Nonlinearity of optical fiber power meters

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Abstract

We have developed a system for measuring the nonlinearity of optical fiber power meters over a dynamic range of more than 60 dB at three telecommunications wavelengths. This system uses optical fiber components and is designed to accommodate common optical powers; it is based on the triplet superposition method. This system provides accurate determination of optical power meter nonlinearity through the use of correction factors.

1. Introduction

The basic assumption for accurate optical power measurement is that the meter output reading is directly proportional to the optical input power. This proportionality property is called linearity, and the departure from this direct proportionality is defined as nonlinearity. Optical power meter nonlinearity is defined as the relative difference between the responsivity at an arbitrary power and the responsivity at the calibration power:[1]

$$\Delta_{NL}(P;P_c) = \frac{R(P) - R(P_c)}{R(P_c)} \qquad (1)$$

where R(P)=V/P is the responsivity of the meter at optical power P, the subscript c indicates the calibration point, and V is the meter output. A function that describes the relationship between the incident optical power P and the optical meter output is called the response function. The inverse of the response function is called the conversion function and is depicted in Figure 1.

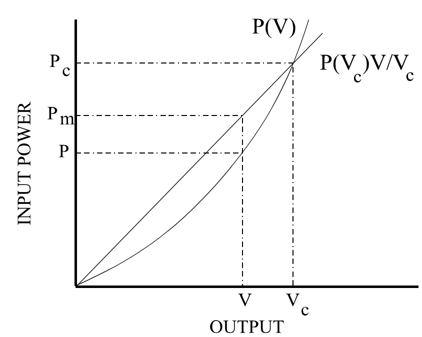

Figure 1. The conversion function.

It is often more convenient to use the conversion function rather than the response function. We can define the nonlinearity in terms of the output V as

$$\Delta_{NL}(V;V_c) = \frac{P(V_c)V}{P(V)V_c} - 1 \tag{2}$$

When the nonlinearity is small, a polynomial can represent the conversion function sufficiently well.

While the calibration gives the true input power from the power meter reading (output) at the calibration point, the measurement of nonlinearity and range discontinuity, together with calibration, provides this input-output relationship at any power within the entire dynamic range of the power meter.

It is, therefore, convenient to express the measured nonlinearity in terms of the conversion function P=P(V), which relates the input power P to the output V, and referenced to the calibration output V_c.

1.1. Correction Factor for Nonlinearity and Range Discontinuity

The true input power P is obtained from the power meter reading V by

$$P = \frac{V}{F_c \cdot CF} , \tag{3}$$

where $F_c = V_c/P_c$ is the calibration factor,

$$\begin{aligned} CF &= \frac{a_1[c]}{a_1[m]} \times \frac{1 + \sum_{k=2}^{n} b_k[c] V_c^{k-1}}{1 + \sum_{k=2}^{n} b_k[m] V^{k-1}} \\ &= \frac{a_1[c]}{a_1[m]} [1 + \Delta_{NL}(V;0) - \Delta_{NL}(V_c;0)], \end{aligned} \tag{4}$$

a correction factor due to nonlinearity and range discontinuity, m is a number that corresponds to a specific range of an optical power meter, a_k and b_k are coefficients, and c corresponds to the calibration point. Consequently, each range of a power meter has its own correction factor. The degree of polynomial, n is usually equal to 3 or 4 depending on the size of the data standard deviation.

2. Measurement system and results

We have based the operation of our system on the triplet superposition method [2,3,4] which relies on the principle that, for a linear meter, the sum of meter outputs corresponding to inputs from two individual beams should equal the output when the two beams are combined and incident on the meter at the same time. The measurement system is depicted in Figure 2. We use a high-power, single-mode, fiber-pigtailed diode laser whose output power is stabilized; the laser is temperature-controlled. An external optical attenuator with a dynamic range of 60 dB is used to provide variable optical power. The optical power from the attenuator is divided into two approximately equal parts by introducing a 3 dB fiber splitter; one of the splitter arms has an additional length of fiber to avoid interference. A computer-controlled shutter is inserted into a collimated-beam section in each arm. Both signals are recombined in a 3 dB fiber coupler. We use single-mode fiber components throughout the system. We call a platform with fiber components and two shutters a switching matrix. The measurements were performed by taking sets of three power readings from the test meter: (1) shutter 1 is open and shutter 2 is closed, (2) shutter 1 is closed and shutter 2 is open, and (3) both shutters are open. This sequence is then repeated at different powers.

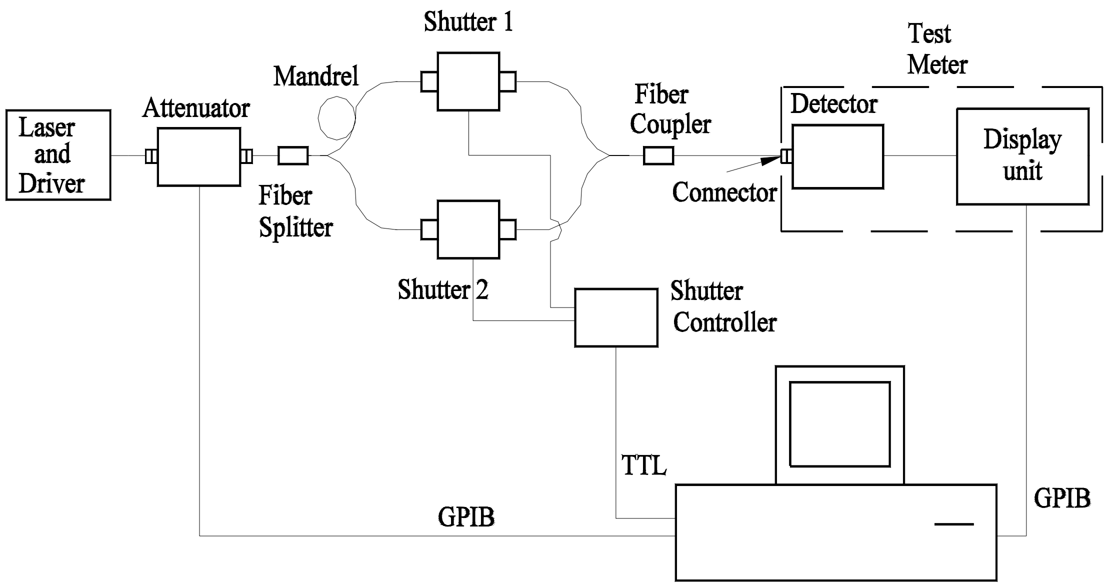

Figure 2. Measurement system.

We constructed two switching matrices: one for 850 nm, and the other for both 1300 nm and 1550 nm. Both switching matrices shared one attenuator. To measure the range discontinuity (offsets between range or scale settings), readings are taken at the lower power end of each range and compared to the readings on the higher power region of the next lower range (if any) at a constant power. The calculated correction factors result from the meter nonlinearity within each range, combined with the range discontinuity.

Figures 3 and 4 depict correction factors obtained on a typical optical power meter at 850 nm and 1300 nm, respectively. Each data group represents a separate power range of the meter. The same optical power meter was significantly nonlinear at 850 nm (Figure 3) and very linear at 1300 nm (Figure 4) .

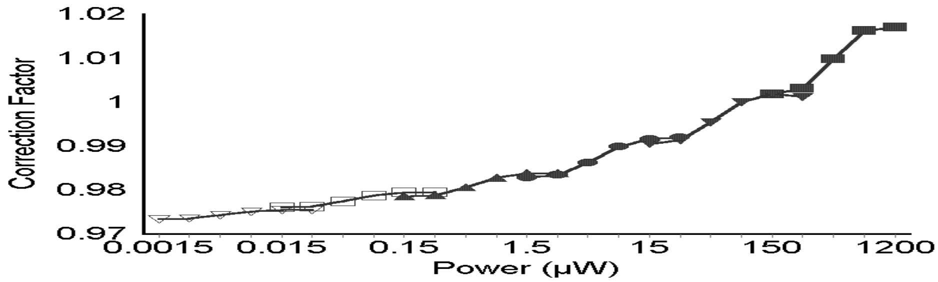

Figure 3. Correction factor vs. power at 850 nm.

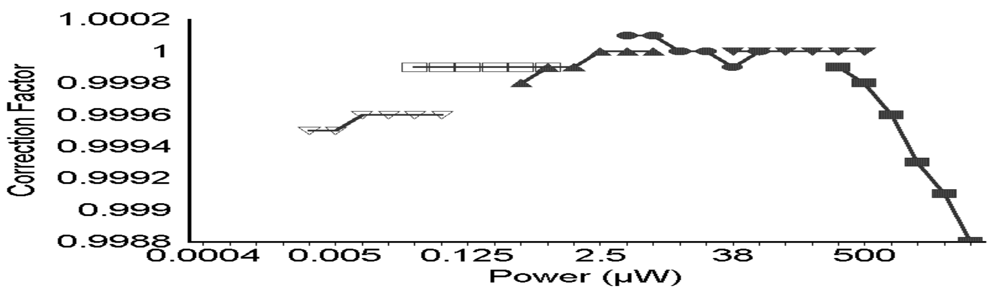

Figure 4. Correction factor vs. power at 1300 nm.

Acknowledgments

This work is supported by the Navy's Metrology R&D Calibration Standards Program under the management of Joe Dressel (NAVSEA 04312).

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