Technical Note
April 1998

microelectronics group

Lucent Technologies
Bell Labs Innovations

Using the Lithium Niobate Modulator: Electro-Optical and Mechanical Connections

Introduction

The purpose of this document is to describe how to use a Lucent Technologies Lithium Niobate ($LiNbO_3$) modulator. Input requirements, test setups, and mounting instructions will be covered.

Input Requirements

$LiNbO_3$ modulators need three types of input to operate properly: an optical signal, an electrical dc bias, and an RF data signal.

Optical

The optical signal is simply a CW beam at 1.55 µm wavelength. For analog applications the relative-intensity-noise or RIN of the laser is important. A low RIN will maximize the overall system carrier-to-noise ratio (CNR). For all applications, a key point is to have the optical beam polarized and to correctly orient the polarization at the input to the modulator. In a real system this can be done by properly splicing PMF from the laser source to the PMF pigtail of the modulator. In a testing environment this polarization is usually optimized with a polarization controller. This is a simple device that flexes standard SM (single-mode) fiber in a controlled fashion to rotate the optical signal through all polarization states. Such devices may be purchased from JDS Fitel, Hewlett-Packard* and other vendors.

Electrical Inputs

Proper electrical input to the modulator consists of a dc bias and an RF signal. The dc bias is used to position the modulator on the steepest part of the response curve so that a small change in voltage gives the maximum variation in output power. An important point to make here is that the dc bias may be placed either on the same input with the RF data signal or on a separate electrode. These two options are illustrated in Figures 1 and 2.

The choice is somewhat dependent on the modulator and the application. Generally, high-frequency applications (above 8 GHz) using the shorter 2 cm electrodes have a separate electrode and port for the dc bias. With such a short electrode, there is space to place another electrode over the waveguide for the dc bias. The lower frequency devices have a 4 cm electrode for the data signal, so the dc bias must ride on one of the data input ports.

* Hewlett-Packard is a registered trademark for Hewlett-Packard Company.

Input Requirements (continued)

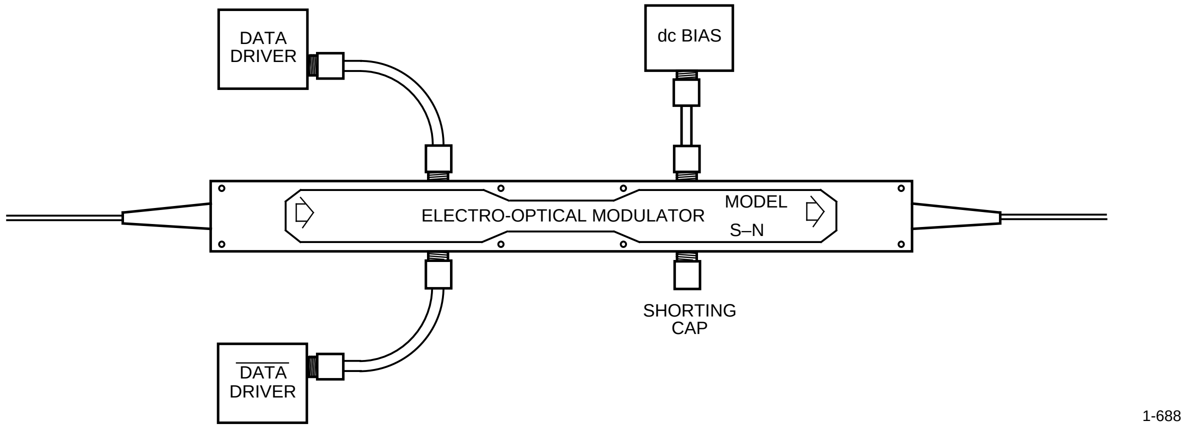

Figure 1. Modulator with dc Bias Entering on a Separate Electrode

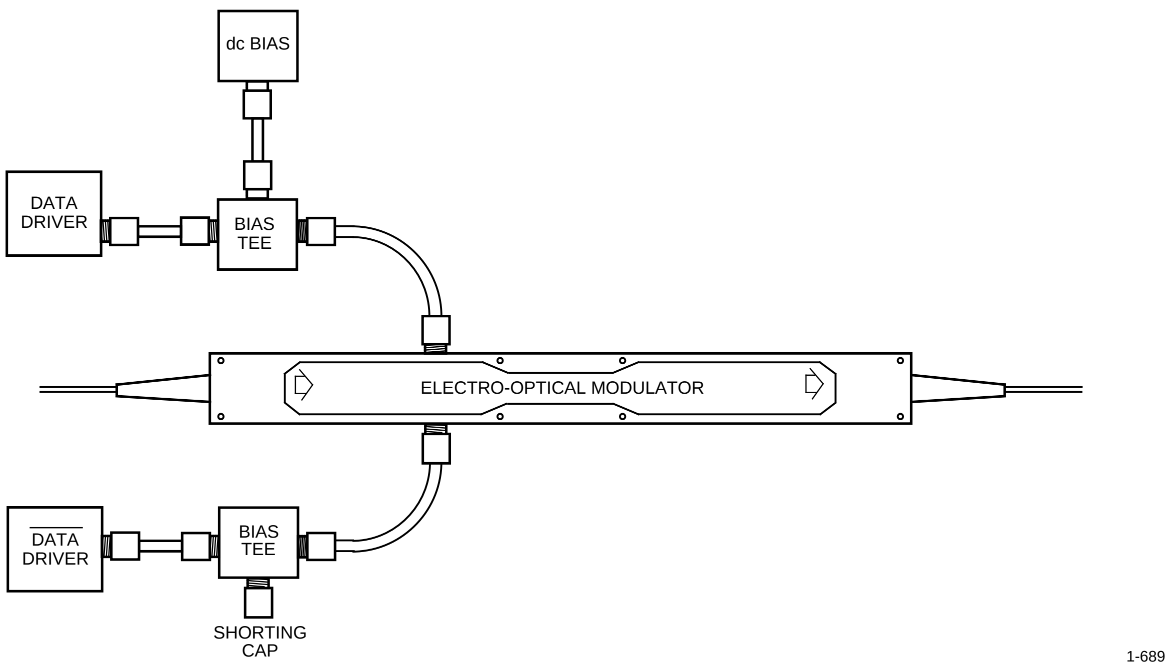

Figure 2. Modulator with dc Bias Entering on the Same Electrode with RF Input

Input Requirements (continued)

Impedance

The electrical impedance of the modulator electrode determines how compatible it will be with traditional 50 Ω systems. The electrode impedance depends on details of the geometry and the electrical properties of the materials. Since the details of electrode geometry influence several aspects of device performance, a compromising impedance of 43 Ω has been chosen. The transmission line of the device is properly terminated with an internal thin film resistor, also of 43 Ω. Since the lower frequency device has a dc voltage applied to the RF electrode, in this situation it is desirable to use a dc blocking capacitor in the termination in series with the 43 Ω resistor.

Laser Driver

A more detailed setup than shown in Figures 1 and 2 is shown in Figures 3 and 4, illustrating the use of a modulator driver in digital system applications up to 10 Gbits/s. The driver should be a differential driver that can source at least 100 mA for 2.5 Gbits/s applications and 300mA for 10 Gbits/s applications. This current source must be converted to voltage, because the modulator is voltage driven.

A 50 Ω termination is used right after the driver. The ac-coupling capacitor is needed as the drivers usually like a direct ground, but the modulator itself may be capacitively grounded. Between the capacitor and the input port, a bias tee is used to bring in the dc bias voltage. With the 43 Ω impedance of the modulator the driver sees about a 25 Ω.

Commercially available drivers specifically for $LiNbO_3$ modulators are produced by Lucent Technologies FORCE group. Model numbers are listed in Figure 3 and Figure 4.

The requirements for the CATV modulator are slightly different. For CATV, the demand is to have the lowest swing voltage possible which dictates a long electrode. However, allowing the dc bias to ride on the signal port can cause negative interactions with the pre-distortion circuitry that is commonly used for analog signals. Therefore, CATV applications that use pre-distortion usually have a dual drive design, but use one port for the dc bias and the other port for the analog signal.

Input Requirements (continued)

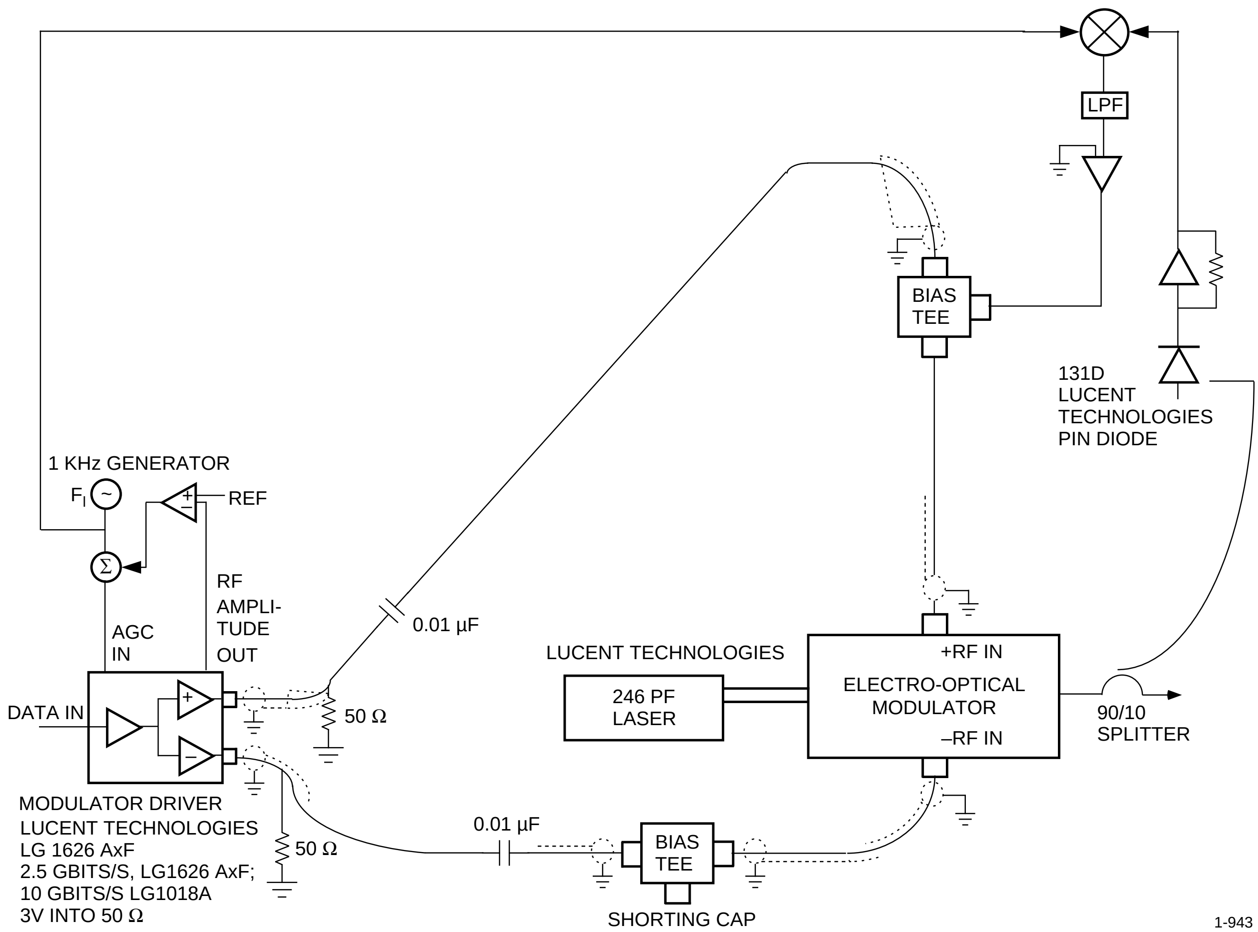

Figure 3. Recommended Operating Circuit Diagram for 2623-Type Modulator

Input Requirements (continued)

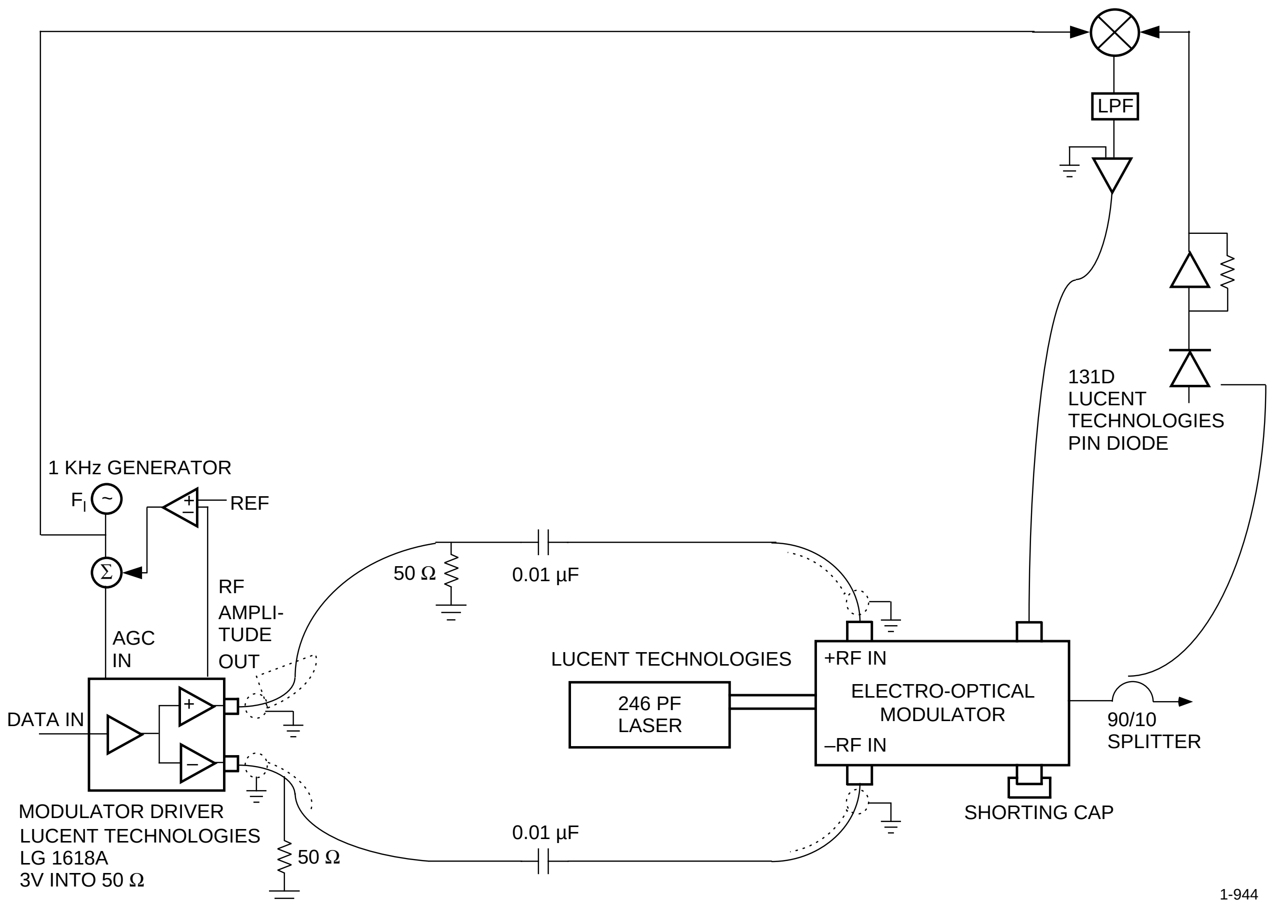

Figure 4. Recommended Operating Circuit Diagram for 2624-Type Modulator

Single Drive vs. Dual Drive

The benefit of the single drive is that one gets a little something for nothing in the E field interactions. Figure 5 shows the electrode layout for a single drive and a dual drive modulator.

With the single drive setup the field penetrates over into the other arm of the interferometer creating a weak phase change in that arm. Therefore, an overall total phase shift can be done for about 80% of the peak-peak voltage swing needed for a dual drive modulator.

The two major advantages of the dual drive design are related to the driving voltage and the chirp. Although the single drive needs only 80% of the total swing voltage, the dual drive can be operated in a push-pull format. For example, if a modulator needed an 8 volt peak-peak swing, a dual drive format only needs 4 volt swings on each input, but 180° out of phase. Lower voltage swings ease the requirements on the driving circuitry.

The other advantage of dual drives is that the push-pull operation can reduce the chirp to zero by balancing the waveguide changes in each arm of the interferometer. Because of the minimal dispersion created, zero or near-zero chirp performance allows a system to be extended to the maximum distance.

Input Requirements (continued)

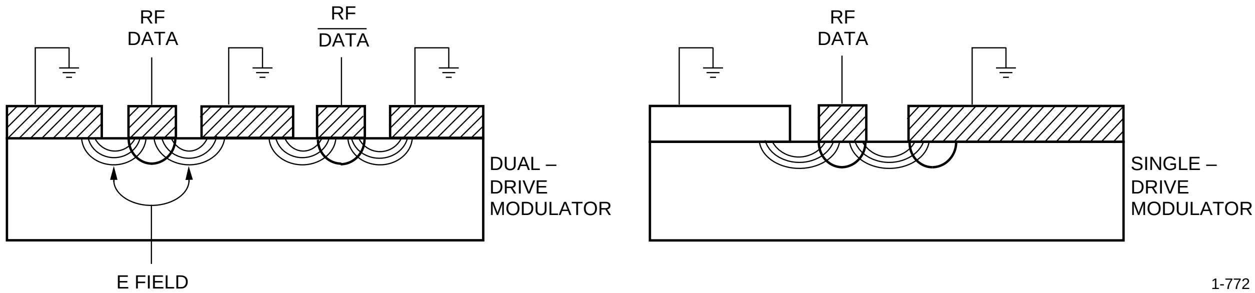

Figure 5. Electrode Layout for Dual- and Single-Drive Modulators

Test Setup

In a testing environment a number of sources may be used to drive the Lucent $LiNbO_3$ modulators. For complete system testing, the HP 8703A Lightwave Component Analyzer or equivalent may be used. In a system, the driver is very dependent on the data rate of the application. It would be nice to drive the device to $V\pi$, but as will be discussed under the section on $V\pi$, this voltage is dependent on electrode length and it tends to increase with data rate.

Lucent uses various test stations for parameter evaluation in factory testing. The basic high-frequency testing is done with the setup shown in Figure 6. This test set is used to measure extinction ratio, bandwidth (BW), S11, and the insertion loss. The heart of the test set is the Lightwave Component Analyzer. This analyzer generates the electrical and optical signals to drive the modulator. It also evaluates the electrical output of a PIN photodiode that converts the optical output of the modulator.

For minimum insertion loss, a polarization controller is used to optimize the polarization states. This also eliminates the need for a PMF pigtail on the laser. A FC/PC connector is used to join the fibers. This type of connection can be broken and reset with consistent performance.

Input Requirements (continued)

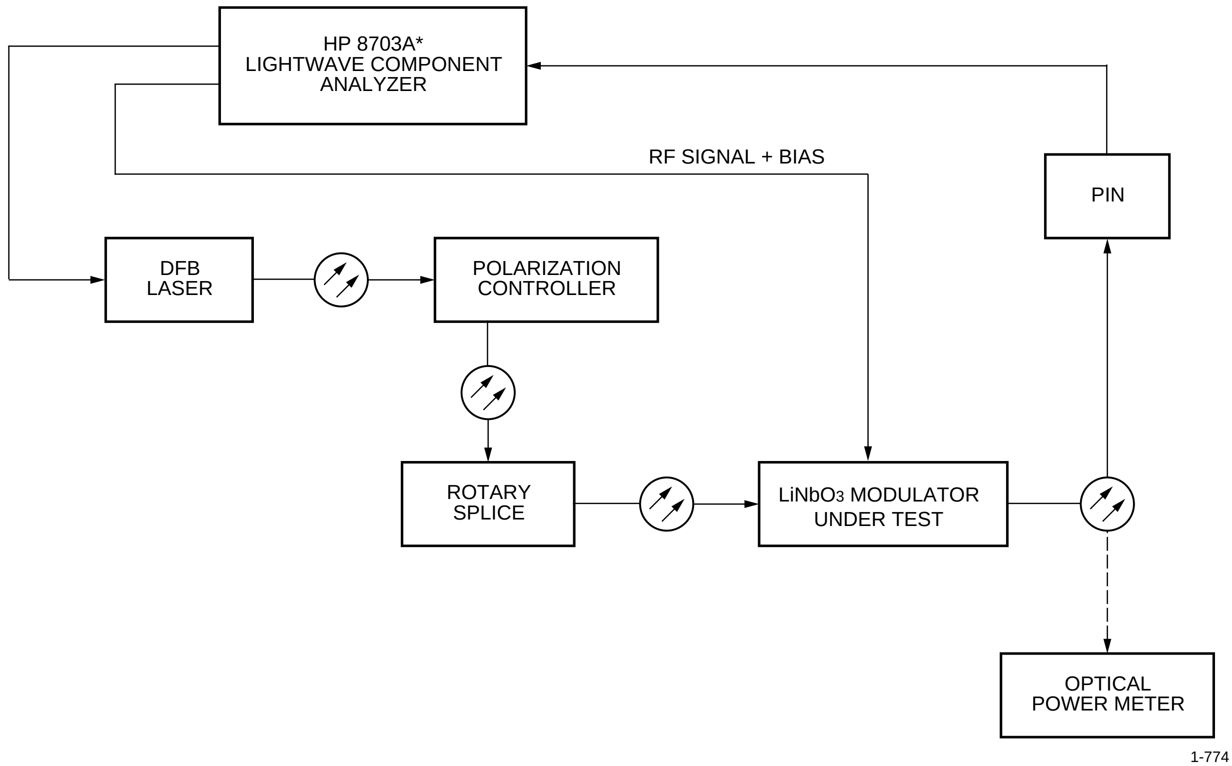

Figure 6. Electrode Layout for Dual- and Single-Drive Modulators

Extinction Ratio

The extinction ratio of an effective modulator should be as high as possible. A clear difference between the optical level of a logic one and a logic zero means that the receiver will have an easier time discerning between these states.

The extinction ratio is measured in the test set as a dc parameter. With no RF data signal present the dc voltage on the modulator is varied and the power output is monitored with an optical power meter. At the lowest power level recorded, the polarization is adjusted with the controller to minimize the value. Then, the voltage is elevated to the maximum power level value and the ratio in levels is used to calculate the extinction ratio.

Input Requirements (continued)

Bandwidth

By definition, the bandwidth (BW) is the E-O-E frequency response of the modulator. Ideally, a modulator will exhibit a flat response up to a certain frequency and then gently roll off. There should be no major peaks and valleys before the 3 dB roll-off point. In real applications, however, modulators always show structure.

At low frequencies, there are ripples due to acoustic resonance of the package. At higher frequencies the 'walk-off' effect caused by different propagation speeds of the electrical and optical signals in their respective transmission lines causes unwanted phase changes.

The test set shown in Figure 6 (HP8703A) measures frequency response from 130 MHz to 20 GHz. For CATV applications, the response at frequencies below 130 MHz is important, so an additional, slower, component analyzer (HP8702A) is used. The second test is run from 40 MHz to 1.6 GHz. The analyzers have only a single-ended output, and typically response is reported for the A side of each device. The input RF power is 0 dBm or ~0.63 Vp-p. During the test the dc bias is adjusted for optimum output power. A typical plot of the result is shown in Figure 7. The vertical axis is optical power at 3 dB/div. and the BW is shown as 8.4 GHz. The modulator for this test was the 2623 type. This uses a 4 cm electrode and is rated for a minimum BW of 8 GHz. The structure of the response up to the 3 dB point is fairly smooth with any local variations being well less than 1 dB.

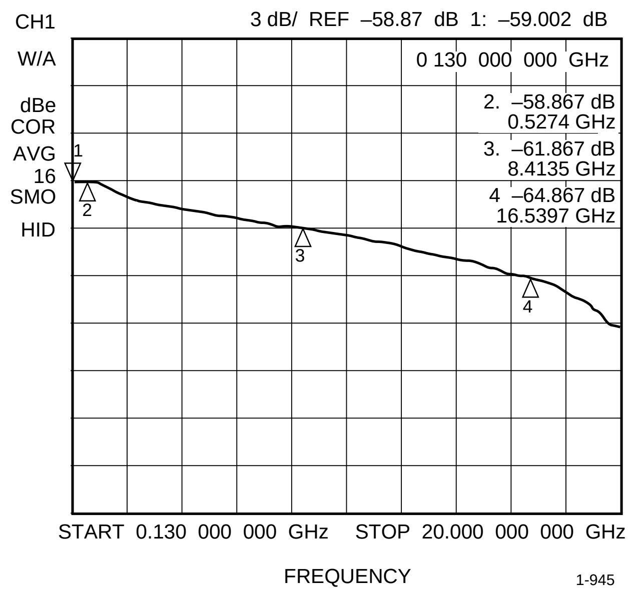

Figure 7. Magnitude of Electro-Optic Response (0.130 GHz to 20 GHz)

S11

The S11 parameter is a measure of the electrical back reflection from the inputs of the modulator. Depending on the application, this value may be critical as back reflections can create unwanted distortion in the signal. This is especially true for CATV applications. Any reflections should be at least 15 dB down over the operating BW of the device. The physical coupling of the incoming signal to the modulator electrode and the design of the travelling wave electrode impedance are critical to minimizing reflections.

A typical response for the 2623 type modulators is shown in Figure 8. The vertical axis is 5 dB/div. Below 4 GHz the reflections are all less than 15 dB. This is another test that is part of the standard tests capable of being performed by the component analyzer in the set up of Figure 6.

Input Requirements (continued)

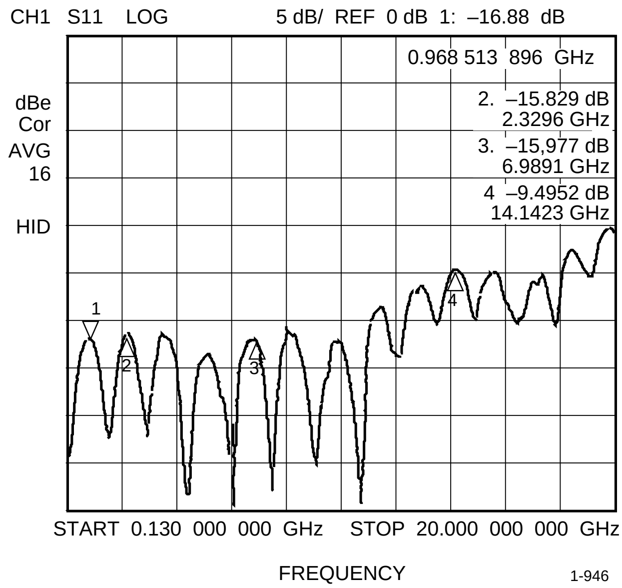

Figure 8. S11 (0.130 GHz to 20 GHz)

Vπ

The Lucent modulators use an Mach-Zender interferometer design to modulate the optical signal. A voltage is applied so that the total phase shift between the two branches of the interferometer to 180° (π radians), causing the light to interfere destructively resulting in minimal transmission. The amount of voltage needed to shift the phase in one branch by π radians from the maximum to the minimum transmission value is defined as Vπ, or swing voltage.

Plotted against optical power output this voltage is a sinusoidal varying function as shown in Figure 9. Again, the benefit of the dual drive design is that only 1/2 the voltage needs to be applied to each of the branches to get the full 180° phase shift. In general, Vπ becomes greater as the frequency increases. This is due to attenuation of the microwave signal in the electrodes, and also to walk-off from the different speeds of propagation of the electrical and optical signals. A well designed modulator must strike a balance between a long electrode, which lowers Vπ, and a short electrode which gives a good high-frequency response

A suitable test set up to measure high-frequency Vπ is shown in Figure 10. Typical dc values for a single-sided, 8 GHz device are around 2.9 V, increasing to about 4.0 V at 2.5 GHz.

Input Requirements (continued)

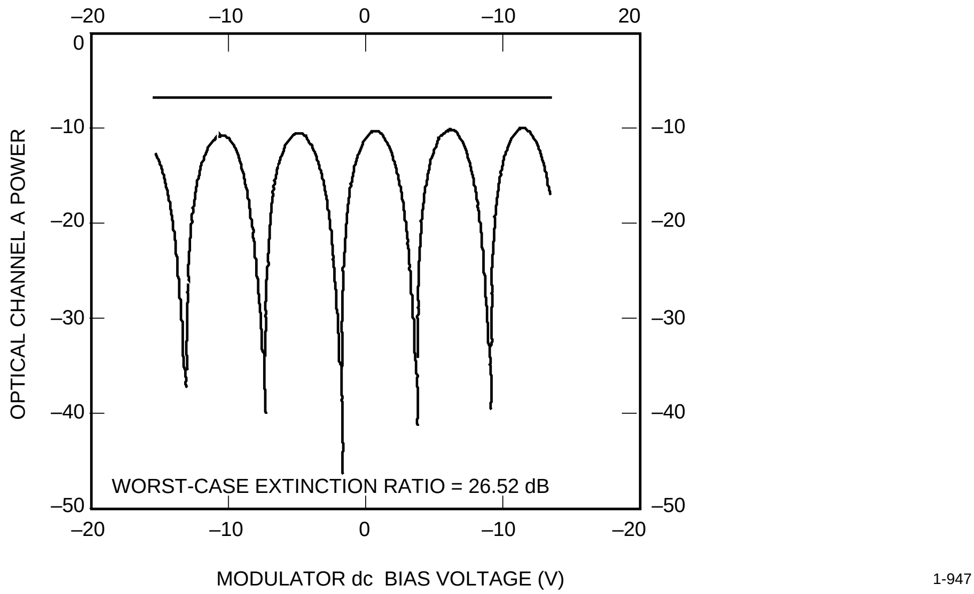

Figure 9. Optical Output Power vs. Bias Voltage

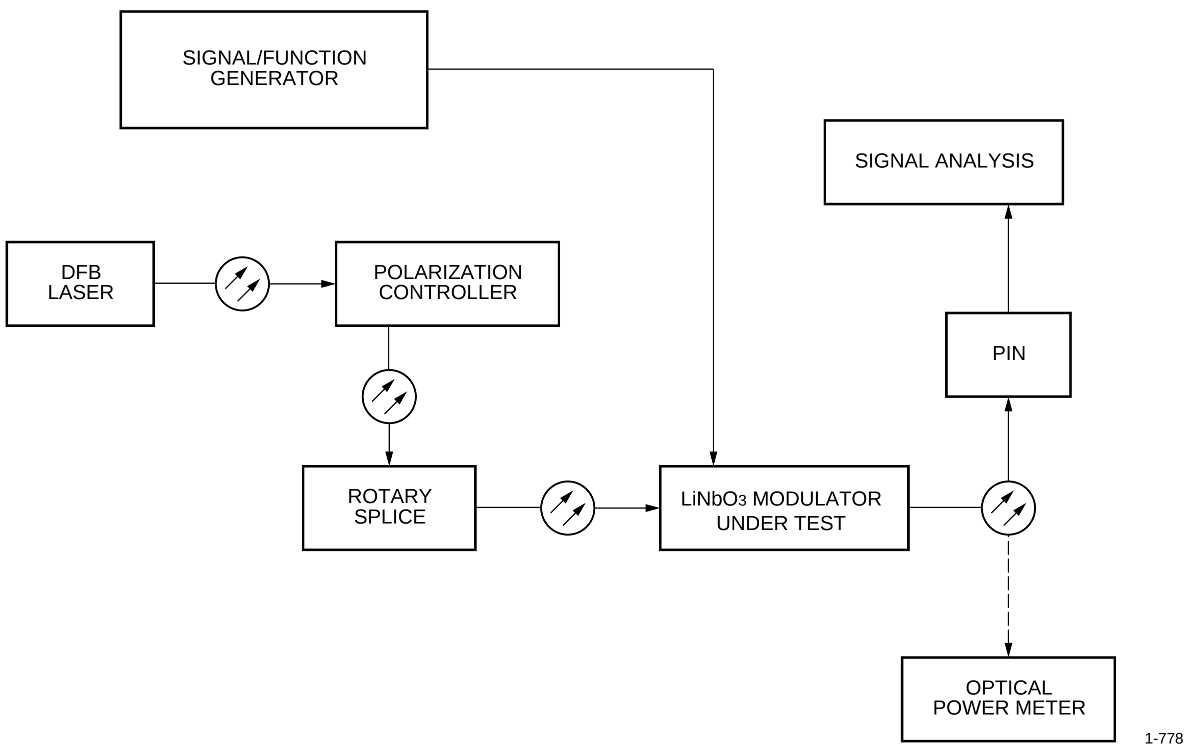

Figure 10. Test Set for Measuring VΠ and Draft/Stability

Mounting and Handling Instructions

Care should be taken on the physical interface to the RF inputs. Because of the high speeds involved, it is important to match the impedance and minimize the reflections as much as possible. Rigid coax with SMA connectors is best used for the connections. Do not exceed a torque of 8 in/lb. when making these connections.

Although the modulator itself has no active components inside (i.e., silicon ICs), care must be taken to prevent ESD and other electrical stress, otherwise delicate electrical structures inside the package can be damaged. When the modulator is not being used the inputs for the RF and the dc bias should be shunted to ground. The easiest way to do this is to use the shorting connectors that Lucent ships with each device. When using the modulator, any unused inputs should always remain shunted to ground.

It is also possible to damage internal blocking capacitors or resistors with improper loading. The dc bias should not exceed 20V on any of the bias electrodes. For models 2613 and 2623 the dc bias must not be placed on the RF input ports or the output ports.

All Lucent modulators can be physically attached to a board using screw holes located on the underside of the package. The holes require #2-56 screws. Care should be taken during attachment to avoid unnecessary warpage of the package.

Lucent can ship the modulator with keyed FC connectors. The key is lined up with the polarization as shown in Figure 11. If the connectors are used, make sure this orientation lines up with the FC connector on the laser's pigtail. As an alternative, the input fiber can be spliced into the fiber coming from the optical laser source. Assuming both pieces are PMF, the best thing to do is to use a reliable fusion splicer designed for PMF such as the Fujikura FSM-20PM or equivalent. Using this splicer the fibers are viewed transversely via an optical beam, rotated until their polarization axes are aligned, and subsequently spliced. Once the splice is complete, the fiber can be treated the same as normal fiber. Care should be taken not violate the minimum bending radius (2 in), and the fiber should not be kinked or pinched since this can change the polarization of the fiber and increase insertion loss.

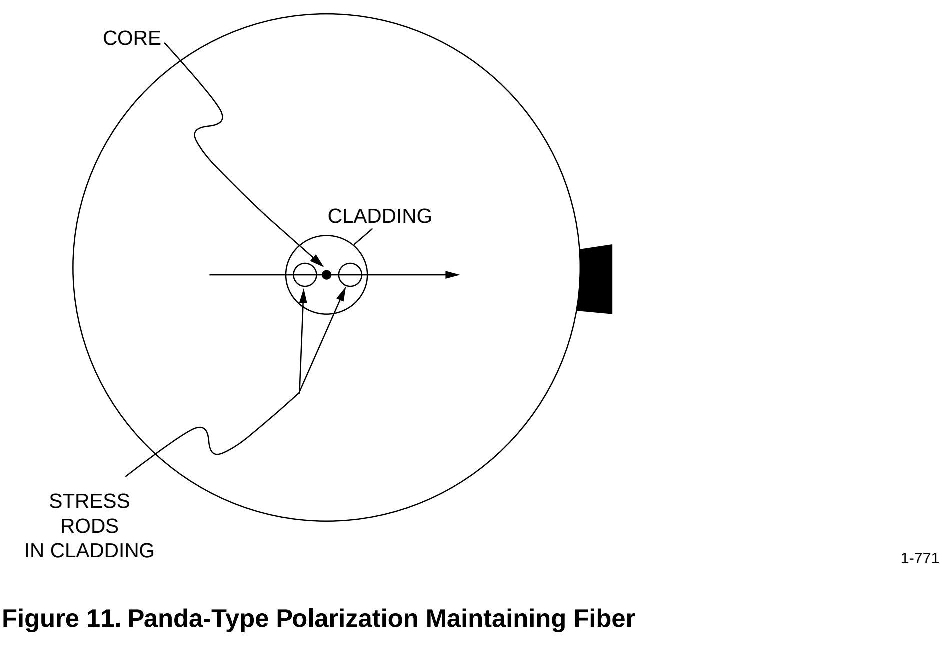

Figure 11. Panda-Type Polarization Maintaining Fiber

List of Abbreviations

$LiNbO_3$	Lithium Niobate
CATV	Cable Television
PMF	Polarization Maintaining Fiber
RF	Radio Frequency
RIN	Laser's Relative Intensity Noise
FORCE	Fiber Optic Regenerator Chip Ensemble
dB	Decibel
CNR	Carrier to Noise Ratio
SM	Single Mode
$V\pi$	Voltage Swing to Maximize Optical HI and LO
S11	Amount of Electrical Reflection from the Modulator Inputs
PIN	Positive-Intrinsic-Negative Photodiode
BW	Bandwidth
ESD	Electrostatic Discharge

Referenced Documents

Lithium Niobate SLIM-PAC Electro-Optic Modulator, Data Sheet (DS96-135LWP), July 1996.

Integrated Optical Circuits and Components, Lynn D. Hutcheson, Marcel Dekker Inc., 1987.

Optical Physics, S.G. Lipson & H. Lipson, Cambridge Univ. Press, 2nd Ed. 1981.

LTU-TX Modulator and Driver Controller System Description, Engineer's Notes, J.

H. Murdock, Lucent Bell Labs, December 23, 1993, Proprietary.

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