

# ENVIRONMENTAL QUALIFICATION AND FIELD TEST RESULTS FOR THE SONAbeam™ 155 and 622

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## ABSTRACT

This paper discusses test methods and results of fSONA Communications Corporation's SONAbeam™ 155-M, SONAbeam™ 622-M and SONAbeam™155-S systems – free-space-optical data communication systems that use 1550 nm lasers. Presented are results of environmental qualification tests and field performance tests over link ranges of 450 meters and 5 kilometers. The SONAbeam™ 155-M, SONAbeam™ 622-M and 155-S are three representatives of a family of products that work in the range of 34-1250 Mbps. Very robust performance is the emphasis in the design of these systems.

**Keywords:** laser communication, lasercom, free space optics, optical wireless, 1550 nm, optical access, metropolitan access, field test, environmental qualification, thermal test, bit error rate

## 1. INTRODUCTION

The following sections should provide an overview of the extensive tests of the SONAbeam™ 155-M product. This FSO (free-space optics) product is intended for metro-access, urban PCS backhaul, and other applications where exceptional reliability, ruggedness, and robust performance are required.

The SONAbeam™ 155-M is designed for OC-3/STM-1 applications at a transmission rate of 155.52 Mbps, or Fast-Ethernet/FDDI applications with a transmission baud rate of 125 Mbps. The data rate is user selectable with a simple click of the mouse on a computer-based GUI display used to control the terminal via an RS-232 communication link. The SONAbeam™ 622-M is designed for OC-12/STM-4 applications and has fixed transmission rate of 622.08 Mbps. With other members, the product family address data rates ranging from 34 to 1250Mbps. The

input/output interface of the FSO link is 1310nm single-mode fiber with specifications consistent with the ITU recommendation for OC-3/STM-1 transmission. Incoming fiber-optic data is fully regenerated and retimed to ensure the highest possible signal integrity prior to transmission over the FSO link. The free-space receive signal is also retimed and regenerated before being transmitted to the network switch or router via the fiber-optic cable.

The SONAbeam™ employs 1550 nm semiconductor laser diodes as the transmitter source. This wavelength was chosen in large part because it offers an eye-safe flux density 50 times higher than sources in the 800 nm region.<sup>1</sup> This allows fSONA to use much higher power laser sources, while meeting the international eye-safety standard IEC-1M - even when the eye is located directly at the transmitter output lens. Exceptionally robust SONAbeam™ performance is realized by using 640 mW of laser power and a 20 cm (8") diameter receiver, resulting in an aperture-power product of 200960 mW-cm<sup>2</sup> : the most potent system in the FSO marketplace.



*Figure 1 A SONAbeam™ 155-M terminal (left): cast-aluminum housing and mounting yoke, shown with standard attachment to a 10 cm (4") dia. mounting pole. A SONAbeam™ 155-S terminal (right) also features a cast-aluminum housing and is shown installed in an actual customer site inside an office.*

## 2. TEST SUMMARY

Presently no testing standards exist specifically for outdoor FSO products. As part of its comprehensive product development activity to provide true carrier-class FSO products, fSONA Communications has developed a test plan based on adaptation of Telcordia (formerly Bellcore) testing standards for application to outdoor FSO products. This test plan has been applied across the fSONA product line. The plan is composed of the general testing categories:

- Transportation, Handling, Vibration and Storage
- Environment Immunity
- Operational Performance
- Electrical and Laser Safety
- Electromagnetic Compatibility
- Materials

The type of testing, its parameters, and duration have been adapted based on the following Telcordia telecommunication industry standards:

- GR-2834-CORE – Generic Requirements for Basic Electrical, Mechanical and Environmental Criteria for Outside Plant Equipment.
- GR-487-CORE – Generic Requirements for Electronic Equipment Cabinets.
- GR-63-CORE – Network Equipment-Building System (NEBS) Requirements: Physical Protection
- GR-1089-CORE – Electromagnetic Compatibility and Electrical Safety- Generic Criteria for Network Telecommunications Equipment.
- GR-2836-CORE – Generic Requirements for Assuring Corrosion Resistance of Telecommunication Equipment in the Outside Plant.

Extensive testing has been performed by fSONA to properly qualify the SONAbeam™ for highly reliable performance in all outdoor environments. For the sake of brevity, not all these tests will be addressed in this paper. Testing has included wind-driven rain tests, pressure tests, and underwater immersion tests to ensure seal integrity against water leakage. We have also performed a long-term test at 35C and 100% humidity in a corrosive salt-fog environmental chamber to assess the corrosion resistance of the terminal and its outdoor power supply. The salt-fog test was performed with the terminal operational and BER tested for the duration.

Testing has also been done to address shipping concerns, testing the product packaged in its standard shipping container to international transportation shipping standard ISTA-2A. These tests included vibration, compression, and shock testing. The shock test consisted of dropping the container 10 times from a height of 66 cm (26"): once on each of the 6 faces, and four times on one of the corners. The system was baselined for optical alignment and system performance prior to the testing, and then was subsequently tested after these stress tests. The SONAbeam™ met all its operational specifications, both before and after this testing.

Extensive testing has been done to certify the system to various international electromagnetic standards, suitable for product use worldwide. These tests have included radiated emissions up to 2 GHz, conducted emissions, and also radiated susceptibility and conducted susceptibility. The emissions tests are required to ensure the FSO terminal and its power supply will not interfere with other systems. The susceptibility tests go one step further, and help ensure that the FSO equipment will not be affected by adverse electromagnetic environments from nearby equipment, such as rooftop air conditioning systems, microwave and cellular transmitters, etc. Also included was testing for harmonic current emissions, and immunity to intense magnetic fields, voltage fluctuations and interruptions, electrostatic discharge, and lightning surge impulses. The SONAbeam™ successfully passed all these electromagnetic tests.



*Figure 2. Extensive electromagnetic emissions and immunity testing was performed to certify the SONAbeam™ for international deployment*

### **3. THERMAL QUALIFICATION TESTING**

A great deal of testing has been dedicated to certifying the operational performance of the system under extreme temperature conditions. This testing has emphasized certification of the system

performance *at temperature* – i.e., monitoring the *operational* performance throughout the thermal tests to ensure the specifications are met over the full temperature range. This is a much more stringent test program than thermal survivability testing, where testing is only performed pre and post thermal cycling. This extensive thermal stress testing is done in-house at fSONA using environmental chambers which are constantly in use. The main thermal chamber is shown in Figure 3.

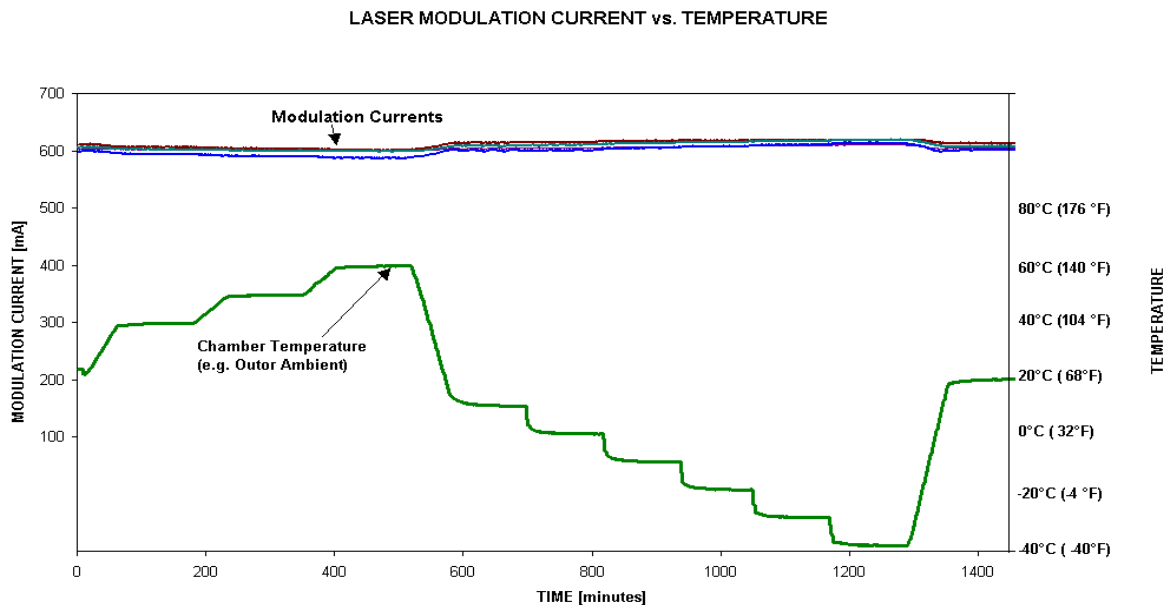


***Figure 3 Thermal test chamber used to validate operational performance from  $-40\text{C}$  to  $60\text{C}$  ( $-40\text{F}$  to  $140\text{F}$ ). Note the window in the chamber door permits optical xmit/rev testing in-situ.***

It can be seen in Figure 3 that the entire terminal is mounted in its yoke on a mounting post, and is subjected to thermal stress tests with its power supply, seen lying on the base of the stand. The chamber door is closed, and a test stand with an optical bench and suitable instrumentation is placed in front of the chamber window. The SONAbeam™ is tested operationally as it transmits

and receives through the window of this large thermal chamber. Transmit and receive functions, as well as all processing electronics, internal CPU, software, and power supply performance are evaluated in thermal test cycles that range from a day to a week in duration. The majority of the testing is done under maximum stress conditions: thermal soaks at the ambient temperature extremes of  $-40\text{C}$  ( $-40\text{F}$ ) and  $+60\text{C}$  ( $140\text{F}$ ) to ensure the system meets all specifications, even at extreme temperatures. System performance is monitored with automatic data acquisition systems, as well as the archival logging capability that is provided as part of the standard software package shipped with the SONAbeam™. The various terminal subsystems (e.g., transmitter assembly, receiver, processing electronics, etc.) are also stress-tested separately in another chamber, over wider temperature extremes ranging from  $-50\text{C}$  ( $-58\text{F}$ ) to  $75\text{C}$  ( $167\text{F}$ ).

Figure 4 is an example of the test results for the transmitters in an operational system under thermal test. The SONAbeam™ xxx-M uses four laser transmitters, which are all independent from each other (4 lasers, each with its own laser driver). The 160 mW InGaAs lasers require very high drive currents. fSONA has developed a custom driver, designed and tested in-house, that modulates the lasers at high datarates with high currents up to 1000 mA.



**Figure 4 Laser modulation currents vary less than 5%, over  $-40\text{C}$  to  $60\text{C}$  outdoor ambient.**

In Figure 4 the four laser modulation currents are seen to be about 600 mA for these four lasers. The ambient temperature of the chamber is varied from a starting temperature of  $22\text{C}$  up to  $60\text{C}$ , then ramped down to  $-40\text{C}$ , then back up to  $20\text{C}$  over a 24-hour period. This particular profile contains some very stressful steep thermal ramps from  $60\text{C}$  to  $10\text{C}$ , and from  $-40\text{C}$  to  $20\text{C}$ . Note

that even over these temperature extremes, the four laser driver modulation currents vary by less than 5%.

In Figure 5 we show the bit error rate performance over temperature. This type of stress test is performed routinely in the qualification and evaluation of SONAbeam™ systems. Note that this test is very stressing: the optical power received by the terminal under test has been attenuated until it is only 2 dB above the receiver error threshold. The terminal is thermally cycled from 22C to 60C to -40C and back to 20C over a 38 hour period. In spite of the very weak receive signal, the BER over the duration of this -40C to 60C test was an impressive  $4 \times 10^{-13}$ .

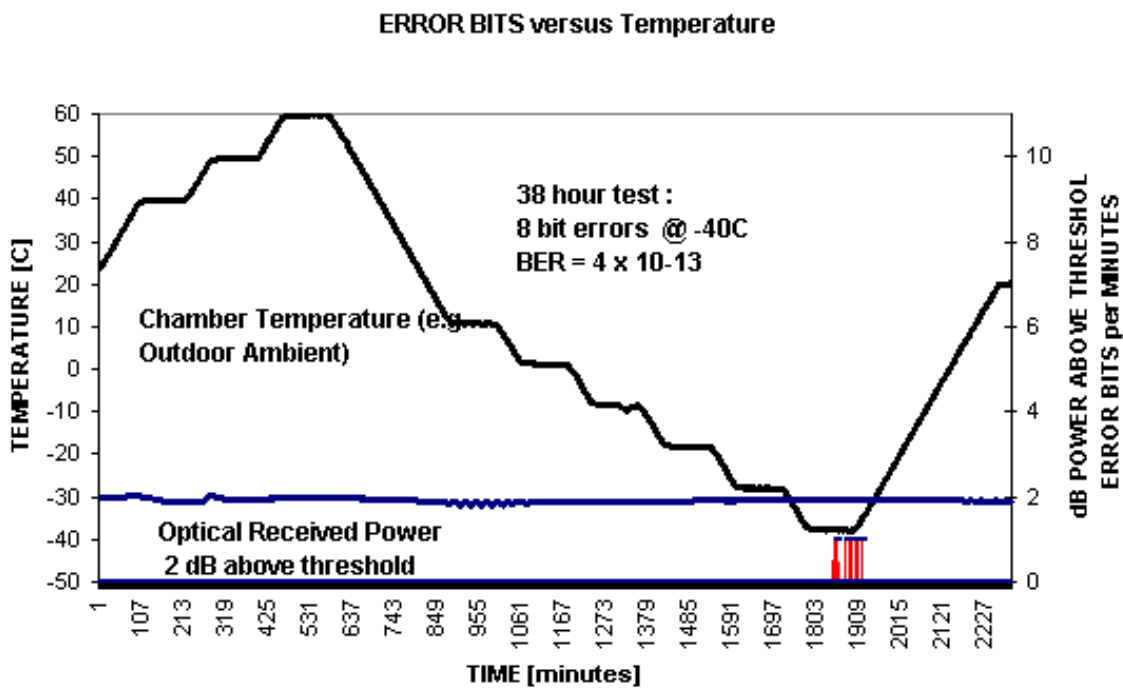
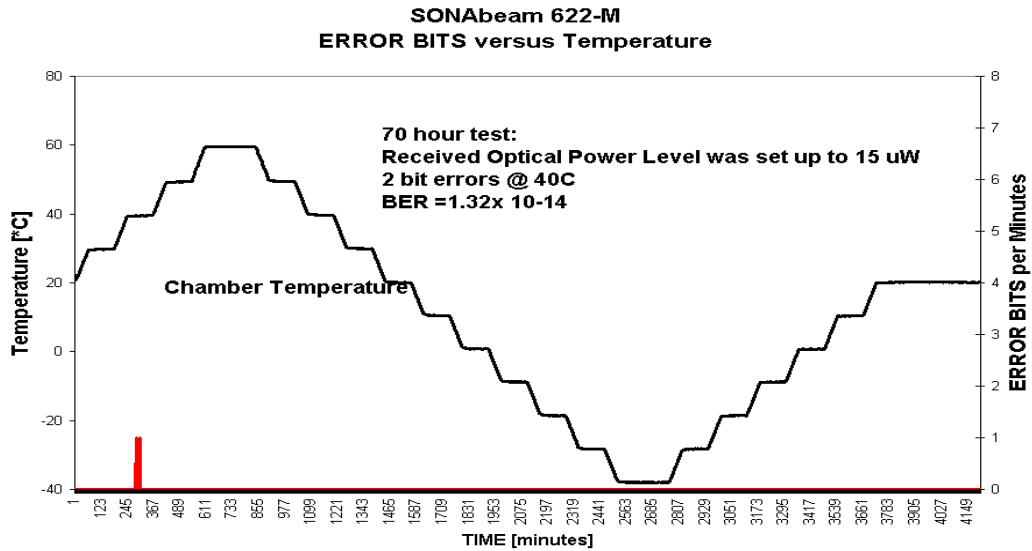
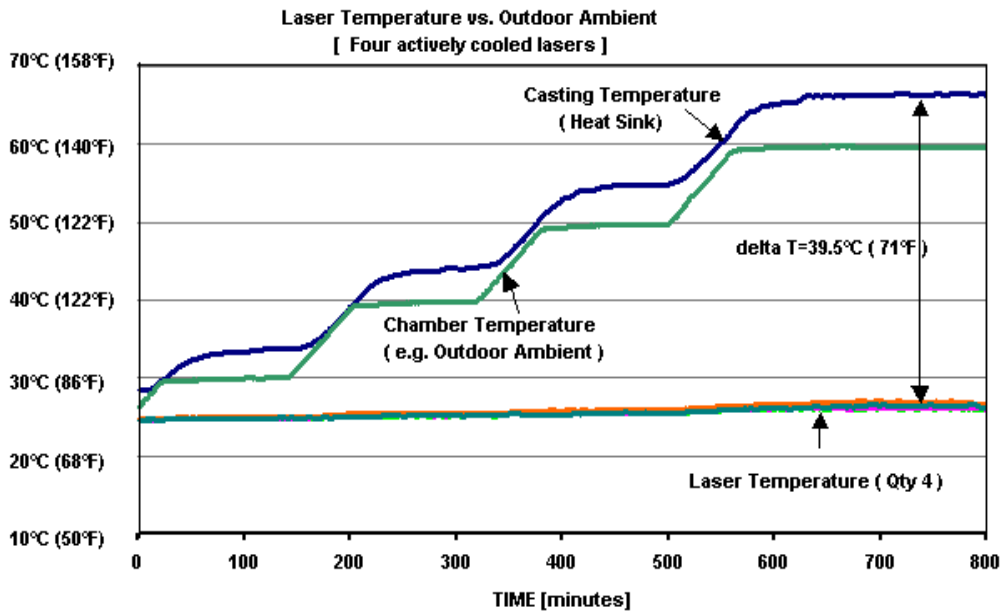


Figure 5 Bit error rate testing with a weak receive signal only 2 dB above the error threshold results in a  $4 \times 10^{-13}$  BER over the full ambient temperature range from -40C to 60C.



*Figure 6 SONAbeam™ 622-M Bit error rate testing with a receive signal only 15 uW resulted in a 1.32x10<sup>-14</sup> BER over the full ambient temperature range from – 40C to 60C. with only 2 bit errors in a 70 hour test*

Another example of thermal testing is shown in Figure 7. This figure demonstrates the performance of the solid-state thermoelectric coolers that actively cool the lasers in hot ambient conditions. Each of the four lasers has its own pair of coolers and cooler controller, resulting in true quad-redundancy of the entire transmitter subsystem. In hot climatic conditions, active laser cooling dramatically enhances the laser reliability and lifetime.



*Figure 7 Four Actively cooled lasers for high-rel operation in hot weather: lasers are cooled 40C (70F) below the heat sink temperature in a 60C (140F) desert environment*



#### 4. FIELD TEST RESULTS

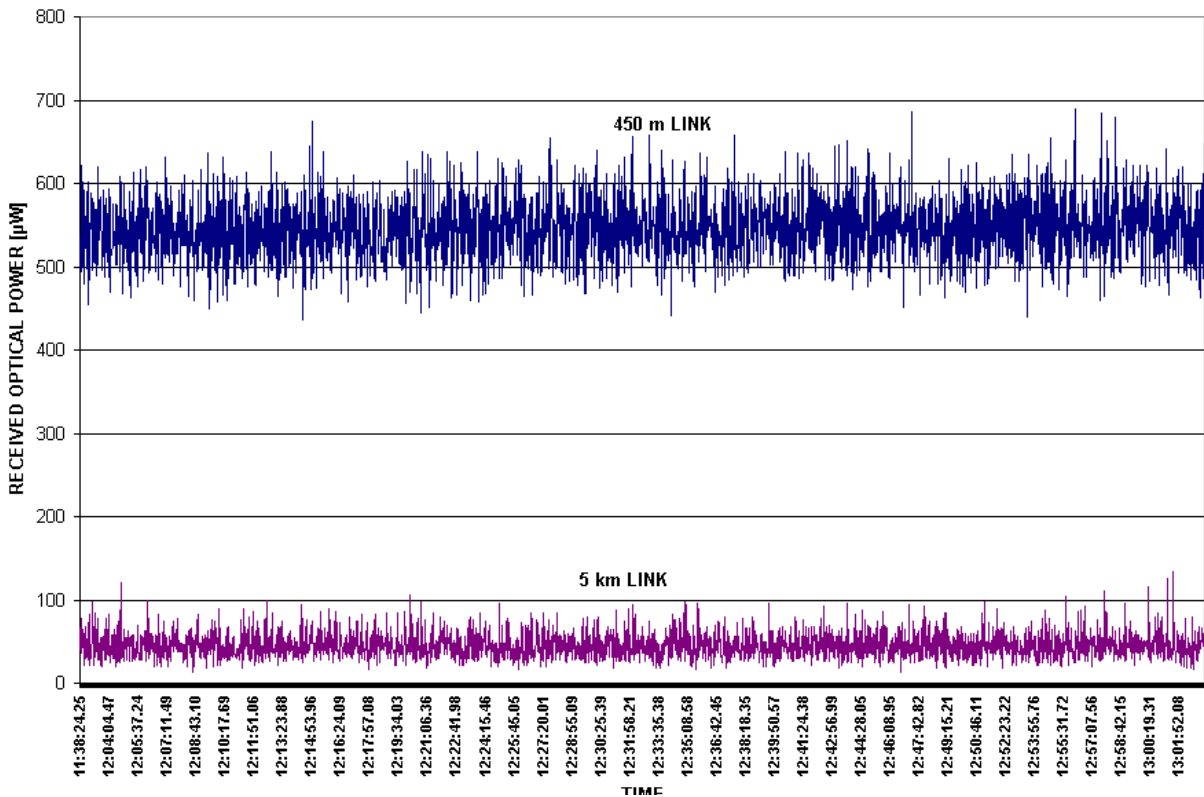
In addition to environmental qualification testing, fSONA performs extensive field testing over our 450 meter and 5000 meter test ranges in Richmond, near Vancouver B.C. The 5000 meter range is used to test the limits of the system under more stressful conditions of deep, saturated scintillation, much higher atmospheric transmission losses, etc. The 450 meter test range is more representative of a deployment scenario for very high weather availability. The Vancouver area is well suited to outdoor weather performance testing because of the unusually rainy and foggy environment. Figure 8 is a photo of the fSONA rooftop and a couple terminals on the 450 meter test range.



*Figure 8. Two terminals being tested over the 450 meter test range from the fSONA rooftop*

We have studied the effects of scintillation on the SONAbeam™ 155-M over both the 450 and 5000 meter ranges. Scintillation is random signal intensity fluctuations due to a spatially and time-varying refractive index integrated along the path length. It is most severe for long paths with saturated scintillation under bright sunny conditions, represented by the 5000 meter range. The 450 meter range offers more benign, and more typical, results representative of typical FSO

deployment ranges for high availability. The scintillation results are dependent on the system design and implementation. It is well known that the parameters that mitigate scintillation surges and fades include increased aperture area for spatial integration, spatial diversity using uncorrelated multiple transmitter sources, and increased spatial separation between those sources. In Figure 9 we show measured results for worst-case midday scintillation under a bright summer sun over our 450 and 5000 meter test ranges for the SONAbeam™. The data shown are for approximately a 90 minute period. The 450 meter range is seen to have 5-sigma surges and fades of +/-1.25 dB, worst-case, and the 5000 meter range experiences +/-5.25 dB, worst-case. The electronics design is such that this dynamic signal variation has no impact on measured BER performance.



**Figure 9 Measured scintillation results: +/-1.25 dB, max, over 450 meters and +/-5.25 dB, max, over 5000 meters for the SONAbeam™ with a 20cm receiver and quad transmitter spatial diversity.**

We have also studied the BER performance and error statistics of scintillation at weak signal levels. An extreme example was a test over the 5000 meter range, with the transmitter power deliberately attenuated so the received signal was only 5 dB above the receiver error threshold. The test was performed over a nine day period in the summer under bright, full sun conditions. In

spite of the weak signal conditions under which this test was performed, the BER was a very respectable  $10^{-9}$ . The results are summarized in Table 1.

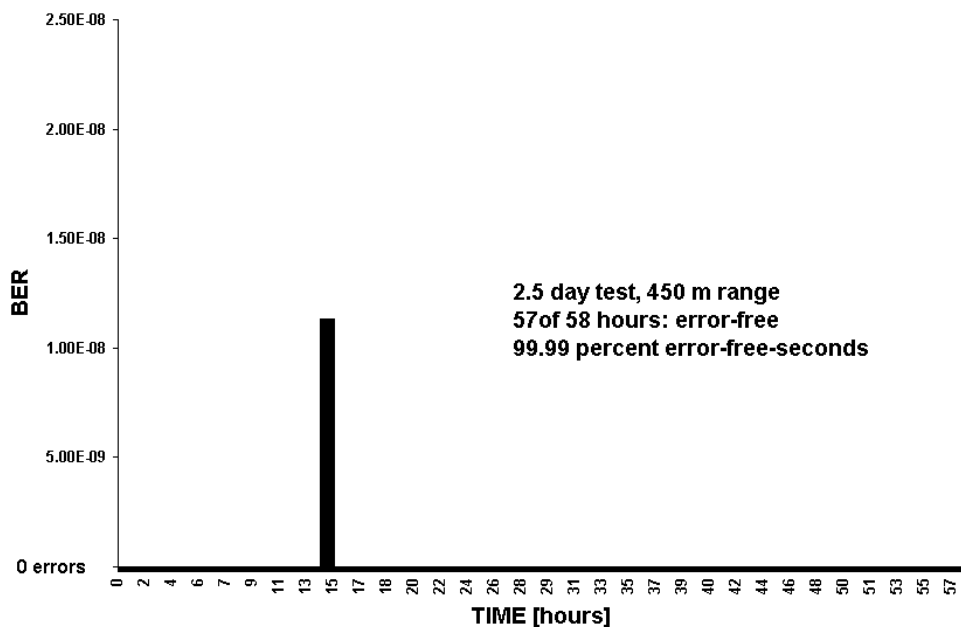
<b>Table 1. SONAbeam™ saturated scintillation test over 5000 meters: lasers attenuated 8 dB, resulting in mean receive signal only 5 dB above receiver error threshold.</b>	
Weather conditions	Nine days of bright, sunny summer weather.
Bit error rate (cumulative over 9 days)	$1.1 \times 10^{-9}$
Percent error-free seconds	99.9%
Percent error-free SONET frames	99.99998%
Percent severely errored seconds	0.000032%

Below are two tables that summarize recent data for the performance of the SONAbeam™ 155-M in actual field tests over our 450 meter and 5000 meter test ranges. Both of the data sets were taken on bright sunny days with scintillation conditions. These long-duration tests were performed over 41 and 73 hour periods, and exhibited a fiber-quality BER of about  $10^{-12}$ , with percent-error-free-seconds better than 99.9999%, and an errored SONET frame rate of only one per billion.

<b>Table 2. Scintillation Test Results – 450 meter Range</b>	
Product under test:	SONAbeam™ 155-M
Terminal tested; Date	Rcv. Term. #7; Date: Sept. 7-10, 01
Link Range for this test	450 meters (far end looped back: 900m round-trip)
Duration of test	> 73 hrs
Weather Conditions	Clear, sunny (scintillation)
Bit Error Rate	$1.26 \times 10^{-12}$
Errored seconds; % error-free sec	2 errored sec; >99.99999% error-free
SONET frames with errors	2 frames out of > 2 billion in 73 hours
Available Seconds	100.00%
Severely Errored Seconds	0

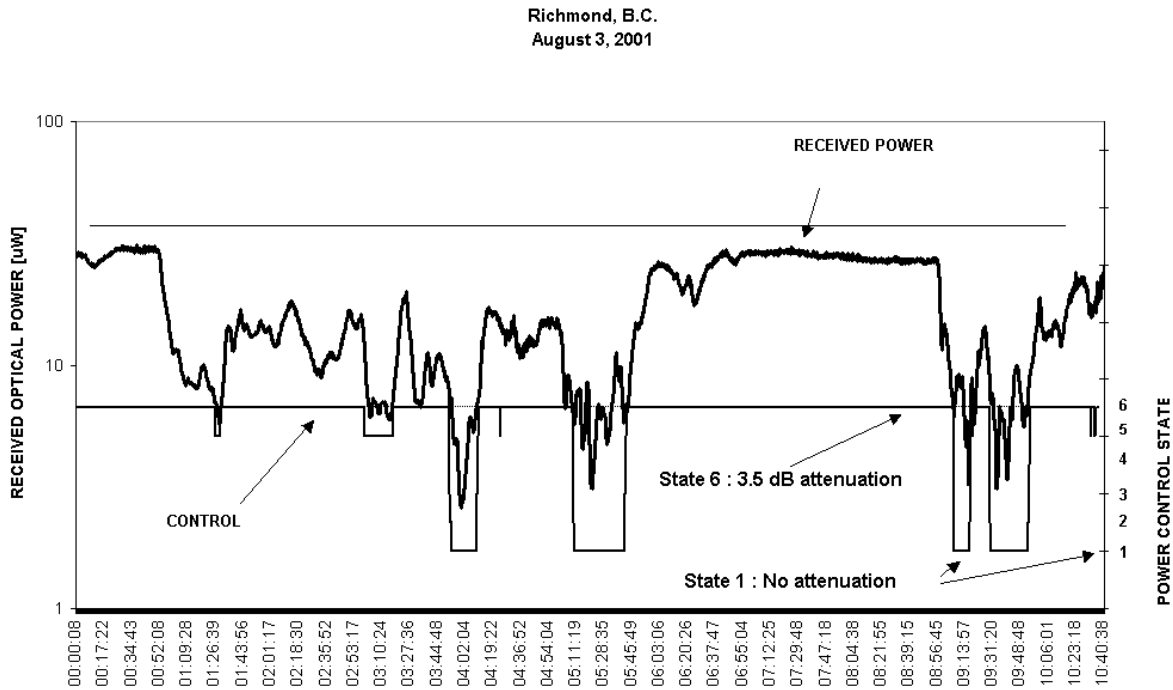
<b>Table 3. Scintillation Test Results – 5000 meter Range</b>	
Product under test:	SONAbeam™ 155-M
Terminal tested; Date	Terminals #41,42; Date: Sept. 4-6,2001
Link Range for this test	5000 meters (far end looped back: 10 km round-trip)
Duration of test	> 41 hrs
Weather Conditions	Clear, sunny (scintillation)
Bit Error Rate	$5.29 \times 10^{-12}$
Errored seconds; % error-free sec	1 errored sec; 99.99993% error-free
SONET frames with errors	1 frame out of > 1 billion in 41 hours
Available Seconds	100.00%
Severely Errored Seconds	0

Figure 10 illustrates the performance of a SONAbeam™ 622-M link over 450 meters test range during a field test. A single, unexplained burst of errors occurred in an otherwise error-free performance over 2.5 days. The final BER was  $5 \times 10^{-11}$ , with 99.99% error free seconds.



*Figure 10 SONAbeam™ 622-M BER performance on 450 meter test range*

The SONAbeam™ also employs an adaptive laser power scheme to dynamically adjust the laser power in response to weather conditions. In clear weather the transmit power is greatly reduced, enhancing the laser lifetime by operating the laser at very low-stress conditions. In severe weather, the laser power is increased as needed to maintain the link - then decreased again as the weather clears. The proprietary algorithm for this scheme has been tested in a wide cross-section of real-world weather conditions over both the 450 and 5000 meter test ranges, including clear-weather scintillation, rain, and fog. Figure 11 is an example of adaptive laser power control.



**Figure 11. Example of adaptive power control in operation.**

In Figure 11, rainy weather of varying intensity occurred over a ten hour period. In this figure, power control state 6 corresponds to a reduced transmitter power level, and state 1 corresponds to full transmit power. As the received signal falls below 5 microwatts due to increasing rain attenuation, the adaptive laser power algorithm increases the transmitter power as necessary. As the weather clears, the transmitter power level is reduced from the higher power state back to state 6, the maximum transmitter attenuation used for a 5000 meter range.

Figure 12 demonstrates the robustness of the SONAbeam™. This test was performed in sunny scintillation conditions on the 450 meter test range. The very large link margin allows the system to perform error-free with only four paper-punch holes in a cardboard disk, in spite of the intense signal scintillation from such small apertures.



*Figure 12 Error-free performance on 450 meter test range in sunny scintillation testing.*

As a final example of the system performance, Figure 13 is a screen shot of a network protocol analyzer. This test was performed over the 5000 meter range over a 12 day period. The Fast Ethernet link was used during this time for customer demonstrations, including video transmission and data transfer. The network analyzer used 14% of the link bandwidth for test packets, as seen in the lower left corner of the screen. During this 12 day period over 1.6 trillion test packets were transmitted. On the lower right portion of the screen, it can be seen that there were no dropped packets and no errors of the course of this 12 day test.

//192.168.1.48/NDIS 802.3 Module (1)			
ARM		CAP+MON	
100 MBPS		12d 10:19:18	
MAC Counters	Value	Errors	Value
Frames Captured	25,561,568,097	CRC Alignment	0
		Undersize	N/A
Frames Received	25,571,488,925	Oversize	N/A
Broadcast	717,981	Fragments	N/A
Multicast	751,734	Jabbers	N/A
Unicast	25,560,098,377	Collision Indication	N/A
Frames/Second	21,731	Packet Dropped	0
Bytes Received	1,636,614,613,350	Errors	0
Utilization	14		

*Figure 13. 12-day Fast Ethernet test: no dropped packets or errors over a 5000 meter link*

## **5. SUMMARY**

As part of a comprehensive product development effort to deliver true carrier class outdoor FSO products, fSONA has developed a test program based on adaptation of Telcordia testing standards, which are the telecommunications industry standard. This testing program is applied across all of the fSONA product lines. We have summarized the rigorous environmental qualification testing that has been performed for the SONAbeam™ 155-M and 622-M. The field-proven performance in the presence of sunny scintillation and rainy conditions has also been presented.

## **6. REFERENCES**

[1] D. A. Rockwell and G. S. Mecherle, "Wavelength Selection for Optical Wireless Communication Systems", SPIE Proceedings Vol. 4530, Denver, August 2001.