Anritsu Advancing beyond

Application Note

Electro-Optical Measurements Using Anritsu VNAs

Introduction

As the data rates of optical communication systems continue to increase, optical transmit and receive modules require characterization to wider bandwidths. Optical modulators (E/O devices), photo detectors and receivers (O/E devices), as well as optical components can be characterized accurately using vector network analyzers (VNAs). This paper describes the techniques and hardware required to characterize these components with economies of scale and flexibility not present in current lightwave component analyzer (LCA) designs.

Background and Use of VNAs

VNAs are traditionally used to conduct native measurements in the electrical realm of the frequency domain, and have been used for decades to characterize electrical devices and networks. VNAs measure transmission parameters in both magnitude and phase in the microwave and millimeter-wave (mmWave) frequency bands in the form of S-parameters. High-speed optical digital signals transmitted on networks have similar frequency content and bandwidth as high-speed electrical digital signals measured by microwave VNAs in the electrical realm. Therefore, VNAs can be an effective tool to characterize these optical components, as long as the signal can be converted between the electrical and optical mediums. Figure 1 shows the typical optical spectrum of a laser modulated at a 20 Gb/s data rate.

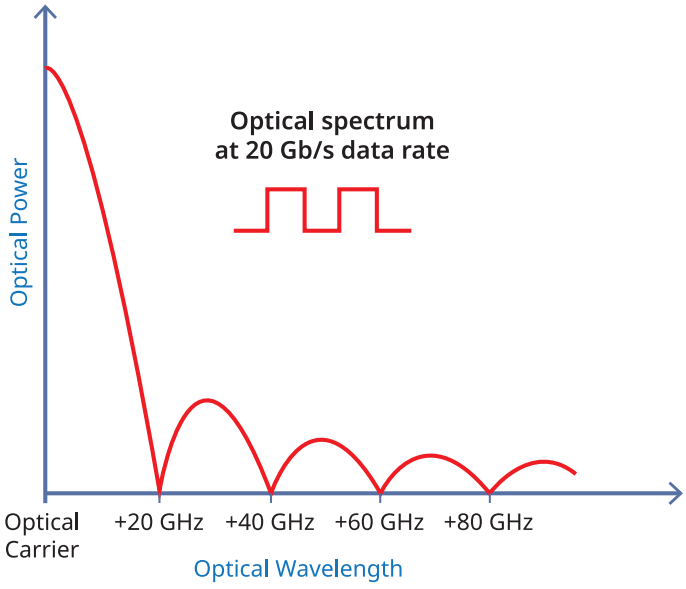

Figure 1. The Optical Spectrum of a Laser Modulated at a 20 Gb/s Data Rate

Since VNAs make electrical measurements, it is necessary to convert these electrical signals to optical signals on the transmit side and convert them from the optical to electrical signals on the receiver side. To accomplish this, a laser with an RF modulator (E/O) is required on one side and a calibrated photodiode (O/E) on the other. It is necessary to implement a method to calibrate the system to establish reference planes for these measurements, since measurements of both magnitude and phase of the signals are required. This calibration will leverage the VNA's 12-term vector error correction algorithms to account for the physical imperfections of the RF components and increase the accuracy of the electrical measurements.

Finally, having the ability to de-embed components is very useful in moving the measurement planes from the electrical to the optical realm. Anritsu VNAs have these native capabilities on the instrument, so there is no need for additional software.

System Calibration

A standard 2-port electrical calibration is conducted on the VNA to establish the electrical calibration reference planes, as shown in Figure 2. A laser and optical modulator are used to convert the electrical stimulus from the VNA output to optical. This results in an optical stimulus at a wavelength determined by the laser that is modulated with an electrical sinusoidal CW signal. This signal is swept in frequency over a desired measurement bandwidth.

A photodiode is used to convert the optical signal back to an RF signal that can be measured by the VNA. The receiver at the VNA's RF input is tuned to the RF frequency with which the optical signal is modulated. Because of its architecture, the Anritsu VNA can be tuned to a very narrow, instantaneous, bandwidth for a very high signal-to-noise (S/N) measurement. The VNA converts these individual measurements into a forward transmission characteristic. It samples the RF output signal and compares it with the measured RF input signal to determine an S21 for each measurement. S21 is the ratio of RF in/RF out, and has both magnitude and a phase terms.

In Figure 2, the device under test (DUT) can either be an optical modulator or a photodiode.

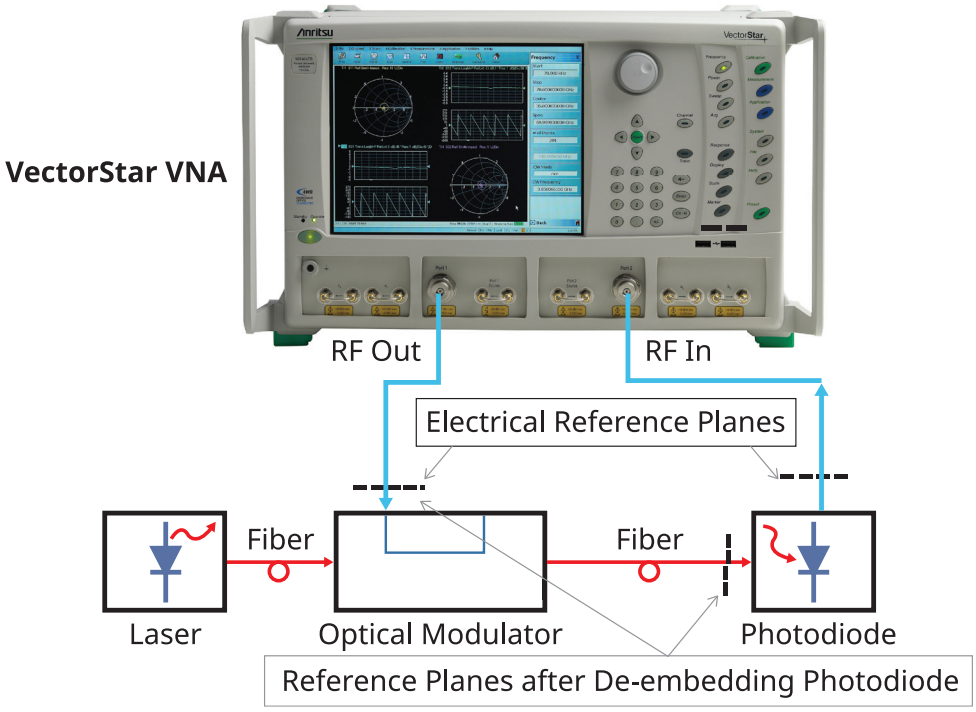

Figure 2. Basic E/O and O/E Setup Showing the Calibrated RF Reference Planes and Reference Planes after De-embedding

This relative transfer function does not take into account the variations in laser output power or optical loss in the fiber, as these don't generally influence the electrical transmission response.

E/O Measurements

A photodiode with a characterized O/E transfer function in magnitude and phase can be de-embedded from the combined measurement. It effectively moves the calibration planes to those shown in Figure 2. This will account for the photodiode response and allow measurements of optical transmitters and modulators with the photodiode effectively removed from the set-up. The resulting E/O measurement is an accurate characterization of these devices. Anritsu provides a characterization file with each O/E calibration module that allows the photodiode to be removed from the measurement. This file is obtained using a primary standard characterized by the National Institute of Standards (NIST), basically a reference photodiode.

When the photodiode is de-embedded from the measurement, its optical response and variation over the measurement bandwidth can be accounted for. Accurate measurement of an optical modulator's electrical-to-optical characteristics, such as bandwidth, amplitude flatness, phase linearity, and group delay, can be made. In addition, electrical return loss of the optical modulator's RF input can be measured.

O/E Measurements

If an O/E device, such as an unknown photodiode, needs to be measured, the same set-up shown in Figure 3 can be used. Because the characterized photodiode has been de-embedded, it can be used to characterize the magnitude and phase performance of the optical modulator to be subsequently used in the O/E measurement. This transfer function file can then be used to de-embed the performance of the now characterized optical modulator. At that point, the unknown photodiode can replace the characterized photodiode to measure its performance.

The uncertainty of this measurement will be slightly higher than the E/O measurement because of the second level of de-embedding involved in the measurement.

Anritsu MN4765B O/E Calibration Modules

Anritsu manufactures several instrument-grade O/E calibration modules (Table 1) that can be used to perform O/E and E/O measurements with the VectorStar® and ShockLine™ VNAs. The MN4765B modules are available in different optical wavelengths with various RF bandwidths to support industry requirements.

These modules enable error-corrected Transfer Function, Group Delay, and Return Loss measurements of E/O and O/E components and subsystems when used with Anritsu VNAs.

Magnitude and phase characterization is obtained using a primary standard characterized by NIST and held in the Anritsu Calibration Lab. The magnitude and phase data is provided (in .s2p format) on a USB drive with the module for the purpose of de-embedding the O/E module from the combined measurement. These modules have internal thermal stabilization and precision voltage regulation to minimize drift in photodiode frequency response.

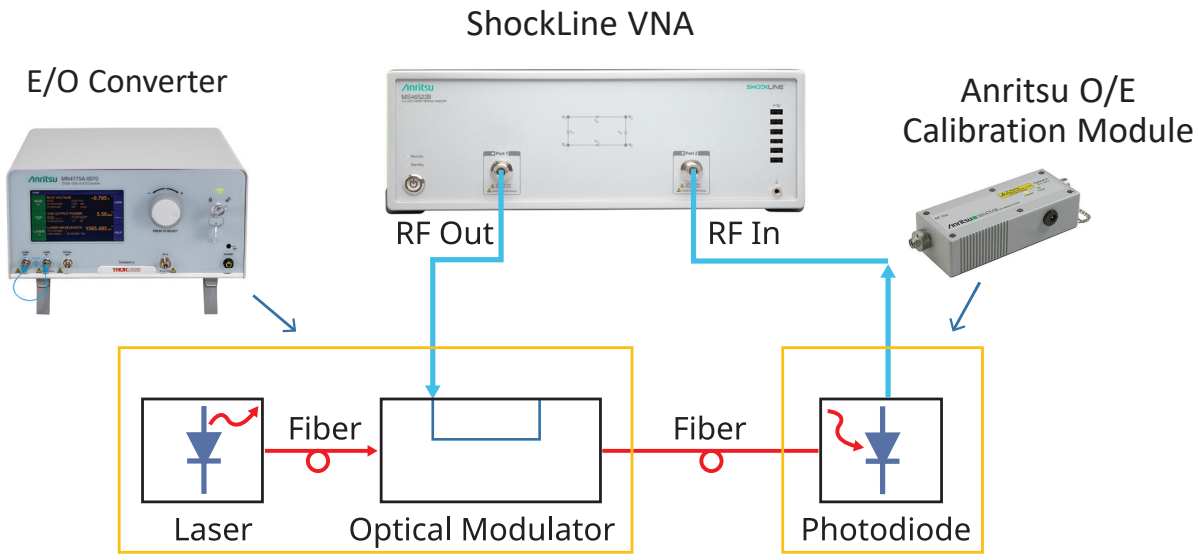

Figure 3. E/O and O/E Solutions Available from Anritsu

Anritsu O/E Calibration Modules		
Anritsu Model #	**Optical Wavelength**	**Frequency Range**
MN4765B–0040	850 nm	70 kHz to 40 GHz
MN4765B–0042	850/1060 nm	70 kHz to 40 GHz
MN4765B–0043	850/1060/1310/1550 nm	70 kHz to 40 GHz
MN4765B–0070	1550 nm	70 kHz to 70 GHz
MN4765B–0071	1310 nm	70 kHz to 70 GHz
MN4765B–0072	1550/1310 nm	70 kHz to 70 GHz
MN4765B–0110	1550 nm	70 kHz to 110 GHz
MN4765B–0111	1310 nm	70 kHz to 110 GHz
MN4765B–0112	1310/1550 nm	70 kHz to 110 GHz
MN4765B–0140	1550 nm	70 kHz to 145 GHz

Table 1. A listing of the O/E Modules Available from Anritsu

E/O Converter-VNA Optical Transmitters

Anritsu also offers a line of laser/optical modulator products to complete the E/O configuration. These units allow easy-to-use, high-performance characterization of photo receivers and photodiodes when combined with the MN4765B O/E module and the de-embedding tools available with Anritsu VNAs.

The laser/optical modulator products (Table 2) feature low RIN DFB laser sources and high bandwidth electro-optical modulators with excellent flatness and low ripple. There is an automatic bias control to lock the operating point of the modulator independent of operating conditions.

Modulator Products		
Anritsu Model #	**Optical Wavelength**	**Frequency Range**
MN4775A–0040	850 nm	70 kHz to 40 GHz
MN4775A–0070	1550 nm	70 kHz to 70 GHz
MN4775A–0071	1310 nm	70 kHz to 70 GHz
MN4775A–0072	1310/1550 nm	70 kHz to 70 GHz
MN4775A–0110	1550 nm	70 kHz to 110 GHz
MN4775A–0111	1310 nm	70 kHz to 110 GHz

Table 2. A Listing of the E/O Optical Modulators Available from Anritsu

Conclusion

This paper presents an accurate, flexible and cost-effective technique to conduct electro-optical testing on fiber optic components, such as laser modulators and photodiodes, using VNAs. The simplicity of Anritsu's MN4765B O/E calibration modules allows highly accurate, vector-error-corrected and stable measurements with the full line of Anritsu VNAs.

Additional Reference Documents

1) Anritsu Application Note *Electro-to-Optical and Optical-to-Electrical (E/O and O/E) converter measurements* (P/N 11410-00798)
2) Anritsu Technical Data Sheet *O/E Calibration Module MN4765B (*P/N 11410-00843)

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List Revision Date: 20250812

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11410-01034, Rev. D Printed in United States 2025-10

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