Testing of MCP PMTs: use of fiber optic coupled Gbps laser drivers to create ersatz laser return pulses.

by

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ABSTRACT

From an operational point of view, it is important to be able to test the MCP (Micro Channel Plate) PMT (PhotoMultiplier Tube) front end of LIDAR transceivers used in SLR (Satellite Laser Ranging) work. In the day-to-day operation of SLR systems, one needs to have an independent method of ascertaining that the receiver half of the LIDAR transceiver is functioning properly. In addition, the sensitivity and stability of the MCP PMT front end of the LIDAR transceiver also needs to be periodically checked against a standardized source to prevent long and short term errors from insinuating themselves into the production data stream. The creation of ersatz laser return pulses is also useful when developing new LIDAR systems such as NASA's micro-laser altimeter and SLR2k robotic observatory. This paper describes a number of ways of constructing a laser return pulse generator from COTS (Commercial Off The Shelf) parts. In particular, we detail the use of currently available single chip laser drivers – normally employed in fiber optic LAN (Local Area Network) and WAN (Wide Area Network) telecommunication systems – as the 'heart' of the generator. Fiber optics is used to 'plumb' the ersatz laser return pulses together with the optical noise baseline to the output connector of the generator. The use of fiber optics allows one to conveniently fold the optic path within the generator without utilizing mirrors or prisms needed in a free space design and so results in a flatter volume for the generator and obviates the need for enclosing the generator in a light tight box. Since the specifying and ordering of single chip laser drivers and fiber optic components involve considerable amounts of jargon this aspect will also be covered.

INTRODUCTION

"There is nothing more terrible than activity without insight." – Thomas Carlyle

This paper is meant to be a top-down description of the process of designing and building of a laser simulator. The laser simulator is used to test the PMT (PhotoMultiplier Tube) front end of the receiver half of a LIDAR (LIght Detection And Ranging) transceiver, i.e., the laser simulator's function is to generate, on command, an ersatz optical return signal superimposed upon an optical noise background. Such a device was found to be helpful in both troubleshooting and operational verification of the receiver portion of the NASA MMLA (Multikilohertz Micro-Laser Altimeter) LIDAR. The laser simulator discussed in this paper will be used in the NASA SLR2k (Satellite Laser Ranging, 2 kHz [laser pulse repetition rate]) robotic observatory that is currently under development at NASA's GGAO (Goddard Geophysical and Astronomical Observatory) located in Greenbelt, Maryland.

At the apex of the top-down description of the SLR2k laser simulator is the requirements document, which ideally describes both the function and form of the device in question. When it exists at all, a requirements document represents a certain degree of tension between the end user, who writes the document, and the designer, who uses the document to design and construct the desired device and probably wishes that they had also written said document. The tension naturally emerges from the desire on the part of the designer to have a set or table of quantitative parameters elucidating the function of the device and the palpable dread the end user feels at having to think their way through such a thicket of far reaching and sometimes-contradictory requirements.

In the case of the SLR2k laser simulator, only a qualitative description was provided, as far as the function was concerned. The form of the device was specified to either be incorporated into a 3-slot NIM (Nuclear Instrumentation Modules) power supply or to fit inside a single or double width NIM module, which could then be inserted into the slots of the 3-slot NIM power supply.[2] To transform the function requirements into a more quantitative form, both the receiver and transmitter of the SLR2k LIDAR transceiver were considered, along with the design of our previous laser simulator used on the MMLA project. Unfortunately, the laser simulator, designed and built for use with the MMLA, came into existence without any extant requirements document, a nugatory amount of as-built drawings and no test data to speak of. Thus, it had to be reverse engineered in order to obtain the as-built drawings and its output had to be inferred from these same drawings. The actual unit itself was usually not available for testing, since it was needed at NASA's WFF (Wallops Flight Facility), Wallops Island, Virginia, where it is routinely flown, together with the MMLA, on a Lockheed P3B Orion aircraft. The end result of these investigations was a set of semi-quantitative requirements for the SLR2k laser simulator:

1) The wavelength of the ersatz optical return pulse must be close to the 532 nm (green) produced by the system laser; red laser diodes (λ_{Peak} = 635 nm) would be fine.
2) The energy contained in the ersatz optical return pulse must match that expected from a real target.
3) If possible, the pulse width (FWHM [Full Width Half Maximum]) should approximate the expected pulse width of $\approx$100 ps (FWHM) for the actual optical return pulse.
4) The timing jitter, i.e., the timing uncertainty between the leading edge of the electronic trigger pulse, used to initiate the optical output of the laser diode, and the actual start of the optical pulse should be <20-50 ns.
5) The wavelength and incident power of the ersatz optical background noise source should approximate sunlight and possibly glint from retrograde motion of the transmitter beam due to unintended reflections from the optical train.

LASER SIMULATOR BLOCK DIAGRAMS

In its most basic configuration, the laser simulator contains two light sources: i) a triggerable, pulsed light source and ii) a CW (Continuous Wave) light source. The outputs of these two light sources must be combined together to yield a composite waveform mimicking the expected optical signature of an echoed light pulse, which is surrounded and even submerged in an optical noise background. The light from the two light sources and the resulting composite optical signal can reach the output connector of the laser simulator either through free space, as is the case in the MMLA laser simulator, or by way of fiber optics, as is the case in the SLR2k laser simulator.

There are two ways of configuring the optical plumbing within the laser simulator. The first approach, used, for example, in the MMLA laser simulator, is to plumb the light using a Y-shaped path with the ersatz optical return pulse and the CW (Continuous Wave) optical background noise being injected into separate arms of the Y, combining (summing) at the junction of the Y, and leaving via the lower leg of the Y. In the second approach, the optical path is I-shaped because the laser diode module itself generates a CW optical background (a.k.a. bias) with a superimposed pulsed optical output (a.k.a. modulation); here, the optical output enters the top of the I, already combined together, and then exits at the bottom of the I. In other words, if we employ a commercially available, laser diode module capable of being modulated, then its output normally contains everything we want, or so it seems.

LASER DIODE MODULES

The most mysterious entity of the laser simulator is the laser diode module. Since the laser diode module is the 'heart' of the laser simulator, one must understand its inner workings in order to use it in a way that does not produce unintended consequences. The MMLA laser simulator utilized a Power Technology, Inc., model PMH04/5077, PMH Laser Diode Module (V_{in} = 4.95-8 VDC, Modulation BW [BandWidth] = 100 MHz, λ_{Peak} = 635 nm (red), P_{Out} = ≈4 mW), which fed one leg of the Y.[3] The other leg of the Y was fed by two incandescent lamps connected in parallel electrically and energized with DC current. The PMH laser diode module, which is housed in a right circular cylinder approximately 1" Dia. X 2-5/8" L, consists of a controller SMT PCB (Surface Mount Technology Printed Circuit Board); an edge-emitting, N type (a.k.a. the laser diode anode and monitoring photodiode cathode are common with the case of the package) laser diode; and a pseudo-collimating lens mounted in front of the exit window of the laser diode package.[4] The controller board has a transistor socket on one end, into which the laser diode can be plugged, and at the other end, there is a M[ale]-SMC connector for the modulation input, a 6-pin power and signal connector, and two multi-turn potentiometers controlling the modulation and forward-bias currents. Although the PMH laser diode module is not the only module that can and will be used, its inner workings are representative of all such laser diode modules whose optical output can be modulated.

Before going on to talk about the organization of this particular laser diode module, it should be mentioned that the modulation of the laser diode's optical output is done directly. There are two schemes for modulating a laser diode's optical output: direct (internal) modulation and indirect (external) modulation. In the case of direct modulation, the current through the laser diode's PN junction is modulated, which causes the optical output to change. This method is the simplest approach to modulating laser diodes, but it does have its disadvantages. The main disadvantage is that spectral purity of the laser diode will be, to some extent, compromised because of the influence of the magnitude forward current on the index of refraction of the active region of the laser diode's PN junction. In other words, changes in the forward current can change the index of refraction and so change the optical length of the resonant cavity and, hence, the peak wavelength, λ_{Peak}, emitted by the laser diode; rapid changes in the peak wavelength are called ‘chirp’. In the indirect modulation scheme, the laser diode is operated in the CW mode with its light being modulated by an external (to the laser diode) electro-optic modulator. The electro-optic modulator, which functions on voltage instead of current, can be either an electro-adsorption semiconductor modulator (reverse biased diode) or an electro-optic material such as lithium niobate doped with titanium ($LiNbO_3$:Ti), for example. Direct (internal) modulation currently has an upper bit rate limit of about 2.5 to 10 Gbps, while indirect (external) modulation can be used at bit rates at or above 10 Gbps.

The block diagram of the PMH laser diode module contains six blocks: the first five of the blocks are associated with the controller board, the sixth block is made up of the laser diode and its pseudo-collimating lens. The blocks associated with the controller board are as follows: 1) the power conditioning block, which uses a Texas Instruments, Inc., model TPS7101Q, Low-Dropout Voltage Regulator; 2) the temperature sensor block, which uses a National Semiconductor Corp, model LM335Z, Precision Temperature Sensor to monitor the laser diode temperature and output an analog voltage representing the value of this temperature to the 6-pin connector on the rear of the module; 3) the adjustable forward-bias current block, which uses one-half of a Texas Instruments, Inc., model TLC252C, LinCMOS Dual Operational Amplifier and a Zetex, Inc., model FZT1049A, NPN Silicon Planar Medium Power High Gain Transistor configured as an adjustable, constant current source; 4) the current sensor block, which uses an Analog Devices, Inc., model AD623AR, Single Supply, Rail-To-Rail, Instrumentation Amplifier and a pair of current viewing resistors to monitor the laser diode forward-bias current and supply an analog voltage representing the value of this current to the 6-pin connector on the rear of the module; and 5) the laser diode driver block, which uses one-half of a Texas Instruments, Inc., model TLC252C, LinCMOS Dual Operational Amplifier and an Analog Devices, Inc., model AD9661AKR, Laser Diode Driver With Light Power Control to modulate the optical output of the laser diode in an open loop manner.[5] The sixth, and last, block contains the laser diode and the pseudo-collimating lens, whose position can be adjusted back-and-forth by way of a wrench supplied by the manufacturer.

Of the five blocks comprising the PMH laser diode module, only the adjustable forward-bias current and the laser diode driver blocks actually provide input to the laser diode. Specifically, the laser diode driver block takes the externally applied modulation signal and drives the laser diode driver IC (AD9661AKR) at a 100 MHz bite rate, while the adjustable forward-bias current block provides a DC current to the laser diode. Note, the electrical output signals from the adjustable forward-bias current block and the laser diode driver block are wired ORed together before being applied to the laser diode. Both the amplitude of the modulation current produced by the AD9661AKR and the amplitude of the forward-bias current produced by the _ TLC252C and FZT1049A current source are separately controlled by two, multi-turn, 10 kΩ potentiometers located at the rear of the module. Thus, if a 10 ns wide TTL pulse is applied to the M[ale]-SMC modulation connector at the rear of the module, the optical output is a 10 ns wide laser pulse superimposed on the CW optical output produced by the forward-bias current. This explanation hides, however, a very important fact.

If one were to turn the forward-bias current control fully CCW (CounterClockWise) so as to reduce the adjustable forward-bias current to zero and apply the same 10 ns wide TTL pulse to the modulation connector, then one would still observe a substantial CW optical output from the laser diode. Note, the visible (635 nm) CW optical output from the laser diode module can be safely observed by simply looking at the optical output as reflected from a piece of dull white paper. This nonzero CW optical output was first observed in the MMLA laser simulator by looking into the optical output connector. At the time, no one could account for this unexpected behavior, since the electrical schematic of the PMH laser diode module was not available and the instructions for the module were quite terse (a.k.a. nonexistent) as far as the inner workings of the module were concerned. The nonzero CW optical output from the MMLA laser simulator essentially defeated the purpose of the two incandescent lamps, which was to create optical background noise in the other leg of the Y-shaped, free space, optical path.

In order to explain the nonzero CW optical output, one might hypothesize that turning the forward-bias current control fully CCW does not set the forward-bias current to zero. Unfortunately, this hypothesis is revealed to be untenable if you examine the electrical schematic, since the circuit diagram does not indicate that the adjustable current source was designed with an offset. The answer to this conundrum lies within the Analog Devices, Inc., model AD9661AKR, Laser Diode Driver With Light Power Control used in the laser diode driver block. According to the AD9661AKR datasheet, this particular laser diode driver IC (Integrated Circuit) not only modulates the laser diode forward current, it also provides a fixed forward-bias current (called “idle current” in the datasheet) of 2 mA (typically) or 5 mA (maximum). It is this fixed forward-bias current that is actually responsible for the nonzero CW optical output from the MMLA laser simulator. Therefore, the total forward-bias current injected into the laser diode by the PMH laser diode module is the sum of the forward-bias current from the adjustable forward-bias current block plus the fixed forward-bias current from the laser diode driver block.

At this point, a bit of clarification is necessary. There are commercially available an almost mind-boggling assortment of laser diode driver ICs capable of being modulated at bit rates as high as 10 Gbps (Giga [10^9] Bits Per Second). These ICs are all very similar to the AD9661AKR in that they produce a modulation current plus forward-bias current for injection into a laser diode, either an edge emitting laser diode or a VCSEL (Vertical Cavity Surface Emitting Laser) diode.[6] In many cases, the value of the forward-bias current produced by the laser diode driver IC can be adjusted by attaching a potentiometer to one or more of the IC’s control pins. All of these ICs are normally used for fiber optic telecommunication transmitters and transceivers employed in LANs (Local Area Networks), WANs (Wide Area Networks) and MANs (Metropolitan Area Networks). In these applications, the laser diode driver ICs are expected to transmit digitally encoded information via a series of amplitude modulated light pulses. However, the photodetector at the receiving end of the fiber optic is not designed to detect a LOW logic level (binary 0 in positive logic) as the complete absence of light and a HIGH logic level (binary 1 in positive logic) as the presence of light above a certain threshold value. Instead, the LOW and HIGH logic levels correspond to a lower light power band (dim) and a higher light power band (brighter), respectively, with the two bands being separated by a middle light power band containing the threshold value plus lower and upper guard values on either side to improve noise immunity. A quantitative measure of the ratio of the power between the two logic states is the extinction ratio, ER,

$$ER = \frac{P_1}{P_0} \qquad (1)$$

where P_1 and P_0 are the optical output powers of the LOW and HIGH logic levels.[7]

In digital telecommunications the important property is high bit rate, and bit rate depends on the transition times (LOW logic level to HIGH logic level and *vice versa*) being as short as possible. To this end, laser diode driver ICs always provide a forward-bias current to the laser diode with a value near the threshold current, I_{th}. Note, the threshold current of a laser diode corresponds to the value of the forward-bias current at which spontaneous emission of light changes over to simulated emission (lasing) of light, i.e., threshold current is where the laser diode stops acting like an LED (Light Emitting Diode) and starts behaving like a true laser. By supplying the requisite forward-bias current, the laser diode driver IC can improve (reduce) the transition time between the logic levels. This shortening of the transition times is achieved by keeping the laser diode lasing so that there is no time wasted building up the longitudinal modes in the laser cavity in going from the LOW (dim) to HIGH (brighter) logic level, for example. The arcane trick of providing a constant bias current $\leq I_{th}$ to improve the switching speed of the laser diode has been known for about 30 years.[8] Initially, this trick was referred to as 'prepumping' but eventually it metamorphosed into the less obvious term 'prebiasing'. Physically, prepumping is required because of the finite free carrier lifetime of the electrons injected in the active region of the PN junction, i.e., it takes a finite time for the free carrier (electron) to drop from the conduction band to the valence band and radiatively recombine with a hole.

All the above paragraphs in this section illustrate the folly of using any subassembly, in this case a laser diode module, within a next higher assembly, the laser simulator, if one does <u>not</u> have detailed information about the inner workings of the device. At the risk of sounding like a curmudgeon, it used to be that instruction manuals came with block diagram(s), complete electrical schematic(s) and a theory of operation section, which referenced both the block diagram(s) and the electrical schematic(s). Today, though, intellectual property concerns, shortened product cycles, and marketing hype have conspired to make it acceptable for some companies to market truly opaque black boxes – boxes which sometimes do <u>not</u> even come with a function mapping the inputs to the outputs.

Many commercially available Gbps laser diode driver ICs are available in an evaluation board where they only require DC power and a modulation signal to function. In a sense, these evaluation boards are similar to the controller board found in the PMH laser diode module, except that they operate in the Gbps range. There are, however, a couple of potential traps the novice experimenter needs to know about. Most companies sell two types of evaluation boards: 1) an optical evaluation board and 2) an electrical evaluation board. The optical evaluation board may or may <u>not</u> be provided with an edge emitting laser diode or a VCSEL diode already installed on the board. Even if the laser diode does <u>not</u> come with the evaluation board, the board is provided with traces, mounting pads, through holes and all the required passive components installed on the board so that a user supplied laser diode can be simply installed by the user.[9] The electrical evaluation board, on the other hand, does <u>not</u> come with a laser diode installed on the board and, further, it is <u>not</u> meant to be used with a laser diode. The electrical output from the electrical evaluation board is applied across a set of passive components meant to mimic the laser diode load and allow the user to examine these signals with a fast oscilloscope. When ordering an evaluation board, make sure to specify the optical evaluation board. If you simply ask for an evaluation board for a particular laser diode driver IC, you may end up getting the electrical evaluation board instead of the optical one. The only exception to this rule, that I am aware of, is the evaluation board for the Maxim Integrated Products, model MAX3865, 2.5 Gbps Laser Driver With Automatic Modulation Control. This particular evaluation board is comprised of two completely separate circuits each with their own MAX3865 IC, one circuit is the electrical evaluation circuit while the other is its optical counterpart *sans* diode laser, which the user must supply. Note, all evaluation boards come with an instruction manual, electrical schematic and, sometimes, a BOM (Bill Of Materials). If any of this documentation is missing, call the applications engineer and ask for whatever is missing.

LASER SIMULATOR REALIZATIONS

Initially, there were two prototype SLR2k laser simulators built. The first prototype laser simulator employed a modified Power Technology, Inc., model PMH03/5475, PMH Laser Diode Module at the input end of an I-shaped fiber optic path. The modifications to the PMH laser diode module were as follows. Only the controller board was used, the rest of the module was discarded. The bias current and modulation current screwdriver adjustable, multiturn potentiometers were unsoldered from the SMT PCB and replaced with wires going to two Bournes, model 3600S-1-103, 3600S-1 Series, 1.5-Watt Knobpot located in the front panel of the double wide, blank NIM module. A Thorlabs, Inc., model LPM-GIF-635-SMA, Fiber Pigtailed Laser Diode was plugged into the transistor socket at the front end of the controller board. The fiber optic path also included a modified Fotec, Inc. (now Fluke Networks, Inc.), model A430, Variable, Gap Loss, 0-20 dB Attenuator with SMA Connectors. The A430 fiber optic attenuator was modified to be able to include up to four ACF-Metals, model ATD –10dD @ 1300 nm, Optical Attenuator Discs. These small (0.125”±0.0001” Dia. X 0.00375”±0.00125” Thk.) amorphous carbon, optical attenuator discs are normally incorporated in fixed fiber optic attenuators. Note, this type of neutral density filter material is much more stable to environmental effects than, say, Kodak Wratten neutral density filters, which are made by dissolving colloidal carbon in gelatin.

Experimentation with this first prototype laser simulator revealed the problem with the forward-bias current never going to zero even when the front panel bias current control was set to zero. That the nonzero forward-bias current was unambiguously associated with the AD9661AKR laser diode driver IC could be shown by applying a TTL HIGH logic level to pin 5 (Inhibit Control) of the 6-pin connector on the rear of the controller board. Pin 5 goes directly to pin 14 (DISABLE) of the AD9661AKR IC, which is normally maintained in the LOW (enabled) state by a 1 kΩ pull-down resistor. When pin 14 (DISABLE) of the AD9661AKR IC was brought to the HIGH (disabled) state, both the modulation and the fixed forward-bias currents were turned off. As a direct consequence of the disappearance of the fixed forward-bias current, the nonzero CW optical output also vanished.

This experience proved that the only way to obtain an independently adjustable optical background noise signal would be to build a laser simulator using a Y-shaped fiber optic path. In the second prototype, the PMH laser diode module resided in one arm of the Y and an adjustable CW light source (white LED) in the other arm of the Y.[10] The modifications of the PMH laser diode module were the same as in the first SLR2k prototype, except that the multiturn potentiometer controlling the bias current was left on the controller board, just turned all the way down; a Bournes' Knobpot on the front of the double width blank NIM module controlled the current through the white LED, thus, controlling the optical background noise. However, there is a trick to using this configuration, due to the PMH laser diode module producing an unwanted nonzero CW optical output. Enough attenuation must be present in the arm of the Y, containing the PMH laser diode module, to completely suppress the nonzero CW optical output. This assumes, of course, that the light pulses due to the modulation currents are of sufficient magnitude that they emerge from the same attenuation process with enough photons to serve their function as fake optical return pulses.

Based on the experience with the first two prototype SLR2k laser simulators, a third prototype was designed and constructed. In the third prototype, the same Y-shaped fiber optic path was kept, but the PMH laser diode module modified controller board was replaced with a telecommunication's diode laser driver IC mounted on its own evaluation board. In the case of the first two prototype SLR2k laser simulators, the modified controller board required a triggered pulse generator to generate the 10 ns wide TTL logic level pulse. The input to the triggered pulse generator is a wide TTL pulse applied to a F[emale]-BNC connector on the front panel of the double wide blank NIM module; the output of the triggered pulse generator is applied to the M[ale]-SMC modulation connector at the rear of the modified controller board. The triggered pulse generator can be realized using either Fairchild Semiconductor FAST™ bipolar TTL logic family (74Fxxx) or for even faster transition times and shorter propagation times, the FASTr™ bipolar TTL logic family (74FRxxx) can be employed. The triggered pulse generator in the MMLA laser simulator utilized the FAST™ technology, while those in the first two SLR2k employed the FASTr™ technology. In the case of the third SLR2k laser simulator, the Gbps evaluation board expects to be driven differentially by a triggered pulse generator producing ECL (Emitter Coupled Logic), PECL (Positive or Pseudo ECL) or Fast (a.k.a. Negative) NIM logic levels.[11] Given that the common mode voltages, V_{CM}, for a differentially driven signal

$$V_{CM(DifferentiallyDriven)} = \frac{V_{HIGH} + V_{LOW}}{2} \qquad (2)$$

of ECL, PECL and Fast (a.k.a. Negative) NIM logic are very different from one another, how can laser diode driver IC on the evaluation board accept all three of these types of logic? The answer is that most, if not all, Gbps evaluation board have their two differentially driven input lines AC, i.e., capacitively, coupled to the laser diode driver IC's input pins.

Since the trigger signal applied to the laser simulator is a TTL signal, it is easiest to utilize PECL to drive the evaluation board. PECL is simply an ECL IC with its power pins connected as follows: VEE = 0 VDC and VCC & VCC1 = +5 VDC instead of VEE = -5.2 VDC and VCC & VCC1 = 0 VDC. In other words, every ECL IC can be used, as a PECL IC, by powering it the same way one would power a standard TTL IC. And so, the triggered pulse generator in the third SLR2k prototype laser simulator begins with a Fairchild Semiconductor Corporation, model 100391PC, Hex Single Supply TTL-to-ECL Translator for PECL, which accepts the external TTL trigger signal and converts it into PECL logic levels. After the 100391PC comes the actual triggered pulse generator, which could consist of a Fairchild Semiconductor Corporation, model 100331PC, Triple D Flip-Flop and model 100302PC Quint 2-Input OR/NOR Gate.

COMPONENT CHAOS

In choosing the manufacturer and model of the various components used in the SLR2k laser simulators, there were two important considerations: wavelength and longevity. The largest commercial market for fiber optic components is the optical telecommunications industry. Unfortunately, the optical telecommunications industry usually operates its WDM (Wave Division Multiplexing) systems around 1310 and 1550 nm, since these two wavelengths minimize dispersion and attenuation, respectively, in glass fiber optics. In addition, long haul fiber optic systems usually employ single mode fibers to limit inter-symbol interference due various types of dispersion. Finding components meant for use in the visible region of the electromagnetic region of the spectrum takes some work even if it something as simple as a coupler/combiner.

Longevity in fiber optic components means the parts being available for a reasonable length of time. This quality is very difficult to find among normal electronic components and it is even more of a problem with fiber optic components. This is particularly true of laser diode driver ICs and their evaluation boards, where the contest to field higher and higher bit rate chips and the meltdown and consolidation of telecommunications companies has led to products being yanked off the market after only a few months. For example, one of the easiest to use and least complicated laser diode driver ICs is the RF Micro Devices, Inc., model RF3750, Serial VCSEL Laser Driver At 3.125 Gbps. Unfortunately, this laser diode driver and its evaluation board were yanked from the commercial marketplace only a few months after their debut due to unfavorable market conditions.

FINAL TESTING

Initial testing of the various prototype SLR2k laser simulators was performed using a Hammamatsu Photonics K.K., Electron Tube Center, model R5900U-00-M4, Multianode Photomultiplier Tube in a model E678-32B, Socket (with its standard voltage divider network). The R5900U-00-M4 is a four anode PMT similar to what is used on the MMLA LIDAR. The actual PMT that will be employed in the SLR2k LIDAR is a Photek, Inc., model Quad PMT 308, Quadrant Micro-Channel Plate Photomultiplier Detector Tube, however, due to the extreme cost of the 308 (≈$20,000.00 ea.), it was decided that all initial testing would be carried out using a less expensive PMT, the R5900U-00-M4 ($855.77 ea.). The PMT (PhotoMultiplier Tube) was ensconced in a black Delrin housing with a ST fiber optic receptacle screwed into the Delrin cover plate directly over the center of the face of the PMT. A fiber optic cable connected the SLR2k laser simulator to the PMT. The PMT was powered with a –800 VDC power supply with the four anodes being at ground potential, 0 VDC, the photocathode at –800 VDC, and the dynodes at increasing positive potential from the photocathode to the multiple anodes. Each of the four anodes is connected via a coaxial cable of 50 Ω characteristic impedance to a 50 Ω load.

The electrical output from one of the four anodes of the PMT was captured using a Tektronix, Inc., model TDS 520D, Two Channel, Digital Phosphor Oscilloscope (500 MHz, 2Gsps). Because the maximum repetition rate of the laser simulator is only 2 kHz and the pulse widths are 10 ns or less, the 'scope's acquisition mode was set to ENVELOPE to allow for the detection of single and multiple photon events in the PMT.

SUMMARY

The end result of this development effort has been to foster a greater understanding of the need for caution when incorporating subassemblies into next higher assemblies, especially when there is incomplete or insufficient information about the inner workings of the subassembly. The ability and necessity of performing reverse engineering on candidate subassemblies cannot be overemphasized as sometimes this is the only way to obtain the needed information.

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[2] U.S. NIM Committee; Standard NIM Instrumentation System, DOE/ER-0457T; U.S. Department Of Energy; May 1990.

Louis Costrell; Standard Nuclear Instrument Modules, TID-20893 (Rev. 4); United States Atomic Energy Commission; July 1974.

Note, the TID-20893 Standard does not contain any mechanical drawings of the NIM bin, module or connectors. All the mechanical drawings associated with the TID-20893 Standard are contained in a separate document designated CAPE-1189. In any event, the DOE/ER-0457T Standard, which does contain all the necessary mechanical drawings, supersedes the TID-20893 Standard.

Standards can be obtained from the following company,

Global Engineering Documents, 7730 Carondelet Ave., Suite 407, St. Louis, MO 63105, (800)854-7179, FAX (314)726-6418. Note, Global Engineering Documents is a division of Information Handling Services®, 15 Inverness Way East, Englewood, CO 80112-5776, (800)525-7052, Web Site: http://global.ihs.com [N.B., do not use the following address: http://www.global.ihs.com.]

[3] Power Technology, Inc., P.O. Box 191117, Little Rock, AR 72219-1117, 501.568.1995, FAX 501.568.1994, http://www.powertechnology.com.

[4] The coherent light produced by edge-emitting laser diodes is astigmatic in nature, i.e., if one observes the coherent light coming from the cleaved output facet of the laser diode, then the point at which the light appears to emanate from within the active region of the PN junction depends on whether one is perpendicular or parallel to the plane of the PN junction. If you try to collimate the coherent light coming from an edge-emitting laser diode with an axial-symmetric spherical or apherical collimating lens, then you run into the problem that the output of the lens will be collimated in one plane (perpendicular or parallel to the plane of the PN junction of the laser diode) or the other, depending on the focal point of the lens, but not both. Hence, the term "pseudo-collimating" more accurately describes the functioning of the lens.

[5] Most laser diodes contain what is called a monitoring photodiode in the same package. The purpose of the monitoring photodiode, which is usually located behind the rear facet of the laser diode, is to allow the laser diode driver IC or discrete control circuit to close the control loop and so stabilize the optical output power of the laser diode against the vagaries of everyday use. Some of the things contributing to variations in the optical output power are ambient temperature fluctuations, temperature increases due to power dissipation within the laser diode, voltage fluctuations and aging of the laser diode due to an increase in defects in the active region which tends to decrease the conversion efficiency (electrical energy to light energy transformation) of the laser diode. The controller board in the Power Technology, Inc., model PMH04/5077, PMH Laser Diode Module does not make use of the monitoring photodiode. This fact is, however, not mentioned in the instructions for the module but can be clearly discerned from the electrical schematic. Likewise, the temperature sensor block is, in fact, an open loop sensor, since the voltage outputted by this block, representing the temperature of the aluminum block holding the

laser diode package, goes straight to the outside world via the 6-pin connector on the rear of the module. Again, this is only obvious if you have the electrical schematic of the module.

[6] VCSELs have a number of advantages over edge emitting laser diodes. The first advantage has to do with ease of manufacturing and *in situ* functional testing. The only way to functionally test the individual edge emitting laser diodes on a wafer is to scribe and cleave the wafer to produce the individual dice. Of the four cleaved facets associated with the resulting dice, two opposite facets are sandblasted to prevent stimulated emission from occurring in a direction perpendicular to these facets, while two other opposite facets are polished and/or coated to form the mirrors requires for a Fabry-Perot resonant cavity. Given that the yields of functioning dice from a wafer is never 100%, edge emitting laser diodes require a significant amount of value added labor (scribing, cleaving, etc.) before they can even be tested to determine whether they work. VCSELs, on the other hand, are completely fabricated at the wafer level. The dielectric mirrors forming the Fabry-Perot resonant cavity are deposited one layer at a time below and above the PN junction. Thus, the light from the VCSEL is emitted perpendicular to the top surface of the wafer and, hence, the VCSELs can be functionally tested on the wafer without first having to be diced. The second advantage has to do with the fact that the light emission occurs in such a way that the planes associated with the light are axially symmetric with respect to the PN junction, i.e., there is <u>no</u> astigmatism associated with the stimulated emission from a VCSEL. However, there is still some polarization of the emitted light due to mechanical strains induced on the active region during the manufacturing process. The third advantage has to do with the speed with which it responds to direct (internal) modulation.

[7] As if there is <u>not</u> enough complexity with regard to laser diodes, it should be noted that the term extinction ratio is also applied to the quantitative measurement of the ratio of the parallel [to PN junction] polarized optical output power to the perpendicular [to PN junction] polarized optical output power. This particular ratio, also known as the polarization ratio, changes depending on the magnitude of the forward current. At maximum power, edge emitting laser diodes produce photons predominantly with a polarization parallel to the PN junction, while at or below the threshold current, the plane of polarization is closer to being random in nature.

[8] K. Konnerth, C. Lanza; Delay between current pulse and light emission of a gallium arsenide injection laser; *Applied Physics Letters*; Vol. 4; No. 7; April 1, 1964; pp. 120-121.

J. C. Dyment, J. E. Ripper, T. P. Lee; Measurement and interpretation of long spontaneous lifetimes in double heterostructure lasers; *Journal of Applied Physics*; Vol. 43; No. 2; February 1972; pp. 452-457.

M. Chown *et al*.; Direct modulation of double-heterostructure lasers at rates up to 1 Gbit/s; *Electronics Letters*; Vol. 9; No. 2; January 25, 1973; pp. 34-36.

[9] The nomenclature associated with edge emitting laser diode can be somewhat intimidating. For example, there are the following terms used when discussing edge emitting laser diodes: Fabry-Perot, MQW (Multiple Quantum Well), DFB (Distributed FeedBack,), DBR (Distributed Bragg Reflector) and ECLD (External Cavity Laser Diodes). From a practical point-of-view, most commercially available laser diodes are of the MQW DFB type. To understand why this so, one must remember that the main purpose of these devices is to produce, as closely as they are able, light of a single wavelength. Excluding the effects of temperature, there are two ways to improve spectral purity: 1) filter the energy of the <u>photons</u> <u>after</u> they are created through electron-hole radiative recombination and/or 2) filter the energy of the <u>electrons</u> <u>before</u> they radiatively recombine with the holes in active region of the PN junction. Since a Fabry-Perot resonant cavity can have many longitudinal modes, one way to suppress unwanted modes is to incorporate within the active region of the PN junction a photon filter, the Bragg reflector; the Bragg reflector, a repeating linear structure of periodically varying indices of refraction, provides the feedback normally created by the mirrored facets in a Fabry-Perot type laser. In the DFB laser diode, the Bragg reflector extends from one facet to the other along the length of the laser diode. Besides filtering the photons, the other way to improve spectral purity is to restrict the transitions of the electrons moving from the conduction band to the valence band, where they radiatively recombine with holes to produce photons. Here, the problem is that change in energy, $\Delta E = h\upsilon$, can be quite variable depending upon where in the conduction band the electrons start from and where in the valence band it ends up (the hole location). The MQW structure that can be introduced into a PN junction discretizes the number of quantum states, thus, reducing the number of possible quantum states in the conduction and valence bands. In so doing this, the MQW structure severely restricts the spread in the change in energy of a transition. The DBR laser diode and ECLD differ from the MQW DFB laser diode by locating the DBR outside the PN junction and by locating both the DBR plus one of the Fabry-Perot mirrors external to the PN junction, respectively. The ECLD, for example, may be used to create laser diodes with adjustable peak wavelength, λ_{Peak}, by varying the length of the cavity by moving the exterior mirror and/or tilting the external Bragg grating. For further information on these points, see,

Jeff Hecht; <u>Understanding Fiber Optics, 3rd Ed.</u>; Prentice Hall; 1999; pp. 177-178 for DFB, DBR & ECLDs.

S. M. Sze; Semiconductor Devices, Physics And Technology; John Wiley & Sons; 1985; pp. 274-278 for DFB.
Cheng T. Wang (Ed.); Introduction To Semiconductor Technology: GaAs and Related Compounds; John Wiley & Sons; 1990; pp. 461-466 for DFB & DBR, pp. 512-516 for MQW.

[10] The 'white LED' is, of course, fashioned from a blue LED with yellow emitting phosphor – by down conversion of some of the blue light - deposited in the cup holding the LED die. The mixture of yellow and blue light is a rather harsh but still serviceable 'white' light.

[11] Although most Gbps laser diode driver ICs are meant to be driven directly by ECL, PECL or Fast (a.k.a. Negative) NIM logic levels, there are exceptions. For example, the Analog Devices, Inc., model ADN2841, Multirate 2.7 Gbps Laser Diode Driver With Dual –Loop Control IC requires attenuated ECL, PECL or or Fast (a.k.a. Negative) NIM logic levels.