GIGABIT DETECTORS FOR VISIBLE SPACE LASER COMMUNICATIONS

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ABSTRACT

Performance data taken on several candidate high data rate laser communications photodetectors are presented. Measurements of bit error rate versus signal level were made in a 532 nm system at 500 Mbps.

INTRODUCTION

High data rate optical communications systems require photodetectors which are sufficiently fast to respond to the desired data rate and as sensitive as possible. While measurements of individual detector parameters may serve as a coarse indication of system performance, it is our experience that detector performance can best be characterized in an operating communication system. Extrapolations made from data measured by detector manufacturers are often inaccurate except when intercomparing devices of the same kind. The comparison between a photomultiplier and an avalanche photodiode, for example, is very difficult.

This paper will describe the testing techniques used and report on the results obtained with several available detector types. Measurements were made at 532 nm at a data rate of 500 Mbps with a pulse delay binary modulation (PDBM) format. This format provides a minimum pulse spacing of 1 ns and is therefore a suitable test for 1.0 Gbps detectors. This system is presently in operation to evaluate detectors for the AF LASERCOM gigabit laser communications program.

This system is used to generate curves of bit error rate versus optical signal level input to the detector. These curves are the ultimate measure of the worth of any photodetector for a communications application.

Optical power is measured with a UDT 21A which is periodically compared with 8 other silicon power meters and a Laser Precision pyroelectric radiometer.

This work was performed under Air Force Contract F33615-75-C-1002 as well as McDonnell Douglas IRAD funds.

532 nm COMMUNICATION RECEIVER TEST SYSTEM

The 532 nm 500 Mbps PDBM communication system is shown in Figure 1. A 500 Mpps mode-locked and frequency-doubled Nd:YAG laser is modulated by a lithium tantalate electrooptic polarization modulator. The data impressed on the transmitted beam is a long repetitive pseudorandom code. A polarization selective time-delay unit follows the modulator. One polarization is delayed with respect to the other polarization by one-half the bit period (1.0 ns). The time-delay unit converts Pulse Polarization Binary Modulation (PPBM) to Pulse Delay Binary Modulation (PDBM) with a minimum pulse spacing of 1.0 ns.

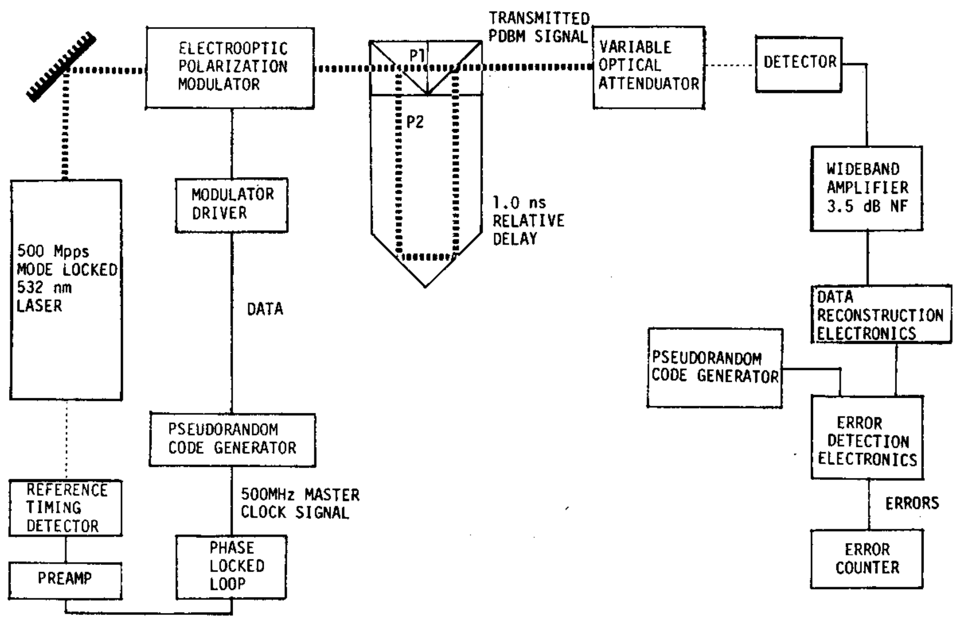

FIGURE 1 532 nm 500 Mbps PDBM LASER COMMUNICATIONS RECEIVER TESTBED

In our 1.0 Gbps communication system, a second electrooptic polarization modulator follows the time-delay unit to set the polarization of the final transmitted pulse. The second modulator operates with twice the speed of the first modulator to handle the closer spaced pulses. This format is called Pulse Quaternary Modulation (PQM) and offers improved efficiency because each optical pulse carries two bits of information in the four allowed states of delay and polarizations PQM requires two photodetectors in the receiver, one for each orthogonal polarization.

For the purpose of evaluating detectors for the 1.0 Gbps PQM system, it is desirable to change to a format which utilizes a single photodetector in the receiver but which otherwise simulates the signal seen by the photodetector in the 1.0 Gbps PQM system. The 500 Mbps PDBM signal meets this requirement if both polarizations are incident on the same detector.

At the receiver, a variable optical attenuator sets the optical signal level to the detector under test. The detector output is amplified by a low noise preamplifier and fed to the data reconstruction electronics. A sample of this signal is used to generate the receiver clock. The PDBM encoded pulse train is compared on the basis of pulse amplitude with a version of itself delayed by 1.0 ns to reconstruct the transmitted data. The reconstructed data is compared serially, bit by bit, with a locally generated and synchronized pseudorandom code identical to that at the transmitter. Errors are detected and counted. The bit error rate or probability of error per bit is plotted as a function of signal power level to the detector.

532 nm DETECTORS

The detector types listed in Table I were evaluated in the 532 nm 500 Mbps PDBM system. The photomultiplier detectors were developed by the Air Force, NASA GSFC, and McDonnell Douglas under various programs with Varian LSE.

TABLE I
532 nm Communication Detectors

Varian LSE	Photomultipliers Static Crossed Field Hybrid EBS Anode Dynamic Crossed Field	 >10 Samples 3 Samples >20 Samples
RCA (Montreal)	Silicon Avalanche Photodiode	5 Samples
Rockwell (Science Center)	Ternary Avalanche Photodiode	2 Samples
Texas Instruments	Commercial Avalanche Photodiodes Silicon TIXL 56 Germanium TIXL 57	 1 Sample 1 Sample
Mitsubishi	Silicon Avalanche Photodiode PD-202B	2 Sample

The best of the Varian photomultipliers used ternary GaAsP photocathodes with external quantum efficiency greater than 30% and excellent stability with time.[2]

The Static Crossed Field Photomultiplier is a high speed baseband to 3 GHz photomultiplier which utilizes the property of constant time of electron flight in a region of crossed static electric and static magnetic fields to achieve low time dispersions.[3] Gain of the SCFP is not readily variable since the electric and magnetic fields must vary by the same ratio. The SCFP has a relatively open structure and suffers from a signal induced noise phenomenon which limits bit error rate performance when operated under the relatively large signal conditions required for a communications detector.

The Varian hybrid photomultiplier is a two-stage cup and slat electrostatic device with a silicon diode anode operated in the electron bombarded semiconductor (EBS) mode. It is intended that the noise figure of this tube be set by the photocathode and two high gain gallium phosphide dynodes before reaching the silicon diode with several keV of energy. The high energy electrons reaching the silicon then receive an impact ionization gain of 10^2 with the ability to deliver substantial output current. Because most of this output current did not travel through vacuum, a source of feedback which stimulates signal induced noise should be minimized. The results of the one successful device are presented. A similar device with baffling to eliminate noise failed without undergoing evaluation at the end of its development program.

The Varian Dynamic Crossed Field Photomultiplier (DCFP) is a synchronously gated device driven by a radio frequency electric field superimposed on crossed static electric and magnetic fields.[4] The synchronous gating is compatible with the regularly recurring pulse train from a mode locked laser. Of the high speed photomultipliers tested, the DCFP offers the best performance. The gain is readily controlled by varying RF drive power. Synchronization is achieved by dithering the gate with respect to the incoming optical pulse train to develop a phase error control signal. Signal induced noise is very low, but several older devices have exhibited this phenomenon. It was largely eliminated by special cleaning techniques during processing. The data presented is for the best device but is typical of recent devices. All recent devices have antireflection coated windows to maximize sensitivity.

The RCA silicon avalanche photodiode has a reach through structure.[5] The transit time delay of the 30 µm thickness yields a speed of response which is just barely suitable for use at 1 Gbps. The standard RCA device is a C30902E and is antireflection coated for 820 nm for fiberoptic work with GaAlAs ILD emitters. The best devices were specially antireflection coated for 532 nm on the silicon surface and operated with windows removed to simulate the performance expected when high quality antireflection coated windows are added in the future. All devices of this type performed uniformly well and the data presented is typical. The standard C30902E operated 1.37 dB poorer in this 532 nm test bed. (Though the C30902E is nearly as fast at 1064 nm, the quantum efficiency is only 5% because silicon is becoming transparent at this wavelength. A severe trade-off is involved in using silicon devices to go to 1.0 gigabit at 1064 nm.)

Rockwell claims to have developed a 10 GHz ternary APD with good gain, gain uniformity, and high quantum efficiency at 532 nm. Several device submitted for evaluation in this system did not achieve measurable performance even at maximum optical power levels of about 1000 nW. Previously the workers at Rockwell developed a hybrid transimpedance preamplifier utilizing microwave MESFETs incorporating a high speed ternary photodiode for 1064 nm.[6] The technique of using a high input impedance preamplifier improves performance by trading speed of response for gain. Noise of the preamplifier increases as the square root of the feedback resistance while gain increases linearly. This technique worked so well that the ternary photodiode at unity gain worked nearly as well as the best silicon avalanche photodiode at optimum gain.[7] Because this technology is available, it is felt that Rockwell will be able to produce a competitive detector when their present 532 nm photodiode problem is solved.

The TIXL 56 silicon APD and the TIXL 57 germanium APD are commercially available devices from Texas Instruments used extensively in this laboratory for many years.

532 nm RESULTS

The results of 532 nm communication system bit error rate measurements are presented in Figure 2. The performance at 10^{-6} bit error rate is summarized in Table II. The best overall detector for 1 Gbps communications at 532 nm is decidely the DCFP. However, if the rules of comparison were changed slightly, the RCA silicon APD would prevail. This would be the case if the comparison were made at less than 10^{-7} bit error rate or if a synchronously gated low duty cycle detector could not be used as with analog data or a PCM encoded laser diode source.

The RCA APD yielded performance equivalent to the best DCFP with a 20% quantum efficiency photocathode. Only the most recent DCFP devices with GaAsP photocathodes surpass this performance level.

The SCFP tubes all suffered from a signal induced noise phenomenon which is characterized by a flattening or bottoming out of the bit error rate curves. The worst could not achieve 10^{-3} bit error rate. The performance of the best sample is shown in Figure 2. Signal induced noise has been observed in other types of high speed photomultipliers.[7] The cause is believed to be either ion or photon feedback within the relatively open and unbaffled structures typical of high speed photomultipliers. Several attempts were made to modify the SCFP structure to baffle the noise mechanisms to no avail.

The hybrid photomultiplier program yielded one device sample that achieved the bit error rate performance shown.

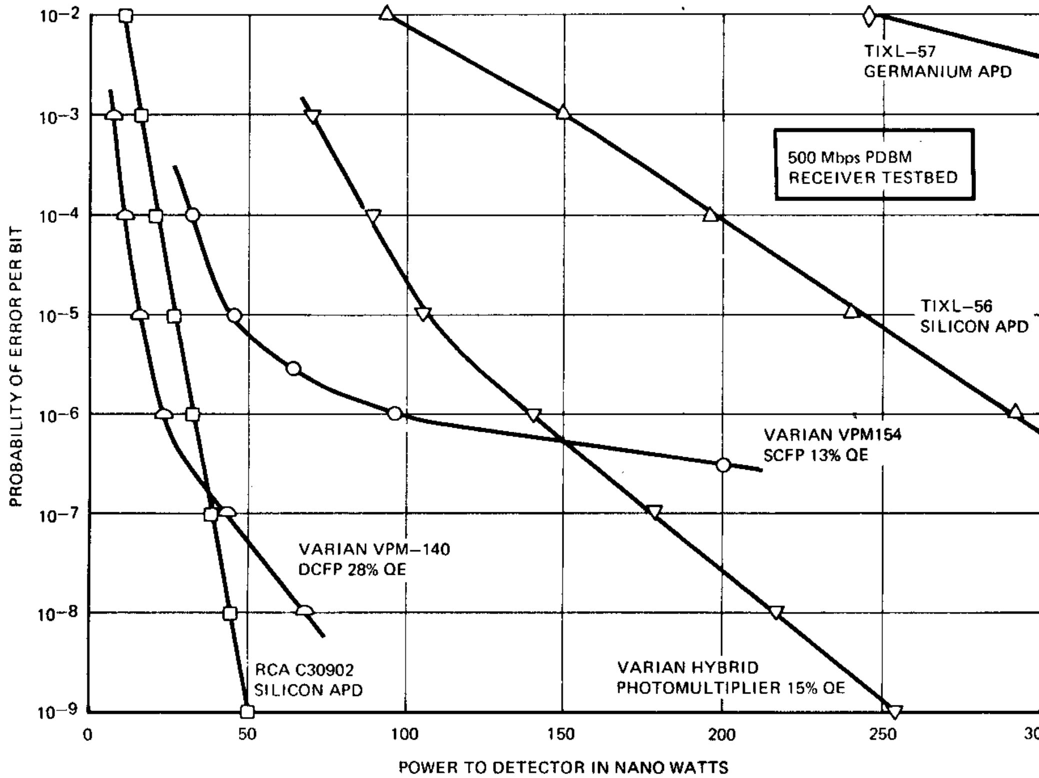

FIGURE 2 COMPARISON OF 532 nm COMMUNICATION DETECTORS

TABLE II
532 nm Results At 10^{-6} Bit Error Rate

Detector	532 nm Power	photons/pulse
Varian DCFP S/N 044	23 nW	123
RCA APD	32 nW	171
Varian SCFP S/N 053	97 nW	520
Varian Hybrid S/N 002'	140 nW	750
TIXL 56	280 nW	1500
TIXL 57	680 nW	3640
Mitsubishi PD-020B		

The Texas Instruments devices did not perform competitively with the photomultipliers or the reach through APD. The silicon device is greatly superior to the germanium device at 532 nm. Previous testing has shown that the opposite is true at 1064 nm because the absorption of silicon is decreasing.7

DISCUSSION OF RESULTS

At 532 nm, the DCFP is presently the best detector available for high data rate communications. It offers several advantages when operating with a mode locked laser transmitter, including a wide gain control range and an inherent integrate and dump action. However, the RCA silicon APD is only 1.5 dB poorer in performance, and would be the logical choice in many similar applications.

The RCA APD has not yet been developed to its ultimate performance level. Thinner devices are being developed by RCA which will offer greater speed and lower dark current. Both should result in improved performance. The increased speed of response will allow the RCA APD to be used with the transimpedance amplifier technique used to great advantage in the Rockwell hybrid devices.[6] Preliminary results using 50-ohm amplifiers will be discussed.

A new Mitsubishi 3 GHz silicon APD with a reach through structure somewhat similar to the RCA devices will also be evaluated and discussed.

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