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## Backscatter signature generator for OTDR calibration

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### Abstract

This paper describes an active characterization technique that generates backscatter signatures to measure the performance of optical time-domain reflectometers (OTDRs). These signatures can be used to test an OTDR's loss accuracy, dynamic range, spatial resolution, loss resolution, and receiver recovery time.

### Introduction

No practical commercially available techniques, devices, or instruments exist today to measure the performance level of OTDRs. Consequently, measurement discrepancies performed on OTDRs often cannot be resolved due to the lack of a traceable calibration standard. Several passive techniques have been proposed that use standard fibers, delay lines, and bulk optics as calibration standards. However, these techniques are not robust, mass producible, or flexible enough to characterize all crucial parameters for long and short haul OTDRs.

We have developed an Optical Fiber Backscatter Signature Generator (OFBSG) as an active characterization system for OTDRs. The OFBSG system consists of an optical source, an optical receiver, a Z80 microprocessor board and some processing logic. The system resides in a light-weight, compact chassis, and interfaces with the OTDR via a short fiber optic cable as illustrated in Figures 1 and 2. The system detects the narrow pulses launched from the OTDR and returns a computer generated backscatter signature. These signatures can be imported from a lap-top computer and can be tailored for short-haul or long-haul OTDRs.

This paper first reviews the definitions for OTDR parameters and tradeoffs between passive and active characterization methods. It is then followed by a description of the OFBSG concept, system overview, computer interface, test results, and conclusions.

### OTDR parameters

A concise definition of OTDR parameters is necessary before discussing characterization techniques. OTDR manufacturers specify some of the parameters, but there is no concurrence in how these parameters are defined. The five most critical parameters are loss accuracy, dynamic range, spatial resolution, loss resolution, and receiver recovery time from overload.<sup>1</sup>

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Loss accuracy specifies the difference between the measured and the actual loss value. Dynamic range is the difference in decibels between the noise floor and the upper limit of the linear range of the OTDR receiver. Spatial resolution specifies the ability of the OTDR to distinguish between defects or fiber perturbations in close proximity. It is determined by the full width of the Fresnel reflection pulse at half of the maximum power (FWHM).<sup>2</sup> Loss resolution is the smallest resolvable loss measurement. The recovery time from receiver overload is the time required for the receiver to recover from saturation.

#### Tradeoffs between passive and active characterization

OTDR characterization methods can be divided into two categories: (1) passive devices using fiber standards, delay lines, and bulk optics; and (2) active devices that generate and detect optical signals.<sup>1</sup> Some of the advantages and disadvantages of each approach are discussed.

Passive characterization using standard reference fibers is a simple and direct concept approach, but it has disadvantages. For example, long-haul OTDRs with distance capabilities greater than 100 km require standard reference fibers longer than 100 km. It is difficult to fabricate a fiber of this length with attenuation that is unaffected by packaging, temperature changes, and vibration. Since the standard fiber has fixed attenuation factor, the fiber signature cannot be changed. An active device such as the OFBSG overcomes these drawbacks by allowing length, attenuation, and other characteristics to be changed by modifying the backscatter signatures in the lap-top computer before importing it into the OFBSG. One disadvantage of the OFBSG is that it is more complex.

Another disadvantage of the reference fiber is that the measurement of the dynamic range requires extrapolation of the backscatter returns at the upper and lower limits of the OTDR's receiver.<sup>2</sup> However, extrapolation may not detect non-linear effects caused by receiver saturation in the "dead zone" region in the front end of the backscatter returns. If the fiber is too short to measure backscatter near the noise floor, the lower end of the dynamic range must also be extrapolated. Hence, effects of incorrect bias levels in the logarithmic amplifier may not be detected.<sup>1</sup> The backscatter that the OFBSG returns to the OTDR can be programmed for length and attenuation to eliminate the need for extrapolation.

We selected the active characterization method because its advantages over the passive techniques outweighed the added complexity. Furthermore, the optical source in the OFBSG can be easily calibrated against transfer standard power meters for NIST-traceable measurements. Unlike the reference standard, the OFBSG can be computer controlled to tailor signatures for measuring all five critical operating parameters described earlier. In addition, this system can be setup to characterize single-mode and multi-mode OTDRs in different wavelengths by simply substituting the LED and coupler to match the OTDR's wavelength and modal characteristics.

#### Backscatter signature concept

Backscatter signatures returned to the OTDR by the OFBSG were designed to appear as fiber Rayleigh backscatter given by equation 1.<sup>1</sup>

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$$\phi(t) = 0.5 \phi_0 W V_g [ \alpha_s F_s + \alpha_n F_n ] \exp [ -\alpha_T V_g t ] \quad (1)$$

$V_g$  = Group velocity

$\alpha_s$  = Rayleigh scattering attenuation coefficient

$F_s$  = Rayleigh capture fraction

$\alpha_n$  = Non-Rayleigh scattering attenuation coefficient

$F_n$  = Non-Rayleigh capture fraction

$\alpha_T = \alpha_s + \alpha_n$

$\phi_0$  = Peak power injected into the fiber

$W$  = Pulse width

The Rayleigh backscatter in a fiber decays exponentially with distance, Rayleigh scattering factor, and non-Rayleigh scattering factor. Hence, in order to simulate the Rayleigh backscatter in a fiber, the backscatter signal generated by the OFBSG decays with time and other scattering factors. This concept allows OTDRs to be tested and characterized using signals that are as realistic as possible.

#### OFBSG System Overview

The OFBSG system illustrated in Figure 3 is comprised of a Z80 microprocessor board, random access memory (RAM), a Digital-to-Analog converter (DAC), a Light Emitting Diode (LED), a directional fused-taper coupler and an optical receiver.

The generation of the signature is initiated upon the receipt of the output pulse from the OTDR. Once the optical receiver-pulse detector senses the incoming pulse, a pre-loaded backscatter signature data in the RAM is sequentially applied to the DAC. The LED converts the analog output of the DAC into an optical signal. The optical backscatter signature signal then launches through the 3 dB fused-taper coupler into the OTDR.

Each data point is represented by a twelve bit digital value. This means that the signal can be signified by any of the 4096 ( $2^{12} = 4096$ ) steps. The number of bits in the DAC defines the inherent loss resolution of the system as described in equation 2.

$$\text{Loss resolution} = 10 \log \left[ \frac{P_i - \frac{P_o \text{ max}}{\# \text{ of steps}}}{P_i} \right] \quad (2)$$

$P_i$  = Input power

$P_o \text{ max}$  = Maximum output power

The inherent spatial resolution of the system is limited by the width of the pulse launched from the OTDR and the clock speed of the OFBSG. There are three selections for clock speeds of 5, 10 and 20 MHz and they correspond to 20, 10 and 5 meters of spatial resolution, respectively. However, even if the OTDR's receiver could resolve a 5 meter distance, the OTDR's transmitter pulse width may only be as small as 100 nanoseconds which translates into 10 meters of spatial resolution. Therefore, considerations must be made in conjunction with the OTDR transmitter pulse width and the response of the OTDR's receiver when determining spatial resolution. Equation 3 defines the OFBSB spatial resolution limit.

$$X = \frac{ct}{2n} \quad (3)$$

c = speed of light in vacuum  
t = period of each data point  
n = index of refraction of the core

#### Computer Interface

A variety of backscatter signatures can be loaded into the RAM from the lap-top computer depending on which OTDR parameter is being measured. The user first determines the characterization parameters by choosing the selections on the software menu as shown Figure 4. After the parameters are selected, the software calculates and produces the backscatter signature data points. These signatures are uniquely made to specifically test the five OTDR parameters. For example, a signature with a non-saturating Fresnel reflection is generated to measure spatial resolution.

The computer downloads all data points via the RS 232 serial interface to the Z80 microprocessor board. It is then transferred to the RAM and sequentially applied to the DAC to generate the analog backscatter signature for the LED. A typical computer generated signature is shown in Figure 5.

#### Test Results

The performance levels of three single-mode 1.3 micron OTDRs that were available in the lab were tested with our system. Figure 6 shows the preliminary test results of the four tests performed on these OTDRs. A signature with 0.10 dB and 0.20 dB splice losses was used to measure loss accuracy. OTDRs 1 and 2 exhibited close correlation to the input loss values. However, the results for OTDR 3 significantly deviated from these values.

Spatial resolution, loss resolution and receiver recovery time tests were also performed. It appears that OTDR 1 performed the best under all four tests and OTDR 3 performed the worst as evidenced by the large loss deviation and long recovery time. These results correlate to the age difference between the two OTDRs. OTDR 1 was acquired about two years ago while OTDR 3 was purchased nearly six years ago. Hence, the performance of OTDR 1 probably reflects improvements

in OTDR technology. Also, OTDR 3 suffers from years of operation in sometimes adverse field environments without routine maintenance. Further testing will be made upon completion of the computer interface and software, but the preliminary test results demonstrate that the OFBSG provides valuable characterization of OTDR performance.

### Conclusion

In this paper, we discussed the OFBSG active characterization technique, its advantages, and preliminary test results. The major advantage of our system is its ability to uniquely generate any form of backscatter signature. Therefore, OTDR performance parameters described earlier and any additional parameters added in the future can be easily characterized.

(1) The backscatter signatures can be tailored to test multiple OTDR parameters.

(2) The LED transmitter in the OFBSG system can be changed to accommodate different wavelength OTDRs.

(3) It can also be tailored for single-mode or multi-mode by substituting the LED and the optical coupler.

(4) This system is portable and light weight. It can be carried by one person to any remote site to perform the characterization procedures.

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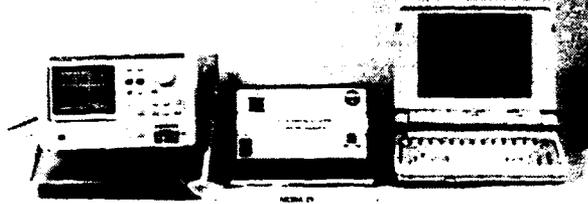


Figure 1. Photo of characterization test setup.  
 (left) OTDR under test.  
 (middle) Optical Fiber Backscatter  
 Signature Generator, OFBSG.  
 (right) Laptop computer.

OTDR Charaterization -- Test Setup

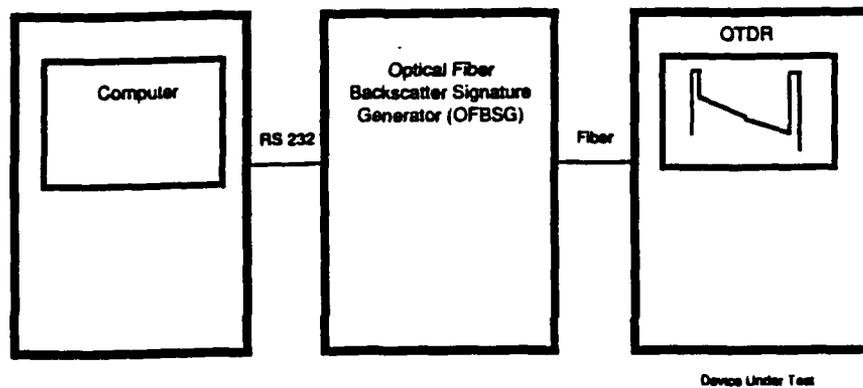


Figure 2. OTDR characterization test setup.

### OFBSG Block Diagram

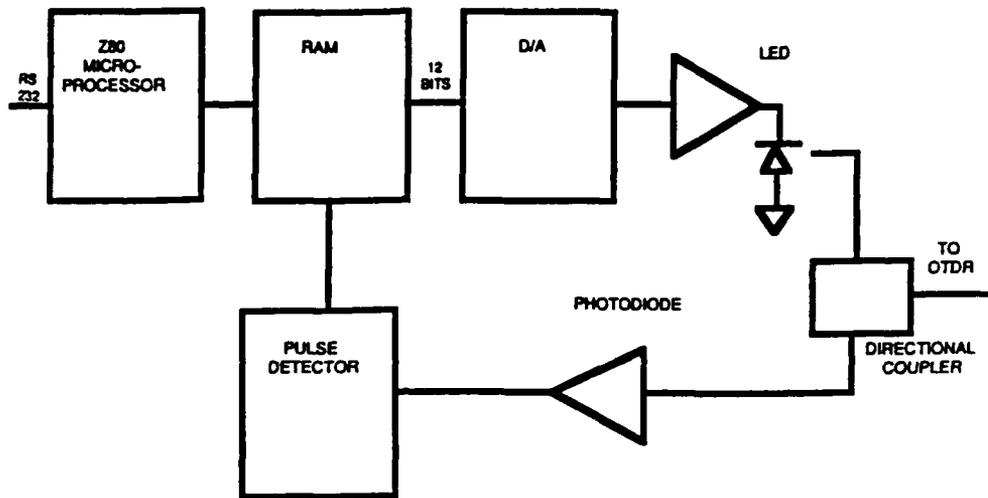


Figure 3. OFBSG Block Diagram.

### OFBSG Menu

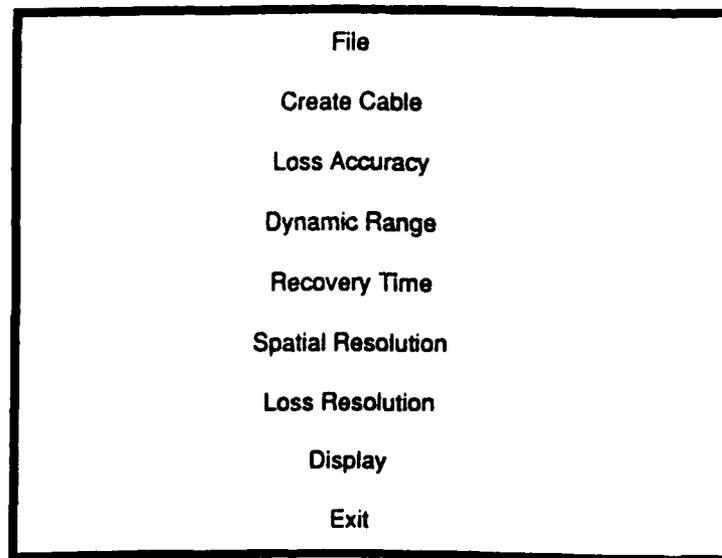


Figure 4. Main software menu.

OTDR @ 1300 nm

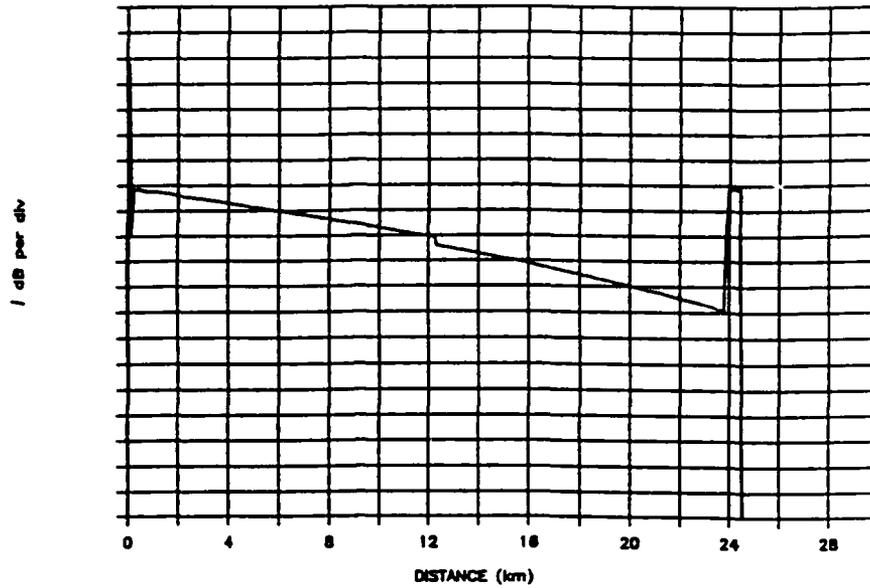


Figure 5. Typical computer generated backscatter signature.

## Test Results

Parameters \ OTDRs	OTDR 1	OTDR 2	OTDR 3
Loss Accuracy (dB)	0.13 0.20	0.13 0.25	0.24 0.77
Dynamic Range	—	—	—
Spatial Resolution (m)	10	51	52
Loss Resolution (dB)	0.01	0.01	0.01
Recovery Time (m)	41	34	60

Figure 6. Characterization test results of three OTDRs.