LUNA TECHNOLOGIES
A Division of Luna Innovations Incorporated

ADVANCED OPTICAL TESTING FOR COMPONENTS & ASSEMBLIES

Using the Phoenix 1400 Tunable Laser for Optical Frequency Domain Reflectometry

A Luna Technologies Application Note

www.lunatechnologies.com

3157 State Street • Blacksburg, VA 24060 • Phone 1.540.961.5190 • Fax: 1.540.961.5191

Using the Phoenix 1400 Tunable Laser for Optical Frequency Domain Reflectometry

Index:

1 Introduction

Optical Frequency Domain Reflectometry (OFDR) utilizes swept-wavelength coherent interferometry to measure reflections in a device as a function of delay. This time of flight can be scaled to distance using the group index and speed of light in vacuum. Access to this information gives the user a way to look inside their optical network; identifying loss events and individual components.

Luna Technologies' Phoenix 1400 laser is ideally suited for OFDR measurements with full C-band highly linear tunability, low noise, built in wave meter, gas cell, power monitors and 2 optical detectors.

This application note details two setups and procedures for performing OFDR measurements. The Basic OFDR Measurement is for a single input polarization state. The Polarization Diverse OFDR Measurement measures the evolution of two orthogonal polarization bases as they propagate down a fiber. From this the user may calculate a polarization averaged amplitude versus delay data set. Furthermore, for both measurements phase data is readily available- allowing access to phase derivative as a function of delay which in turn may be scaled to reflected frequency versus delay. This is useful for locating and characterizing wavelength dependent reflective devices like FBGs, WDMs, etc.

2 Basic OFDR Measurement Setup

The Phoenix 1400 system and accompanying PC will need to be powered on and the USB 2.0 data transfer cable from the Phoenix 1400 system plugged into an available USB port on the computer. The user should ensure that FC/APC connections are used to mate the OFDR measurement network to the Phoenix 1400 as shown below in figure 1.

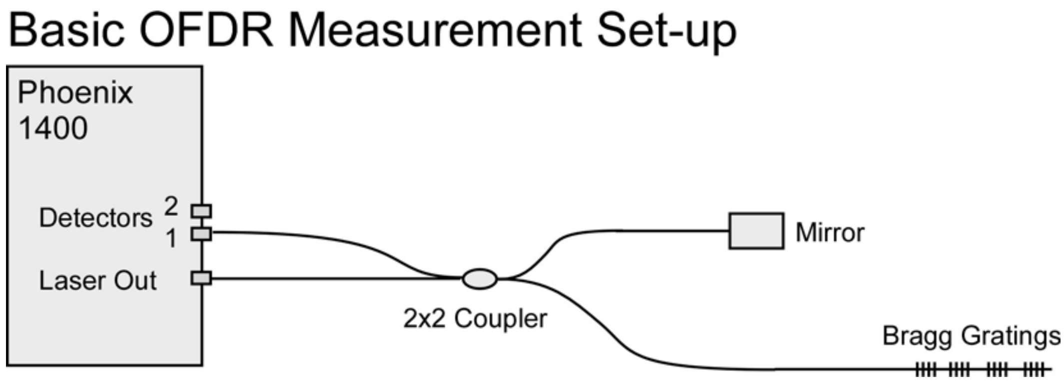

Figure 1. The basic OFDR measurement setup for measuring reflection amplitude versus delay down a fiber. All connections must be FC/APC.

Once the device is connected, the user should open the Phoenix 1400 software and specify the parameters of the measurement. This will include the start and end wavelengths, laser sweep rates, laser power, trigger settings and number of sweeps.

Note that the approximate maximum achievable spatial resolution is related to the sweep range of the measurement. This is due to the Fourier transform relation between optical frequency and delay. Accordingly, the following is an estimate of achievable resolution:

$$\Delta z \approx \frac{\lambda_1 \lambda_2}{2 n_{eff} \Delta\lambda}$$

where Δz is the spatial resolution, n_{eff} is the effective group index of the Fiber Under Test (FUT), λ_1 and λ_2 are the start and end wavelengths of the scan and $\Delta\lambda = |\lambda_1 - \lambda_2|$ is the wavelength range. Hence, scanning over larger ranges gives better resolution (smaller Δz).

The total measurable distance down the fiber is bounded by the sampling rate at the detector. According to the Nyquist sampling criterion, the sample rate at the detector must be twice that of the measured frequency. For example, if the sample rate at the detector is known this implies a maximum distance down the fiber given by

$$Z_{\max} \approx \frac{f_s}{4} \frac{\lambda^2}{Rn}$$

such that Z_{max} is the maximum distance, f_s is the sampling rate, λ is the center wavelength of the sweep range, R is the sweep rate of the laser and n_{eff} is the effective group index of the fiber under test. Note the factor of four comes from Nyquist sampling theorem and the double pass nature of the interferometer. Hence for a 1.25MHz sample rate, 1550nm center wavelength, 50 nm/s scan rate and group index of 1.468 the maximum distance is approximately 10.2 meters down the fiber.

With these considerations accounted for the user should acquire data with detector 1. The data may then be imported into the users preferred processing code (LabView, MatLab,etc) where the following algorithm is employed.

1. Resample the detector 1 data to equal frequency increments using the wavemeter data.

2. Perform a Fast Fourier Transform (FFT) on this resampled data. This gives amplitude and phase arrays.

3. Reflection amplitude versus delay in the fiber is calculated by plotting the amplitude of the FFT of the resampled detector 1 data versus delay . To convert from frequency increment back to time delay use the following Fourier transform relation

$$dt = \frac{1}{N * d\nu}$$

   where dt is the time *increment* ,N is the number of samples and dv is the frequency *increment.*

4. To scale this to distance, simply multiply the x-axis by the speed of light over twice the group index. Explicitly, the following is the relationship between frequency range and spatial resolution.

$$dx = \frac{c}{2n_{eff}\Delta\nu}$$

   where dx is the spatial resolution, c is the speed of light in vacuum, n_{eff} is the group index of the FUT and Δv is the frequency range.

Below in Figure 2 is the resulting plot of reflection amplitude versus distance.

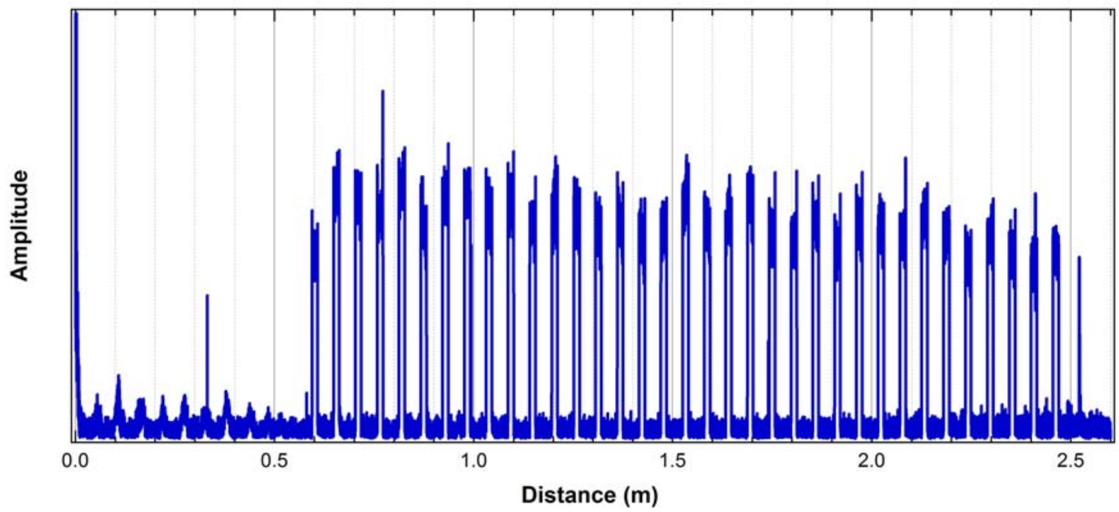

Figure 2. Basic OFDR measurement data displaying reflected amplitude (arbitrary units) as a function of distance along the FUT. The FUT pictured here is smf-28 with embedded FBGs.

As mentioned in the introduction, one may take the derivative of the phase data to view the phase derivative as a function of delay. This data can be scaled to reflected frequency by multiplying by the frequency range over 2 pi and adding the center frequency.

Explicitly, the phase derivative is defined by the following

$$d\vartheta = \angle\left(D_i D_{i-1}^*\right)$$

such that D denotes the FFT of the power incident on detector 1.
Below in figure 3 is a plot of these data sets.

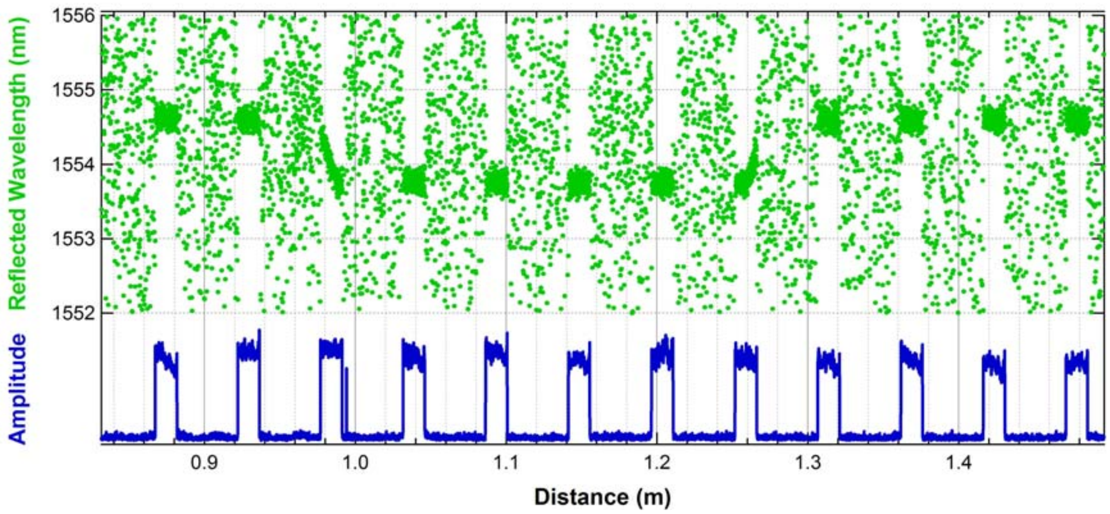

Figure 3. Basic OFDR measurement data displaying reflected wavelength and amplitude as a function of distance along the FUT. Note the middle 6 FBGs are were strained during the measurement, indicated by their spectral shift.

3 Polarization Diverse OFDR Measurement Setup

The Polarization Diverse Measurement setup is shown below in Figure 4.

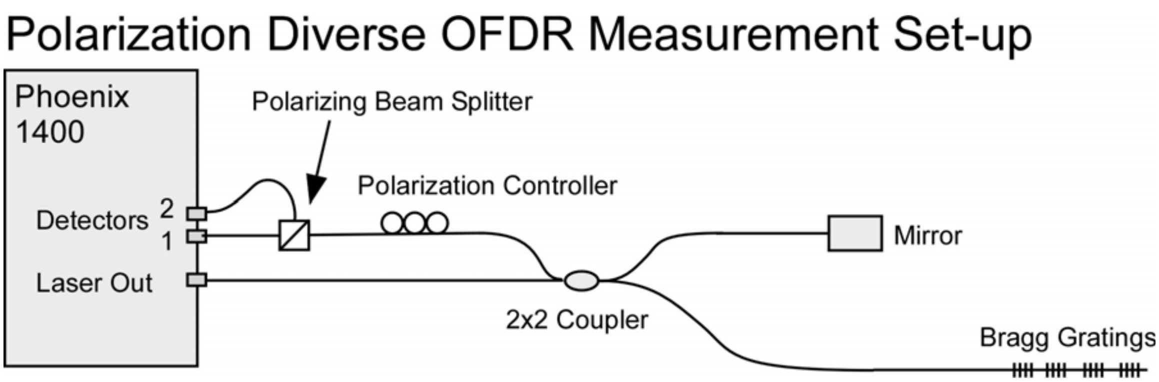

Figure 4. Polarization diverse OFDR measurement setup for tracking orthogonal polarization evolution as a function of delay. Connections to the Phoenix 1400 system must be made with FC/APC connectors.

This setup measures the reflected amplitude of orthogonal polarization states as a function of delay down the fiber. The equations that relate to the basic OFDR measurement hold, as well as the basic measurement procedure. Once all scan parameters are entered into the Phoenix 1400 GUI, the polarization controller should be used to equalize the DC power on detectors 1 and 2 with no DUT attached. Once this is achieved, the user simply splices in their DUT and clicks the scan and acquire data button, obtaining wavemeter data, output power and measured power on detectors 1 and 2.

The saved text file can now be loaded into the desired processing software where the aforementioned process of resampling and transforming both channels of data leads to reflection amplitude versus delay data for orthogonal polarizations. The polarization diverse reflection amplitude is then calculated using the following equation

$$A = \sqrt{|S|^2 + |P|^2}$$

such that S is the FFT of detector 1 power, and P is that of detector 2.
To calculate the polarization diverse phase derivative, one uses the following formula

$$d\vartheta = \angle\left(S_i S_{i-1}^* + P_i P_{i-1}^*\right)$$

Below in figure 5 is a plot of reflected amplitude versus delay for detector 1, detector 2 and polarization diverse data sets.

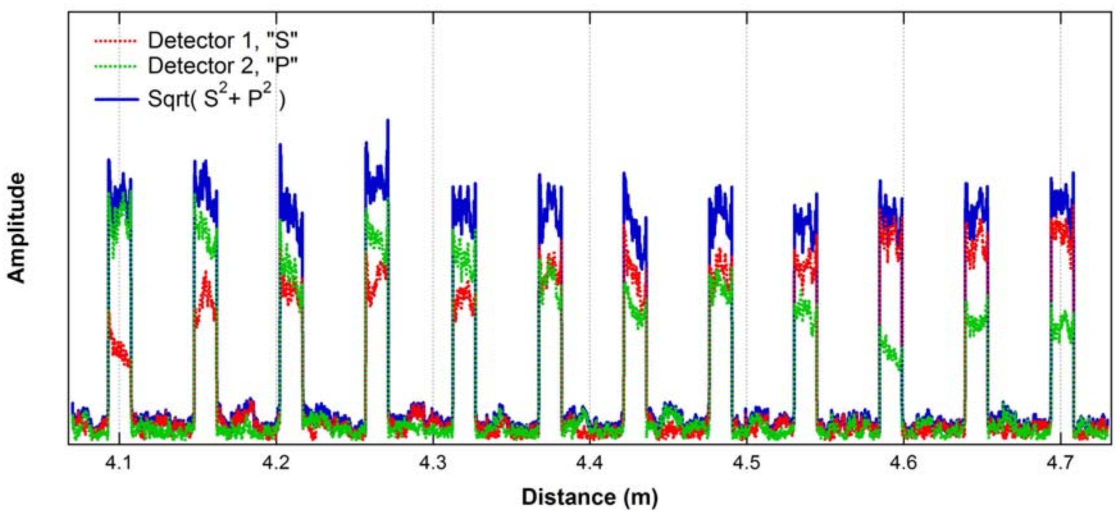

Figure 5. Polarization diverse OFDR measurement of reflected amplitude versus distance. This is the same DUT (multiple FBGs) as used in the basic OFDR measurement.

3 Summary

The Phoenix 1400 is ideally suited for OFDR measurements over the full C band with linear tunability, low noise, unique built-in wavemeter, gas cell, power meter and optical detectors. Furthermore, with a few easy modifications to the measurement network and post processing algorithm, polarization diverse OFDR measurements are achieved. From this data the phase derivative is extracted yielding reflected frequency versus delay information.