Widely Tunable EAM-Integrated SGDBR Laser Transmitter for Analog Applications

L. A. Johansson, Y. A. Akulova, G. A. Fish, *Member, IEEE*, and L. A. Coldren, *Fellow, IEEE*

***Abstract*—A widely tuneable electroabsorption-modulated sampled-grating distributed Bragg reflector laser, integrated with a semiconductor optical amplifier is characterized for analog applications. The wavelength can be tuned anywhere from 1522 to 1573 nm. The suboctave spurious-free dynamic range (SFDR) is between 125–127 dBHz$^{4/5}$ measured at eight sampled wavelengths over the tuning range. The broad-band SFDR is in the range of 103–107 dBHz$^{2/3}$ limited by third-order intermodulation products or 95–98 dBHz$^{1/2}$, limited by second-order intermodulation products.**

***Index Terms*—Distortion, distributed Bragg reflector lasers, wavelength-division multiplexing.**

I. Introduction

Highly linear analog links have been demonstrated using typically a high-power low-noise optical source in combination with either an external linearized Mach–Zehnder modulator [1], or an external electroabsorption modulator (EAM) biased for minimum third-order distortion [2]. EAMs have the advantage of ease of integration with a laser source, offering advantages in terms of transmitter size and cost. Recently, an electroabsorption-modulated distributed feedback laser has been demonstrated as a low-cost high-performance source for dense wavelength-division multiplexing/subcarrier multiplexing long-haul transmission [3], taking advantage of the high available linearity and moderate chirp of the source.

In this letter, we show how enhanced functionality and performance can be achieved by the integration of a Franz–Keldysh modulator with a sampled-grating distributed Bragg reflector (SGDBR) laser and a semiconductor optical amplifier (SOA) to demonstrate a high linearity wavelength-tunable analog optical transmitter.

II. Optical Transmitter

Directly modulated SGDBR lasers have been shown to have a high dynamic range of up to 112 dBHz$^{2/3}$[4]. However, external modulation of SGDBR lasers has the advantage of decoupling the modulation and wavelength control circuitry, and thereby improves overall wavelength stability and the modulation response becomes less sensitive to laser bias point and emission wavelength. Another benefit is the lower chirp of the

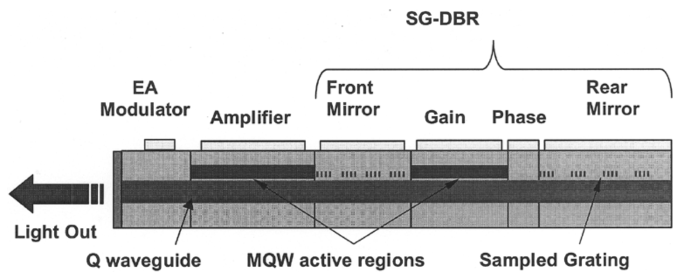

Fig. 1. SGDBR-SOA-EAM device schematic.

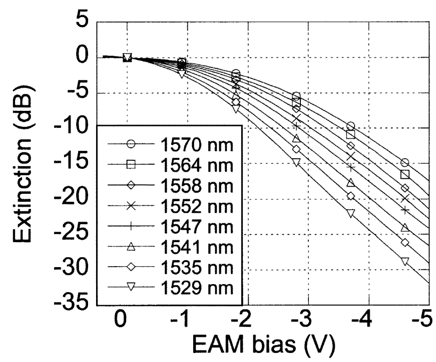

Fig. 2. EAM extinction over the tuning range of 1522–1573 nm.

external modulator, an alpha factor about one around the operating point. As illustrated in Fig. 1, the widely tunable optical transmitter consists of a four-section SGDBR laser monolithically integrated with an SOA and EAM [5]. The integrated SOA compensates modulator loss and cavity losses caused by free carrier absorption in the tuning sections and allows independent power levelling and wavelength control. The active region of the EAM uses the same bulk quaternary waveguide as the tuning sections of the laser. The composition of the bulk waveguide is optimized to achieve high tuning efficiency for the laser and a target extinction ratio of the EAM over the entire C-band. Fig. 2 shows the EAM extinction over the tuning range of 1522–1573 nm. Typical performance characteristics in continuous-wave mode of operation include the fiber-coupled output power of > 10 mW, linewidth < 2 MHz, and side-mode suppression ratio > 40 dB for 90 50-GHz-spaced ITU channels. The transmitter device is packaged in a cooled butterfly package with coplanar radio-frequency (RF) input.

III. Analog Performance

The spurious-free dynamic range (SFDR) of the device is measured at 0.5 GHz by two carriers at 1-MHz offset of between -5 to 5 dBm modulation power each. Fig. 3 shows the

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L. A. Johansson and L. A. Coldren are with the Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106 USA (e-mail: leif@ece.ucsb.edu).

Y. A. Akulova and G. A. Fish are with Agility Communications, Inc., Santa Barbara, CA 93117 USA.

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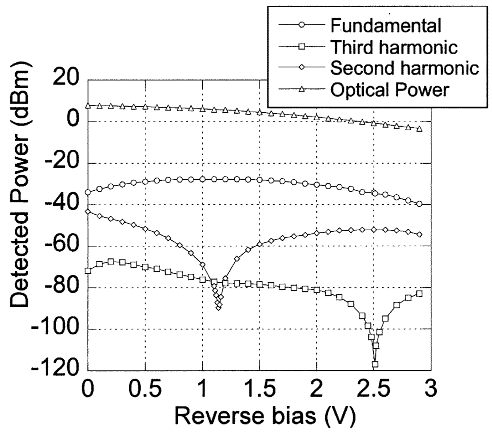

Fig. 3. Measured power of fundamental, second-, and third-order intermodulation products together with optical output power for 0-dBm modulation and 1545 nm.

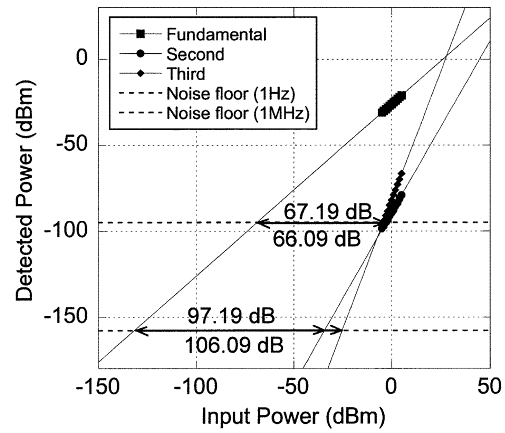

Fig. 4. Measured power of noise floor, fundamental, second-, and third-order intermodulation products at 1552 nm, for −5- to 5-dBm input RF power, 6.3-mW optical power, and −1.1-V EAM bias. Broad-band SFDR is also shown in 1-Hz and 1-MHz bandwidth.

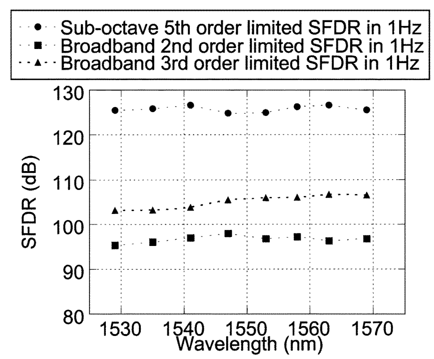

Fig. 5. Measured suboctave and broad-band spurious-free dynamic rage, left scale, normalized to 1-Hz bandwidth for different wavelengths. Suboctave SFDR is measured at the third-order inliction point and limited by fifth-order intermodulation products. Broad-band SFDR is measured at the sectond-order infliction point and is limited by second- and third-order intermodulation products.

power of the fundamental, second, and third harmonic intermodulation products as a function of EAM bias for 0-dBm modulation power of each carrier. The received optical power is regulated such that the optical receiver is operating in its linear regime. Also shown in the plot is the optical output power, all for 100-mA bias current to gain and SOA sections at 1545-nm wavelength. Minimum second-order distortion is observed at the bias point where the modulation efficiency is maximum (-1.1 V at 1545 nm). Minimum third-order distortion appears at -2.5 V EAM bias voltage. The power of the distortion products relative to the fundamental and optimum EAM bias point for minimum distortion do not change significantly for modulation frequencies within the bandwidth of the modulator (6.5 GHz) indicating that the dynamic range data measured at 0.5 GHz can be extrapolated up to 6-GHz modulation frequency, with a correction for the increased relative intensity noise (RIN) level around resonance at 6–8 GHz, up to 10 dB higher depending on gain section bias current. The overall SFDR performance will, therefore, be correspondingly degraded close to the SGDBR laser resonance frequency, determined by the increased detected noise power density.

For broad-band linearized applications, both even-order and odd-order distortion products need to be taken into consideration. The optimum bias point for broad-band operation is, therefore, at maximum absolute slope efficiency (5.5 mW/V, fiber-coupled), minimizing second-order distortion. Fig. 4 shows the measured dynamic range, both for 1-Hz and 1-MHz bandwidth, limited by second- or third-order intermodulation products for 180-mA bias to SOA and gain sections and 1552 nm. The received optical power is 6.3 mW, resulting in a noise floor at -157 dBm/Hz, limited by shot noise and laser RIN; -161.5 dB/Hz well below the resonance RIN peak ($<$ 2.5 GHz), at high bias current to SOA and gain section (180 mA) and only low applied bias to phase and mirror sections to optimize the RIN level [6]. Due to the different slope dependence of second- and third-order distortion, the SFDR is limited by third-order distortion measured in noise bandwidths down to about 200 kHz, after which second-order distortion will be limiting. The SFDR limited by second-order distortion is 97.19 dB in 1-Hz bandwidth, corresponding to 67.19 dB in 1-MHz bandwidth. The SFDR limited by third-order distortion is 106.09 dB in 1-Hz bandwidth, corresponding to 66.09 dB in 1-MHz bandwidth. Fig. 5 shows the broad-band SFDR measured at eight arbitrary sampled wavelengths over the tuning range of the laser. The SFDR remains within a 103–107 $\mathrm{dBHz}^{2/3}$ range limited by third-order intermodulation products, or 95–98 $\mathrm{dBHz}^{1/2}$ range limited by second-order intermodulation products.

For suboctave linearized applications, even-order distortion products can be filtered away after detection. The EAM is, therefore, low biased to the bias point of minimum third-order distortion with a fiber-coupled slope sensitivity of 1.8 mW/V, resulting in a fifth-order slope dependence of the distortion at detectable power. One further advantage of low biasing the EAM is reduced chirp of the modulator, shown to cause distortion over longer fiber transmission [7]. The alpha factor is about 0.5 at the point of minimum distortion, compared to ~ 1 at maximum modulation efficiency. Fig. 6 shows the measured dynamic range, both for 1-Hz and 1-MHz bandwidth. The SFDR is limited by fifth-order intermodulation products for 120-mA bias to the SOA and 180-mA to the gain section and 1552 nm. The lower bias applied to the SOA is to protect the modulator

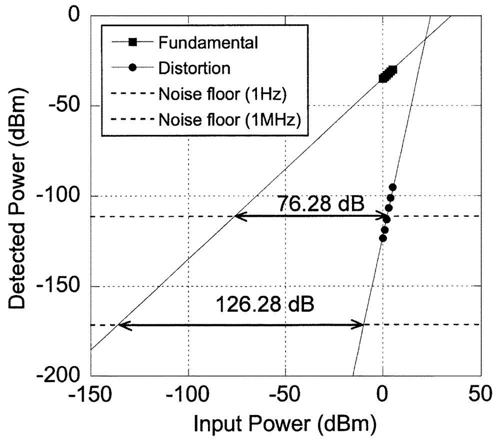

Fig. 6. Measured power of noise floor, fundamental, and third-order intermodulation products at 1552 nm, for 0- to 5-dBm input RF power, 0.96-mW optical power and −2.5-V EAM bias. Suboctave SFDR is also shown in 1-Hz and 1-MHz bandwidth.

from Joule heating from excessive v–i product, i being the EAM photocurrent. The received optical power is 0.96 mW, resulting in a noise floor mainly limited by shot noise. The SFDR is 126.28 dB in 1-Hz bandwidth, corresponding to 76.28 dB in 1-MHz bandwidth. Fig. 5 shows the suboctave SFDR measured at eight arbitrary sampled wavelengths over the tuning range of the laser. The SOA and gain section biases are kept constant and the same as for the results presented above. Mirror and phase section bias was adjusted to achieve optimized RIN performance at each wavelength, respectively. The SFDR remains within a 125–127 dBHz$^{4/5}$ range, all limited by fifth-order intermodulation products. The wavelength dependent variations in SFDR is mainly due to variations in the relative noise level, as determined by RIN and shot noise.

IV. Conclusion

In this letter, we have demonstrated a high-performance widely tuneable source for analog applications, a widely tuneable electroabsorption-modulated SGDBR laser, integrated with an SOA. The wavelength can be tuned anywhere from 1522 to 1573 nm. The suboctave SFDR is between 125–127 dBHz$^{4/5}$, measured at eight arbitrary sampled wavelengths over the tuning range of the laser. The broad-band SFDR is in the range of 103–107 dBHz$^{2/3}$, limited by third-order intermodulation products, or 95–98 dBHz$^{1/2}$, limited by second-order intermodulation products. The optical transmitter is attractive for use in a wavelength-division-multiplexing analog system, such as for cable/access and hybrid fiber-wireless applications; it is an integrated and potentially low-cost component and wavelength tunability ensures efficient and dynamic utilization of fiber infrastructure. Yet, the demonstrated performance is comparable to the best published results using high-power laser sources combined with external modulators [1], [2] in terms of SFDR.

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