Toward future generation digital avionics fiber optic communication

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ABSTRACT

Digital avionics technology options to consider for fiber optics communication on future generation aerospace platforms encompass transmitters and receivers operating at 25 Gb/sec and higher data rates. A new round of device and packaging innovation and development will likely ensue as a stepping-stone based on prior work in the areas of single wavelength transmitter, receiver / transceiver and multi-wavelength optical subassembly development.

Keywords: digital avionics, fiber optics, optical communication, optoelectronics, transmitter, receiver, packaging

1. INTRODUCTION

Over the past decade, development cycles have diverged between the commercial data communications and avionics sectors to the point where comparisons between the 1990s light emitting diode (LED) transmitter and the 2000s vertical cavity surface emitting laser (VCSEL) transmitter eras to today's environment has become almost moot for avionics. Development cycles have diverged within the aerospace sector as well creating another conundrum. Predicting how future generation digital avionics fiber optic communication will evolve, and become recognized as qualified products is expected to remain uncertain until a new generation technology is established at the appropriate technology readiness level (TRL) for implementation on aerospace platforms. In this paper, we provide the reader technology options to consider when developing future generation digital avionics fiber optic communication systems. We base our discussions by first looking at recent past history championing a new wavelength division multiplexed (WDM) local area network (LAN) avionics network topology and infrastructure. We provide a summary of the technology readiness advancement that occurred in the previous generation, which resulted in transition to aerospace platforms. Finally, we provide our perspective on how fiber optic communication may move forward in future generation avionics.

2. THE AVIONICS WDM LOCAL AREA NETWORK

The avionics WDM LAN concept presented at the 2003 IEEE Digital Avionics Systems Conference in a paper titled "Wavelength division multiplexed optical technology solutions for next generation aerospace networks" proposed an approach to developing a WDM LAN backbone network standard for aerospace platforms.[1] Subsequently the SAE Avionics Systems Division developed the SAE AS5659 WDM LAN standard. WDM allows the transmission of information (i.e., data and/or video) over multiple independent channels on separate optical wavelengths over a single optical fiber.[2] The WDM LAN concept is a response to the need for defined avionics interfaces, in order to provide guidance for avionics equipment upgrades. A successfully realized avionics WDM LAN could result in enormous life cycle cost benefits for the aerospace industry. It was also envisioned the avionics WDM LAN would provide a near term application for photonic lightwave and integrated circuits (PLCs and PICs, respectively), and a market opportunity for the ever-expanding commercial device industry to tap in to. A number of aerospace-centric technology developments ensued post-2003 including WDM LAN network concepts based on ring, bus, star and cross-cube architectures, and enabling hybrid and integrated components including tunable and fixed wavelength transmitters, wavelength converters and receivers, a waveguide amplifier, and single-mode fiber avionics-grade packaging technology. A few examples of this prior work are shown in Figures 1-2.[3-7]

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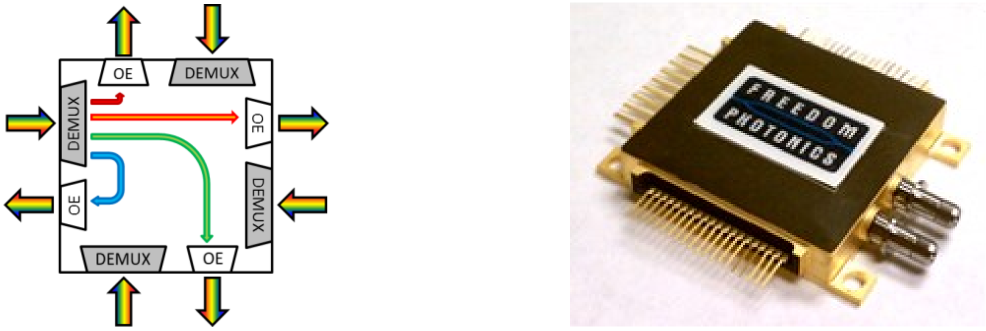


Figure 1. Cross-cube WDM LAN node based on tunable wavelength converter (left) and tunable wavelength converter (right).

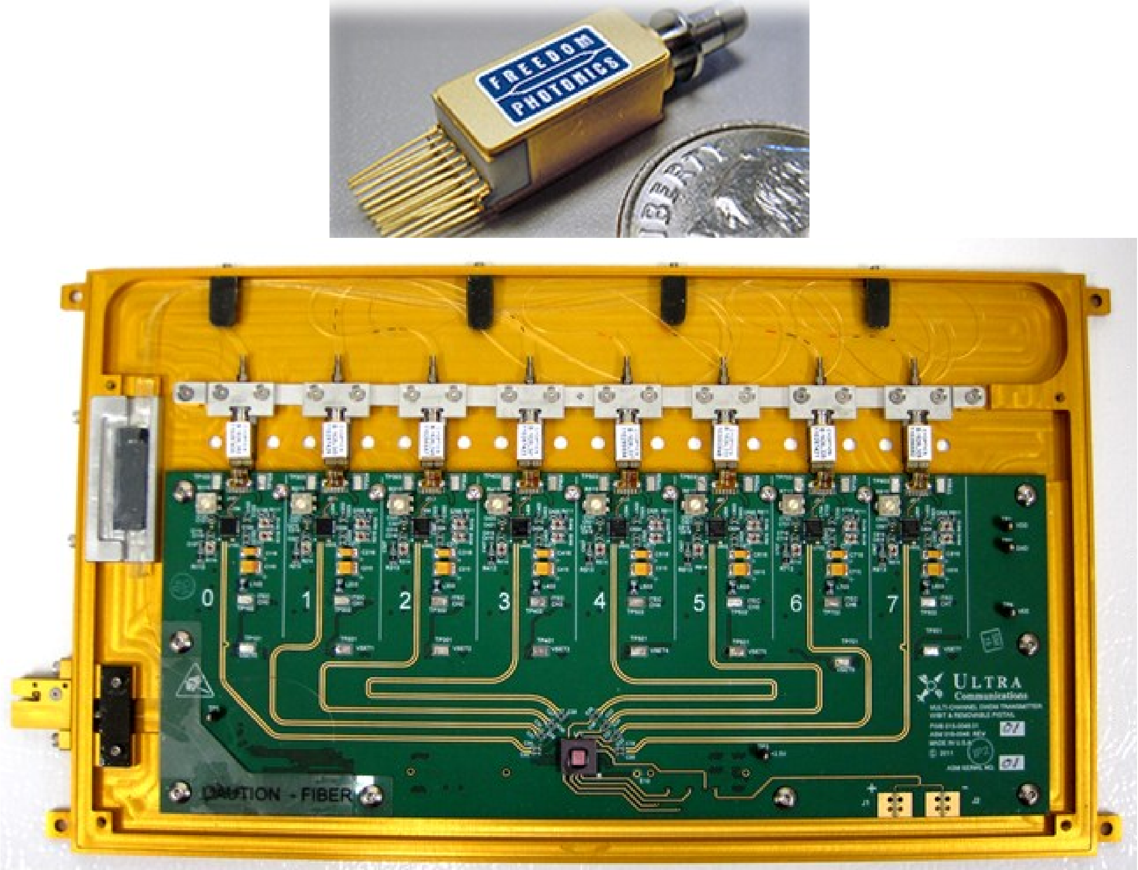


Figure 2. Tunable laser transmitter (top) and tunable 8 channel DFB laser transmitter (bottom).

3. MARKET FORCES

Commercial data center market forces that drove the development of new Ethernet standards and VCSEL based transceivers caused the aerospace WDM LAN and commercial data center LAN visions to diverge. Although data center transceiver products were obtainable for purchase by avionics suppliers, they generally were not readily qualifiable for avionics application. As a reminder, typical avionics transceivers are required to operate over a much wider temperature range, vibration and mechanical shock environment than data center transceivers. Data center transceivers are expected to be low cost, whereas avionics transceivers are not.

VCSELs operating in the 850nm window on multimode optical fiber have dominated the short distance optical interconnect market in data centers since the ratification of IEEE 802.3z (Gigabit Ethernet) and ANSI X3.T11.2 (Gigabit Fibre Channel). This was due to multiple reasons, including an installed multimode fiber base that supported 10Mb/sec Token Ring and 100Mb/sec FDDI; the relatively low cost of producing and packaging VCSELs compared to Edge Emitting Lasers and single mode fiber; and the overwhelmingly short distances that were needed in the data center. These solutions dovetailed nicely into commercial and military avionics as the longer distances required by the communications standards could easily be traded for higher link budgets and lower bandwidth optical fiber deployed in aircraft. (Note larger core fiber is often used to mitigate the inherent lifetime limits of optical connectors in the harsh avionics environment.)

As the demand for higher-speed Ethernet and Fibre Channel emerged, the limitations of the VCSELs, detectors, and optical fibers began to limit the link distances and available power budgets. In fact, distances have shrunk from over 500m to a few tens of meters as the speeds have increased.[8] To keep link distances that are needed in historic data centers, the standards organizations implemented forward error correction (FEC) which allow data links to operate at bit error rates up to $1\text{x}10^{-5}$, while still recovering the data. FEC adds power and latency to the optical link, both of which limit their appeal to the military and avionics community. Furthermore, as the technical challenges to making the high-speed links increased, the data communications community began to relax operating temperature range requirements from the historical -40 to 85°C range to reflect a limited indoor temperature range of 0 to 70°C. This has led to the reduced availability of optical components in ruggedized packaging that is required in both commercial and military aircraft. Because embedded cabling is so very difficult to replace in aircraft, there is a need for a new paradigm in the VCSELs, detectors, and packaging approach for use in future generation avionics.

The Boeing ARINC 636 125 Mb/sec transmitter and receiver (circa 1995) and the Ultra Communications dual-quad 10 Gb/sec transceiver (circa 2014) are shown in Figure 3.[9-10] Note the stark difference in packaging philosophies and package form factors. The Boeing devices are completely hermetically sealed and fiber pigtailed with single 100 micron core multimode fiber (160 MHz-km fiber bandwidth), whereas the Ultra Communications transceiver is connectorized with 50 micron core multimode fiber arrays (4700 MHz-km fiber bandwidth) resulting in 4 transmit and 4 receive channels. The optical interface in the Ultra Communications (UCI) transceiver is not hermetically sealed owing to the low-profile connectorized design approach.

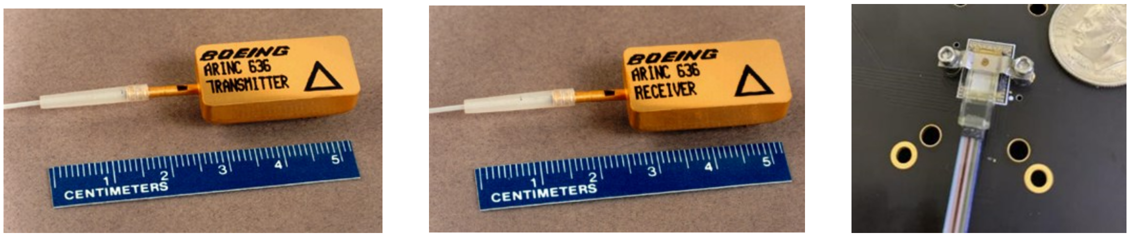


Figure 3. Boeing 777 125 Mb/sec transmitter and receiver (left) and Ultra Communications 10 Gb/sec transceiver (right)

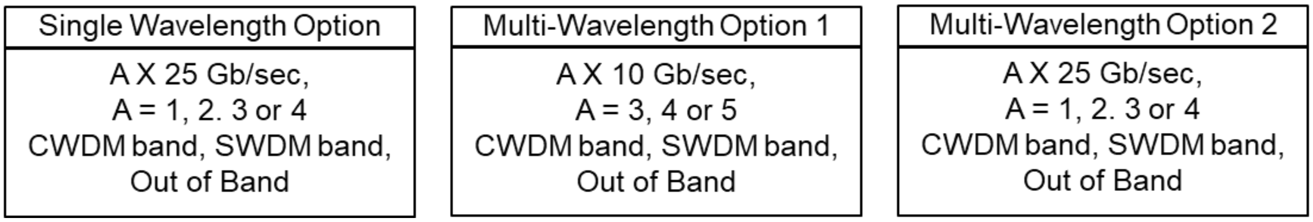
The UCI optical transceiver meets the MIL-PRF-38534, Rev L qualification and typical aerospace link performance requirements. The transceiver operates over -40 to 95 °C temperature range and is impervious to salt fog, moisture, and other contamination. The transceiver withstands the vibrations of aircraft takeoffs and landings, rocket launch, and cannon firing. Weighing only 0.4 grams with the 8 x 10 mm footprint, and worst-case power consumption of less than 1.5 W, this UCI transceiver was designed for up to 80 Gb/sec communication (4 transmit and 4 receive channels each at 10 Gb/sec). The package is designed for conduction cooling to the customer circuit board with a 3.5 °C temperature rise to the VCSEL devices.

4. FUTURE GENERATION TRANSMITTER / RECEIVER CONCEPTS

Future generation digital avionics fiber optics will likely include fiber optic links and network nodes that operate at greater than 10 Gb/sec per lane. Following the commercial Ethernet standards and digital networking market infrastructures, there appears be a clear path to no less than 25 Gb/sec links for avionics, including multiples of 25 Gb/sec depending on transceiver design, optoelectronics and packaging solutions. Figure 4 summarizes some of the potential opportunities. Both directly modulated VCSELs and externally modulated laser diodes (fixed or tunable) are viable options for transmitter emitters. Loss budget concerns and the lack of consensus in the avionics community with respect to network topologies and forward error correction usage makes receiver design forecasting less straightforward.

For example, high-speed photodetectors may require development at speeds 25 Gb/sec or higher. In some cases, photodetectors with amplification may be required to close on-off keyed (OOK) non-return to zero (NRZ) type digital links.

Figure 4 summarizes practical options for designing the transmitters and receivers. The single wavelength option is for links operating between 25 Gb/sec and 100 Gb/sec, whereby the laser is directly or externally modulated. The multi-wavelength options are for links operating between 25 Gb/sec and 100 Gb/sec, with intermediate link bandwidths between 30, 40 and 50 Gb/sec for multi-wavelength Option 1, and 50 and 75 Gb/sec for multi-wavelength Option 2.



Single Wavelength Option	Multi-Wavelength Option 1	Multi-Wavelength Option 2
A X 25 Gb/sec, A = 1, 2. 3 or 4 CWDM band, SWDM band, Out of Band	A X 10 Gb/sec, A = 3, 4 or 5 CWDM band, SWDM band, Out of Band	A X 25 Gb/sec, A = 1, 2. 3 or 4 CWDM band, SWDM band, Out of Band

Figure 4. Single wavelength option (left) and Multi-wavelength options (middle and right)

4.1 Ultra Communications (UCI) Transceiver Single Wavelength Concept

The transceiver concept that has been designed and prototyped by UCI fits the single wavelength option in Figure 4. The UCI transceiver is built on a packaging platform that scales in data rate by upgrading the internal circuitry, with on-going development of 25, 32, and 50 Gb/sec per fiber over 8 fibers, for 200, 256 and 400 Gb/sec total bandwidth respectively (see Figure 5). The increased data rates are achieved by upgrading the transceiver ASIC, VCSEL and PIN detector devices.

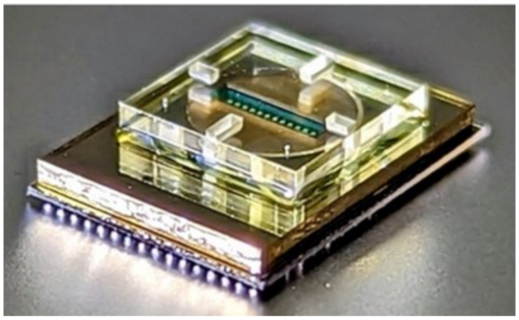


Figure 5. Ultra Communications 25 Gb/sec transceiver

4.2 NAVAIR and Freedom Photonics Multi-Wavelength Concept

One multi-wavelength concept option proposed by NAVAIR in 2014 was based on the cross-cube WDM LAN network node shown in Figures 1 (Left) and 6 (Left). The node utilized an optical demultiplexer (DEMUX) to separate the input WDM signals into separate channels, which are then routed to an output element (OE). The OE is comprised of tunable wavelength converters (WC) to receive data from one wavelength and re-transmit onto another wavelength. This concept was demonstrated by Freedom Photonics utilizing an array of 4 high-speed receivers connected to an array of 4 high-speed tunable transmitters, within a single output optical coupler, shown in Figure 6 (Right). The array of 4 high-speed tunable transmitters, or QUAD Tx, has been previously reported.[11]

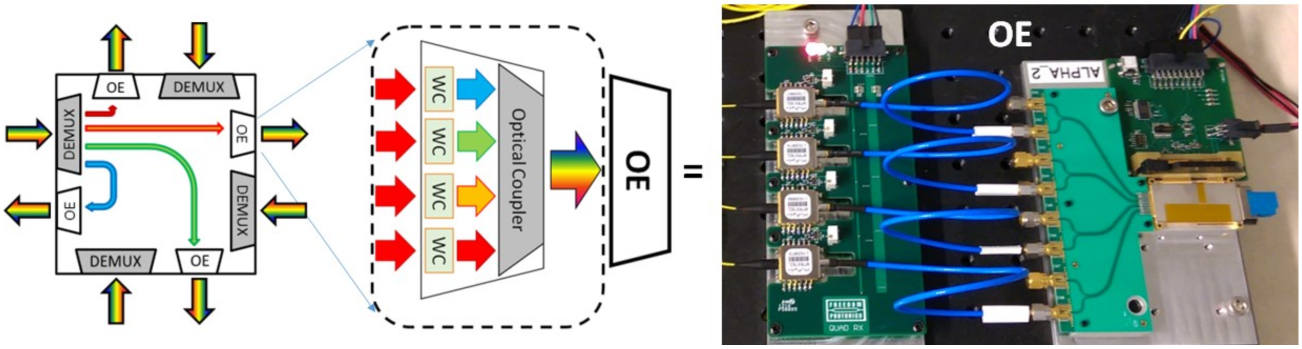


Figure 6. (Left) Concept of a single cross-cube node, with connections shown for one of the input WDM signals. These signals are demultiplexed (DEMUX) and routed based on wavelength to one the 4 output elements (OE), comprised of wavelength converters that are optically combined into a single output. (Right) Freedom Photonics implementation of the cross-cube node OE, comprised of an array of 4 optical receivers connected to a QUAD transmitter.

The device consists of 4 functionally equivalent widely tunable optical transmitters, connected to a single output multimode interference coupler. Each transmitter consists of a Sampled Grating Distributed Bragg Reflector (SGDBR) laser, followed by a semiconductor optical amplifier, and an electro-absorption modulator. The SGDBR tunable laser in the QUAD device employs two different mirrors, with comb-like reflectivity spectra, obtained by periodically sampling the Bragg gratings in the mirrors. Each mirror provides a different pitch spectral comb, allowing the Vernier effect to be used to enhance the tuning range. The laser phase electrode current is used to optimize the position of the cavity modes relative to the mirror peaks, as well as to allow continuous laser tuning coverage. An integrated semiconductor optical amplifier (SOA) is placed at the output of the SGDBR laser to provide additional optical amplification of the laser signal, as well as to allow for optical power control when the laser is tuned, without having to change the laser gain current. Amplified laser light is then modulated using electro-absorption modulation (EAM), which is the simplest method that meets the requirements of the application for the QUAD chip. The EAM is realized using Franz-Keldysh effect in bulk material, with the modulator detuning of about 80 nm from the quantum well gain peak. The modulators used in this design use lumped electrode designs, which is sufficient for 12.5 Gb/sec operation targeted by this application.

Light from the 4 tunable transmitters is combined at the output using an optimized 4x4 multimode interference (MMI) coupler. Only one of the MMI output waveguides is used to couple the light out of the chip. This coupling scheme has an inherent power loss of 6 dB. 4x4 MMI couplers were designed using numerical simulations of the splitters. The QUAD transmitter is designed to operate at 55 °C, which determined the composition and the photoluminescence peak of the quantum wells, waveguide, and the modulator regions. This elevated temperature of operation reduces the total system power consumption due to reduced cooling requirements.

Full performance of the QUAD devices (e.g., Figure 7 (Top Left)) was characterized through several system level, data transmission experiments and demonstrations. Figure 7 (Top Right) shows the eye diagrams of a QUAD transmitter module in operation, with all four channels operating, at 55 °C. High extinction, open eyes are achieved across the operating wavelength range of interest. QUAD modules were also used more recently in optical system level demonstrations of a network architecture.[12] In this demonstration, one QUAD module was used to generate the incoming traffic, while the second QUAD module was turned into a 4-channel tunable transceiver by having the QUAD modulators modulated by signals detected by photodetectors at the transceiver input, Figure 7 (Bottom Left). Bit-error rate diagram of the reference path, versus the 4-channel transceiver path, showing signal regeneration and negative power penalty through signal detection and remodulation using the QUAD output stage is shown in Figure 7 (Bottom Right).

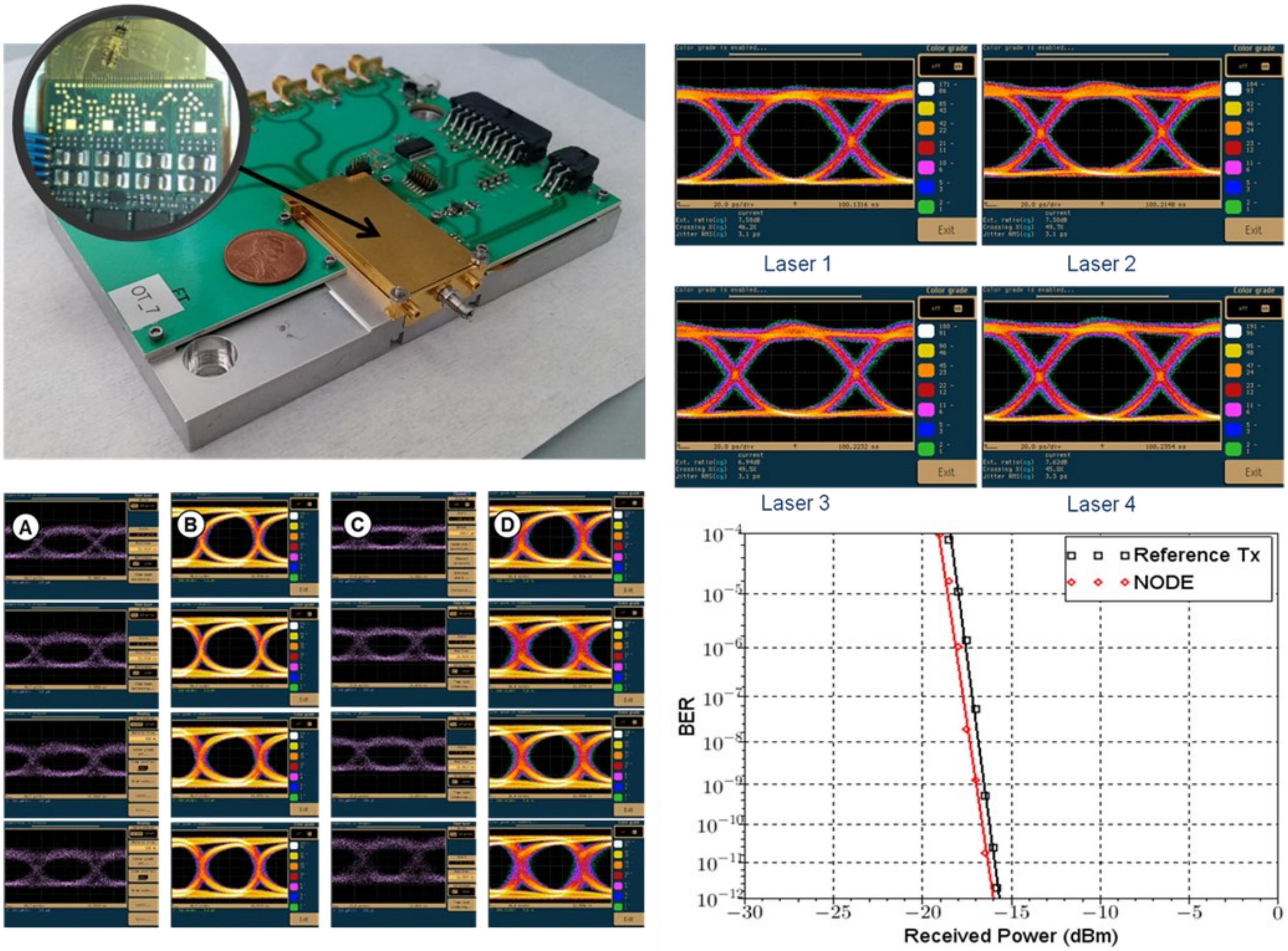


Figure 7. (Top Left) Example packaged QUAD Tx on an evaluation board. Inset is a magnified view of the QUAD Tx chip-on-carrier (CoC) connected to the driver PCB. (Top Right) QUAD Tx output eye diagrams, operating simultaneously each at 12.5 Gbps and 55°C. (Bottom Left) Corresponding received electrical eye diagrams (A) and (C), and the retransmitted optical eye diagrams (B) and (D) for 15xx nm to 15xx nm wavelength conversion, and 15xx nm to 15xx nm wavelength conversion, for (A-B) and (C-D), respectively. (Bottom Right) Bit error rate (BER) as a function of received optical power, comparing a reference Tx (black, squares) and the cross-cube node (red, diamonds) demonstrating error-free performance with negative power penalty.

5. OPTOELECTRONICS

5.1 Tunable Lasers for Transmitters

Freedom Photonics has developed many tunable laser devices at a variety of center wavelengths, with differing levels of integration complexity and performance. As mentioned in the previous section, widely tunable lasers with >40 nm of tuning range have been demonstrated, along with integrated SOAs and EAMs to realize monolithically integrated transmitters. Depending on the application and performance requirements, such large tuning range may not be needed to address WDM links, especially if power consumption is a concern. In 2018, Freedom Photonics demonstrated a novel approach to design of DBR lasers that utilizes sampled gratings to optimize mirror loss and mirror bandwidth independently, known as the comb-optimized (COMBO) DBR laser.[13] This versatile new approach has enabled a wide variety of lasers, from compact low power consumption to high power single mode designs.

Two distinct design spaces exist for these COMBO lasers. In type 1 COMBOs, the SGDBR grating is designed such that the reflection comb peaks are separated in wavelength by (i.e., have free spectral range (FSR) of) at least the FWHM of the gain bandwidth. The laser then operates only on the narrow comb peak nearest the peak of the gain medium. This laser design can have a strong SGDBR reflector at the back facet and a weaker PR facet at the front, or conversely, a strong HR coated back facet reflection and a weaker SGDBR front reflection. Type 2 COMBOs utilize an SGDBR with tighter FSR at one end of the cavity to down select cavity modes, and a broader DBR at the other end of the cavity which selects a single comb peak. Both COMBO types result in extremely robust SMSR while simultaneously ensuring that reflection strength and reflection bandwidth are decoupled to allow for a wide range of DBR designs in a single epitaxial platform. Figure 8 shows wavelength maps from type 1 and type 2 COMBOS. To date, Freedom Photonics has demonstrated successful COMBO laser designs at 1550, 1650, and 1270nm wavelengths, all on offset-quantum-well platforms.

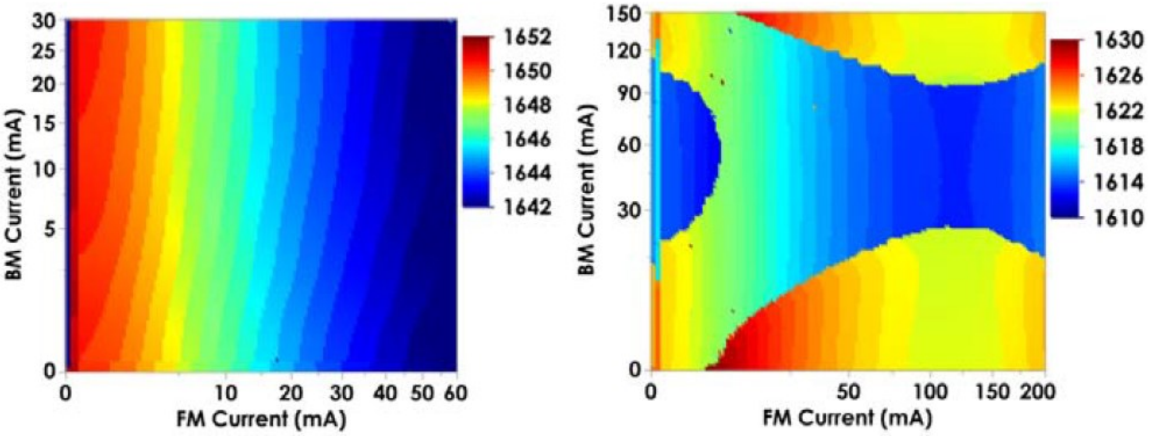


Figure 8. Measured wavelengths maps two types pf COMBO lasers, (left) Type 1 and (right) Type 2

5.2 Externally Modulated Laser Transmitters

Existing and future avionic systems will greatly benefit from highly efficient optoelectronic devices that can operate at elevated temperatures. As discussed in the previous section, Freedom Photonics has developed tunable laser-based transmitters that can operate up to 55°C, however to maintain sufficient link margin in challenging environments, higher output powers are desired. To address this need, Freedom Photonics is actively developing highly efficient distributed feedback (DFB) lasers at 1310 nm (O-band) and 1550 nm (C-band), to address multi-wavelength laser sources needed for data and telecommunication applications. A recent example of the O-band DFB lasers was reported in 2018 demonstrating a proof-of-concept eight-channel wavelength-division-multiplexed (WDM) source for future terabit interconnects based on a highly efficient laser array.[14] The array is composed of novel, high-power DFB lasers with record electro-optical efficiency, operating at 1280 nm, with >250-mW laser output power and laser efficiencies of up to 36%. The eight-laser array, with ~100-GHz channel spacing is optically butt-coupled to a planar lightwave circuit that consists of low-loss silicon nitride waveguides clad with silicon oxide for appropriate optical routing. Results from the O-band WDM source are shown in Figure 9.

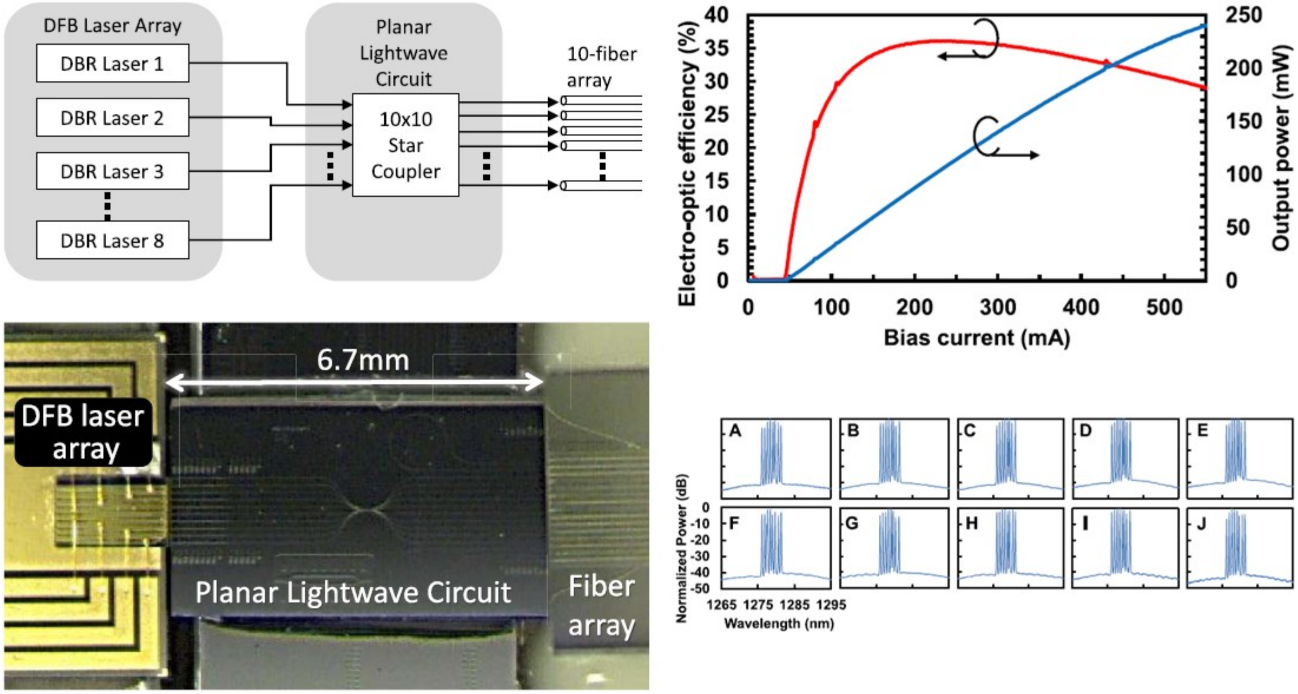
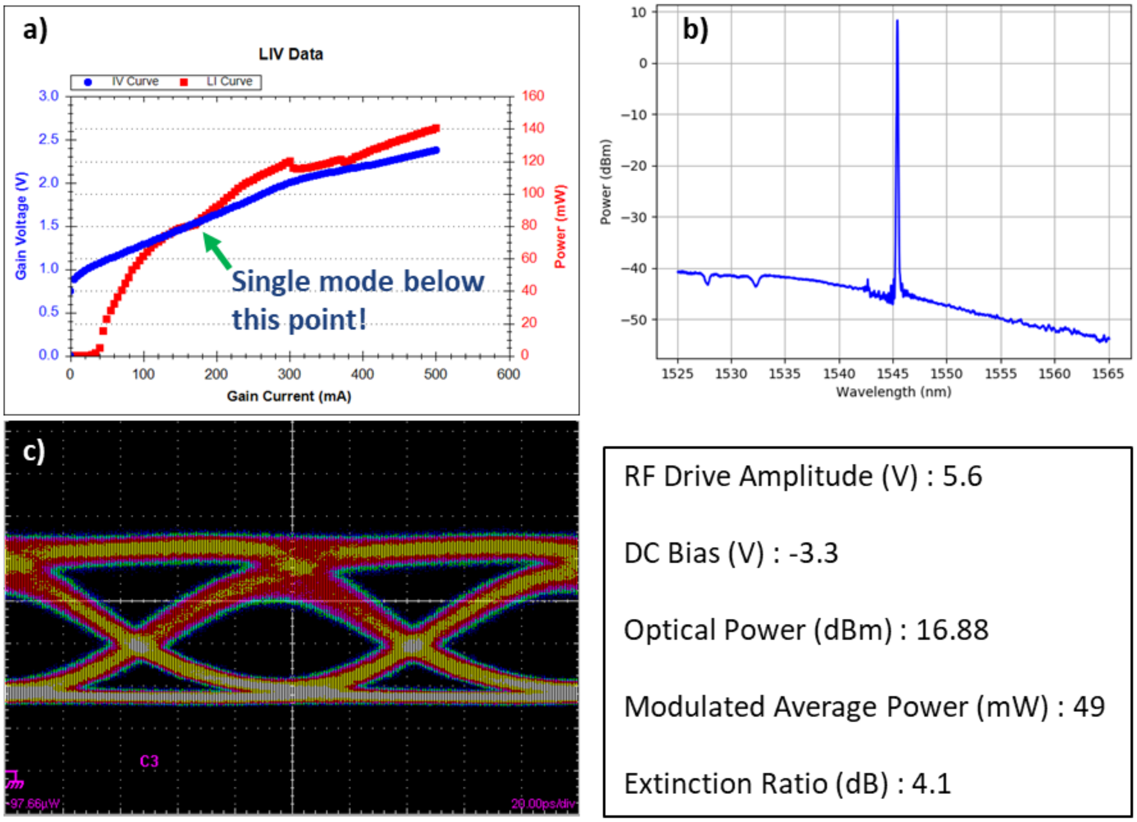


Figure 9. (Top Left) Diagram of 8-channel WDM source with 10 outputs. (Bottom Left) Photo of assembled proof-of-concept demonstrator. (Top Right) Output power and electro-optical efficiency of a single DFB laser. Back facet is HR coated such that the light primarily exists from the front facet and is detected. (Bottom Right) Normalized optical spectra from each of the output ports of the star coupler (A-J), each port containing the signal from the combined WDM source. Data for all 10 ports are plotted on same scales.

When highly efficient DFB laser sources are coupled with high-bandwidth and low V_π thin-film lithium niobate (TFLN) modulators, a high-performance externally modulated laser (EML) can be realized to address both analog and digital avionic links. In 2022, the hybrid integration of a DFB laser on a TFLN Mach-Zehnder modulator (MZM) was demonstrated, with 25 mW of output optical power, $V_\pi = 4.3$ V, and small-signal 3-dB bandwidth of ~50 GHz.[15]

Monolithically integrated lasers and modulators can be realized through a technique known as quantum-well intermixing (QWI), whereby the bandgap energy of the as-grown epitaxial material can be locally changed to realize both active (i.e., light generating / absorbing) and passive (i.e., light guiding / phase shifting) devices on-chip. In 2011, the QWI approach was utilized to demonstrate a 20 Gb/sec monolithically integrated coherent optical transmitter. However, the low output power would limit its use to low link margin or pre-amplified optical links; higher output power would be needed for avionic fiber optic links.[16] Freedom Photonics has recently developed a monolithically integrated platform enabling high-power laser sources and external modulators via QWI, operating at 1550 nm.

In Figure 10 below, we demonstrate a QWI DFB laser with monolithically integrated electro-absorption modulator (EAM), driven at 10 Gbps with a clear eye diagram at 20°C. With greater than 4 dB of RF extinction, it boasts almost 50 mW of single mode average power under modulation, and >50 dB side-mode suppression ratio (SMSR). Higher power operation of the laser is possible with improved design, which would increase the link margin, in addition to reduced RF drive voltage of the EAM through optimized QWI processing. As discussed in the previous section, high output power and high temperature operation can be achieved through careful device design and optimization, enabling high-speed and high link margin WDM optical links for future-generation digital avionics.



RF Drive Amplitude (V) : 5.6

DC Bias (V) : -3.3

Optical Power (dBm) : 16.88

Modulated Average Power (mW) : 49

Extinction Ratio (dB) : 4.1

Figure 10. a) LIV curve showing 140 mW of output power, with up to 80 mW of single mode operation. b) Optical output spectra verifying single mode operation. c) Clear 10 Gb/sec eye on our newly fabricated quantum well intermixing platform with monolithically integrated EAMs.

5.3 Uni-Traveling Carrier Photodetector for Receivers

In a conventional PIN photodiode, bandwidth is ultimately limited by the velocity of the slower carrier (holes). A uni-traveling carrier (UTC) photodiode, on the other hand, facilitates rapid collection of holes, so that the primary carriers traveling through the device are fast electrons, which generally allows for a shorter transit time than in a conventional PIN photodiode.

A further advantage of the UTC structure is that it can achieve high speeds due to the separation of the absorption and depletion regions of the device, which decouples the RC limit from the transit time limit. In other words, a very thin absorption region can be used to attain a short transit time, while a thicker depletion region maintains a reasonable RC limit. The UTC structure also allows for high saturation powers, as it only accumulates space-charge from electrons, which have a higher saturation velocity than holes and thus experiences higher output saturation at a much higher current density. In modified UTC (MUTC) structures, the internal electric field can be pre-biased to counteract the space-charge effects at high optical powers/intensities, such that devices resist saturation at high input optical powers.

Freedom Photonics has developed high-speed, high-power photodiodes for RF analog link applications, based on MUTC technology transferred from Professor Andreas Beling et al. at the University of Virginia. Freedom's MUTC devices have been developed into two families of fully packaged, fiber-pigtailed modules. One family of devices focuses on high power applications. These devices include high-power photodiodes with 3-dB bandwidths of 22 GHz coupled with output powers in excess of 23 dBm, as well as 35 GHz photodiodes with output powers greater than 19 dBm. An image and representative S21 data for the 22 GHz device are shown in Figure 11.

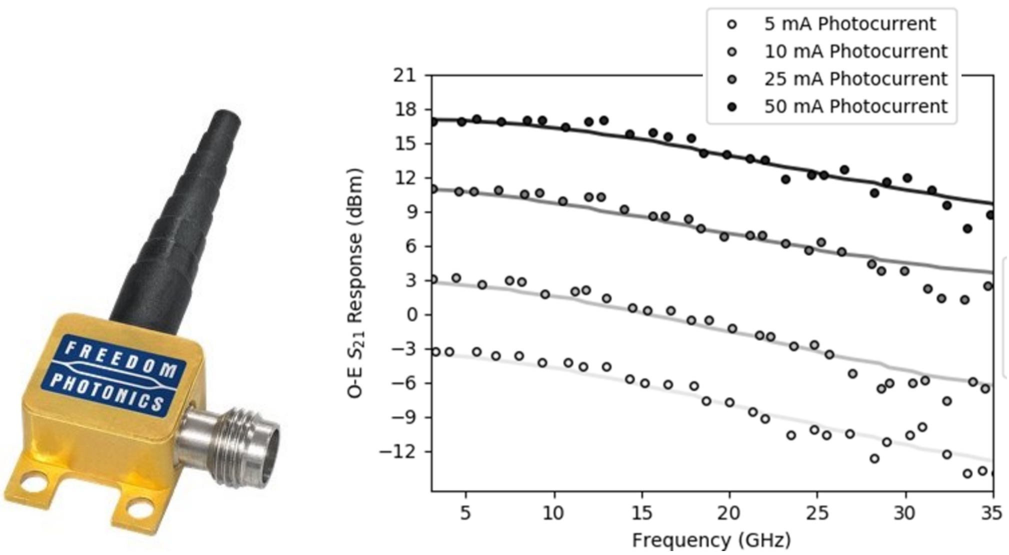


Figure 11. (Left) Photograph of a packaged 22 GHz photodiode module with a pigtailed optical fiber input and V-type connector. (Right) RF power vs. frequency for a fully packaged device, with a responsivity of 0.45 A/W. The 3-dB bandwidth of this device ranges between 15 and 25 GHz, depending on incident optical power. Responses are shown for photocurrents ranging from 0.5 mA to 10 mA. Circles show the data; lines overlaid are polynomial fits.

Another family of devices focuses on high-speed applications, including photodiodes with 3-dB bandwidths of >65 GHz and >100 GHz. An image and representative S21 data for a 110 GHz photodiode module are presented in Figure 11 .

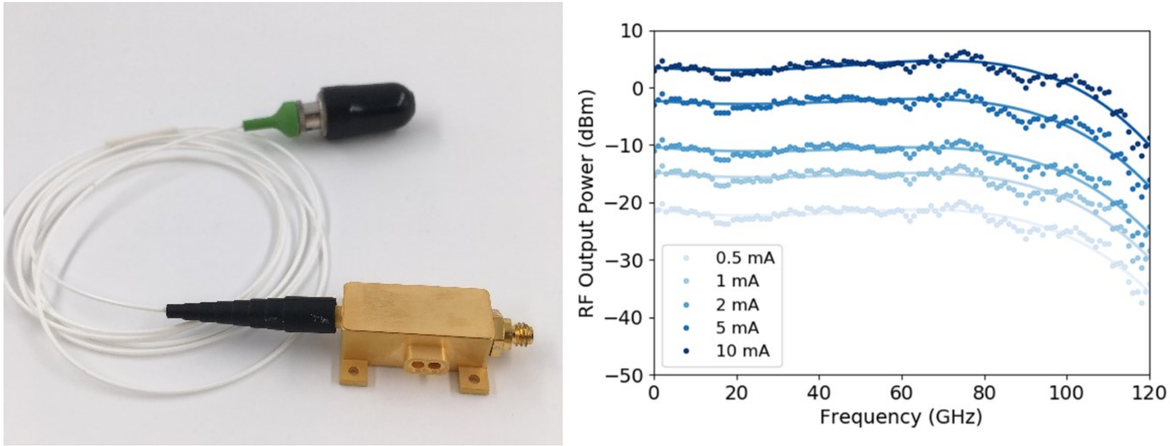


Figure 11. (Left) Photograph of a packaged 110 GHz photodiode module with a pigtailed optical fiber input and 1mm connector. (Right) RF power vs. frequency for a fully packaged device, with a responsivity of 0.07 A/W. The 3-dB bandwidth of this device ranges between 90 and 110 GHz, depending on incident optical power. Responses are shown for photocurrents ranging from 0.5 mA to 10 mA. Circles show the data; lines overlaid are polynomial fits.

These MUTC photodiodes have a major impact on peak performance in a photonic link. The high power-handling capability and high speeds of these devices support high link gain and large bandwidths, while the high linearity of these devices minimizes noise and signal distortion, maximizing spurious-free dynamic range (SFDR). All of these devices are commercially available through Freedom Photonics.[17-19]

5.4 Vertical Cavity Surface Emitting Lasers for Transmitters

The fundamental requirements for VCSELs and detectors are to enable higher passive loss interconnects at distances to a few tens of meters over multimode optical fiber and over the entire mechanical and thermal operating window at speeds up to 100Gb/sec without the need for FEC. There are two primary approaches to achieving this objective. The first is to increase the fundamental operating speed of the VCSELs to enable direct NRZ communications and to further increase the available optical power from the VCSEL. One approach uses a photonic-crystal VCSEL (PC-VCSEL) that creates a photon-photon resonance between spatial modes of two cavities in close proximity.[20] A schematic cross section of a PC-VCSEL is shown in Figure 13a. These devices have been shown to produce dramatic increases in the small signal modulation bandwidth as shown in Figure 13b, and have now demonstrated open eye diagram operation in excess of 70Gbps as shown in Figure 13c. These devices provide the designer with new tools to engineer the laser, and are a fundamental change to the tenets of VCSEL design.

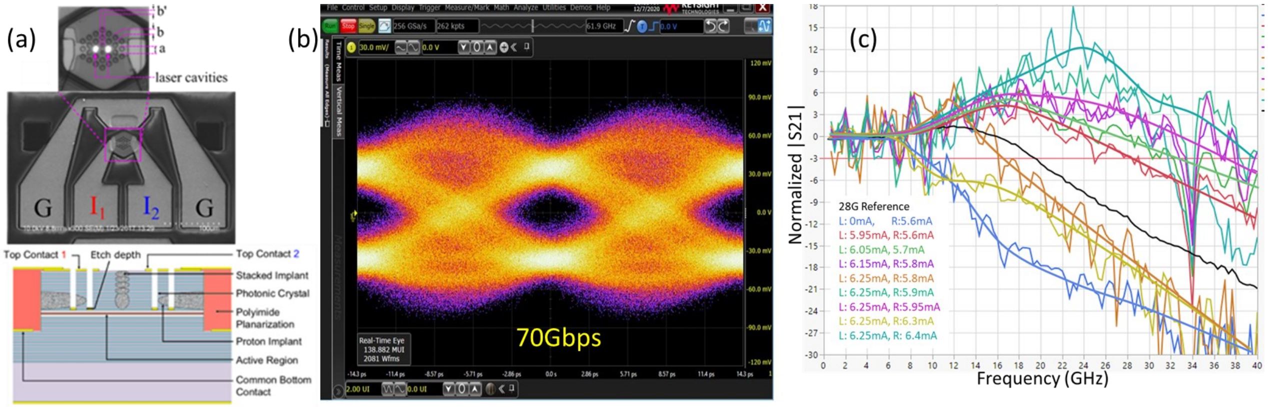


Figure 13 (a) Cross section of a PC-VCSEL, a top down view of the PC-VCSEL and an image showing the two cavities lasing. Diagram from K. Choquette at University of Illinois. (b) Eye diagram at 70Gbps measured by S. Ralph at Georgia Tech (c) Normalized small signal response of the PC-VCSEL at various operating conditons for the two cavities.

The second design approach is to utilize wavelength division multiplexing to increase the operating budget. One approach that has been taken by the commercial sector is using wavelengths at 850, 880, 910, and 940nm (30nm grid). These transceivers are targeted for brownfield installations and are only rated for limited temperature ranges. The approach here is to increase the wavelength spacing to 45nm to enable operation over the full -40 to 85°C range while still utilizing the 850 to 980nm window where VCSELs are traditionally fabricated. 850nm and 980nm devices have been measured over the entire temperature range for power and eye diagrams. The power as a function of current is shown in Figure 14a for the 980nm VCSEL and Figure 14b for the 850nm VCSEL. Figures 14c and d show eye diagrams at 25Gb/sec for the 850 and 980nm VCSELs operating at 25Gb/sec at room temperature. Figure 14e shows the measured small signal frequency response at over temperature at a constant 8mA bias condition for both 850nm and 980nm VCSELs.

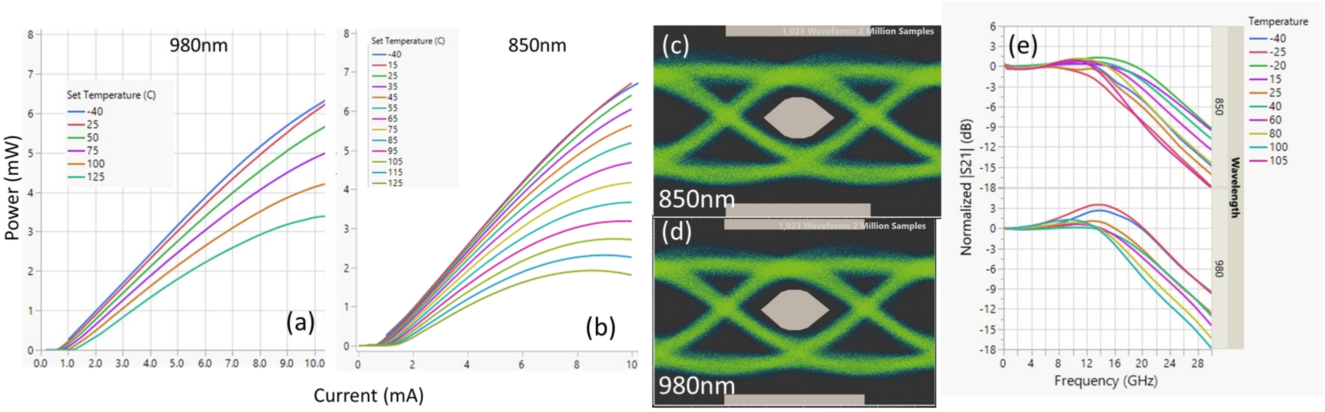


Figure 14(a) Light output as a function of current for a 980nm VCSEL from -40 to 125°C. (b) Light output as a function of current for a 850nm VCSEL from -40 to 125°C (c,d). Eye diagrams at 25G for the 850 and 980nm VCSELs respectively (e) Measured frequency response over te3mperature for both 850 and 980nm VCSELs.

5.5 Photodiode for Receivers

One of the other significant challenges in making higher speed links is the photodiode. Here the competing challenges of optical bandwidth, low capacitance, large active area, and responsivity require a trade off in the design of the active region thickness and diameter. To make a photodiode capable of receiving a 100Gb/sec NRZ signal, frequency response more than 60GHz is needed. This drives an active region thickness on the order of 0.5µm to achieve the carrier transit time limited speed. However, the capacitance is significantly increased with such a small thickness, and responsivity will be nearly 4x lower than a current 25G photodiode. To keep capacitance reasonable, the active region diameter will need to be on the order of 15µm. While it is feasible to make such a photodiode, the practicality will be limited. At 100Gb/sec, the design of the photodiode and transimpedance amplifier (TIA) must be taken together, and perhaps the frequency response of the TIA can be tailored to overcome the photodiode limitations. Figure 15a shows the calculated capacitance and responsivity as a function of the photodiode active region thickness with a vertical line showing the 0.5µm design point. Figure 15b shows the calculated transit time bandwidth and the parasitic capacitance limit as a function of the photodiode active region thickness with a vertical line at the 0.5mm design point.

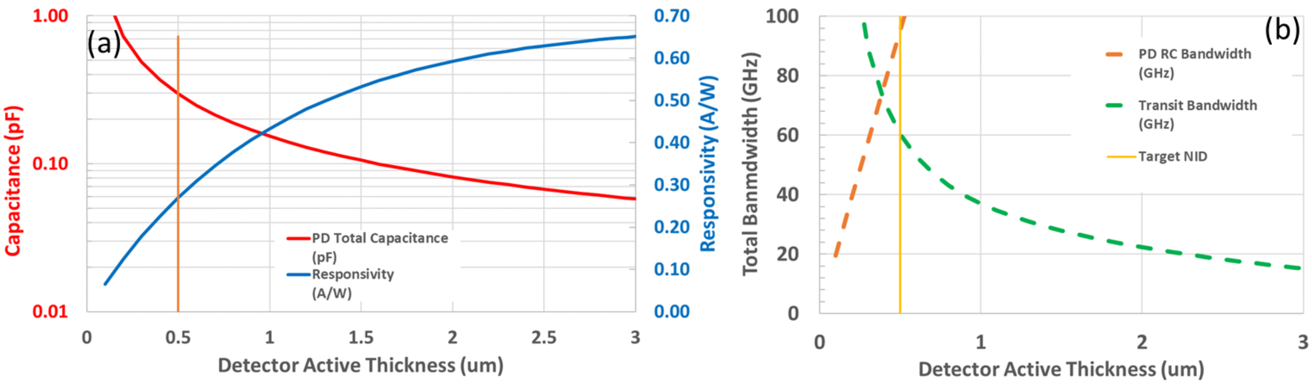


Figure 15 (a) Photodiode capacitance and responsivity as a function of active region thickness. (b) Transit time limited bandwidth and electrical parasitic bandwidth limits as a function of the photodiode active region thickness.

Due to the bandgap of GaAs, traditional GaAs based photodiodes do not respond to wavelengths longer than about 860nm, and most commercial InGaAs devices are designed to operate in the 1310-1550nm windows and do not function well at the shorter wavelengths. . They are also significantly higher cost than GaAs substrate-based devices. To address this gap, metamorphic InGaAs based photodiodes have been grown on GaAs substrates. They are designed to operate up to 1060nm and allow additional wavelengths in the WDM grid. The photodiode responsivity at 850nm and 980nm is shown in Figure 16a, and the measured leakage current of a large area diode is shown in Figure 16b.

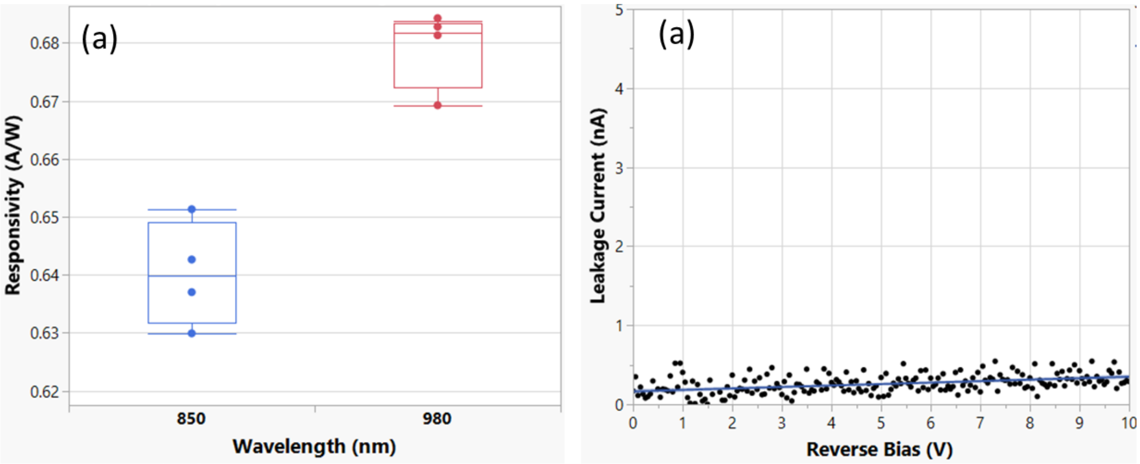


Figure 16 (a) Metamorphic photodiode capacitance and responsivity as a function of wavelength. (b)Measured leakage current on a large diameter (>100µm) metamorphic photodiode.

6. PACKAGING

Packaging innovation will again be paramount to realizing future generation digital avionics fiber optic communication modules. SAE ARP6318 is a recommended practice resource for assessing packaged photonic device technology readiness, and accelerating the maturation of photonics technology aimed toward future qualification of advanced digital avionic modules.[21] Various levels of package integration can be utilized to realize high-performance photonic avionic components, including monolithic, heterogeneous, hybrid, and co-package to formulate compact single or multi-chip solutions. Such advanced techniques from the electronic integrated circuit community are now being employed to address photonic solutions, primarily driven by the needs of data center applications. Using these advanced packaging techniques to address future digital avionics will require additional consideration for ruggedness and reliability.

7. SUMMARY

The needs of the aerospace industry and data centers have diverged as the overall use of fiber optics components has increased. The drive to higher speed and lower cost in the data center applications has led to compromises on the mechanical and environmental robustness of the many optical components. Various laser and photodiode technologies developed to address future avionics have been presented. The continued development of photodiodes, VCSELs, tunable and fixed wavelength edge emitting lasers, and their related packaging technologies focused on the unique needs of the avionics industry is vital to their continued use in avionics applications requiring 25 Gb/sec and higher operation performance.

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