linearity, and SFDR of our optical links were comparable to reported literature [3,4] at around 105 dB·$Hz^{2/3}$. This result is somewhat notable in that our work exclusively used commercially available TOSA components while the published research included VCSELs optimized for analog/RF modulation. Furthermore, our SFDR results were comparable to RF photonic links based on single-mode fiber and DFB lasers [6]. This important result is a consequence of two key facts: 1) Modal dispersion in multimode fiber does not affect RF link performance at length up to ~100-500 meters [3]. 2) Although VCSELs possess multiple transverse lasing modes and exhibit pronounced modal dynamics [9,10], the noise and linearity of the aggregate optical output is of high quality, owing to its single longitudinal operating mode. Techniques developed to extend the SFDR of DFB/single-mode fiber links may be expected to apply to VCSEL/multimode fiber links. In particular, pre-distortion laser drivers have been shown to provide 12-24 dB of linearity enhancement [7,8] allowing typical DFB based links to achieve ~120 dB·$Hz^{2/3}$ SFDR, allowing them to meet the requirements of applications such as CATV video distribution over kilometers of fiber. We can expect similar performance from VCSEL based links over ~100 m links, but with greatly reduced size, weight, power, and cost.

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