Low Cost Fiber Optic Teaching Aid with Wide Dynamic Range Optical Power Meter and Bandwidth Analyzer

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Abstract—**Fiber optic communication technology is an essential component in any Electrical Engineering curriculum. Unfortunately the expensive fiber optic communication equipment is a major drawback in teaching fiber optics theories and principles especially in the 3rd world countries. This paper presents a development of a low cost Fiber optic power meter and a bandwidth analyzer to be used in laboratories as a teaching aid. Both power meter and analyzer are designed to operate at 850nm, 1310nm and 1550nm optical wavelengths. Analyzer measures the bandwidth of a modulated optical signal up to 500 MHz. The logarithmic amplifier enhances the power meter dynamic range. The cost of the product is less than 100 US dollars at small scale production and can be further reduced if mass produced.**

Keywords—Fiber Optic Communication; Optical Power Measurements; Optical Signal Bandwidth Analyzer; Low Cost; Teaching aid

I. INTRODUCTION

Fiber optic communication theories and principles are essential in any Electrical Engineering course curriculum. Regrettably the expensive fiber optic equipment is a major drawback in teaching fiber optic technologies [1].The development of fiber optic teaching aids at low cost is a timely requirement for the benefit of fiber optic education. Optical power, Bandwidth and Dispersion measurements are the main concepts in any subject relevant to Fiber optic communication.

Measuring the optical power is an ideal way to determine the connectivity and attenuation in optical fibers. Optical signal bandwidth analyzing is a key measurement due to its ability to reveal the characteristics of the optical light source and the relationship between optical and electrical bandwidths. The measurement of dispersion is also a critical factor that should be properly managed for effective communication [2].The effect of attenuation and dispersion through optical fibers varies with the wavelength used for the optical communication. In the telecommunication wavelength spectrum the second window (1310 nm) region and third window C brand (1550 nm) are used due to the low attenuation and dispersion [3]. Therefore it is significant to design optical equipment to operate on these wavelength regions. Wide dynamic measurement range and reasonable accuracy should be major objectives during the design process [4]. Considering the optical power measurements, both absolute and relative measurements are possible. Absolute measurements are difficult and costly. The difficulty is collecting all the light appears. But relative optical power measurements and subsequent calibration respect to a reference is an easy and effective design concept [5].

An optical metering system consists of an optical detector which converts an optical signal into an electrical signal. A Germanium (Ge) or an Indium-Gallium-Arsenide (InGaAs) detector can be used for infrared signal measurements up to approximately 1.8 μm [6]. Optical measuring systems include a computing system which calculates the optical power or energy represented by the electrical signal. Calibration is a crucial step in obtaining accurate optical power measurements. In order to accurately obtain an absolute measurement, a meter must be calibrated against an accepted reference [7].

II. DEMONSTRATABLE CONCEPTS

By employing this design of Fiber optic power meter and Bandwidth Analyzer, optical power measurements and optical bandwidth analyzing can be performed. Using this equipment demonstration of following main concepts in fiber optic theories is possible.

A. Carrier Life Time of an Light Emitting Diode

The carrier life time is one of the most important operating parameters of an electro-optic device. In general, the excess carrier density (n) of a LED decays exponentially due to recombination with time (t). According to,

$$n=n_0e^{-t/\tau} \qquad (1)$$

Where n_0 is the initial injected excess electron density and the time constant τ is the carrier life time. The rate equation that generates carrier density in the active region is given by (2).

$$dn/dt=I/V-n/\tau \qquad (2)$$

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Where I is the supplied current, V is the volume of the active region. The approximate photon generation rate due to spontaneous emission is given by n/τ [8]. The light output power (P) of a LED behaves as in (3).

$$P \propto n/\tau \tag{3}$$

By solving (2) for a sinusoidal current input (I) given by $I=I_0e^{j\omega t}$, the output power $P_{(\omega)}$ is given by (4).

$$P_{(\omega)}=P_0/\sqrt{(1+(\omega\tau))} \tag{4}$$

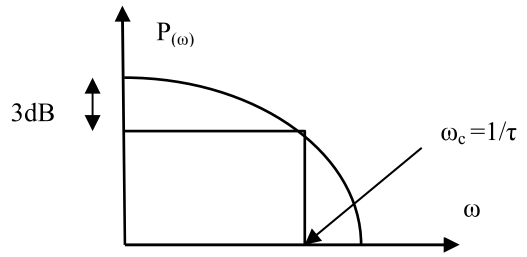

Fig.1. Carrier Life Time calculation of an LED

For most LEDs Bandwidth is less than 500MHz.Therefore, the (4) can be utilized to find out the carrier life time (τ) of a LED by measuring 3dB Bandwidth of the response as in Fig.1.

B.Dispersion Calculation

Pulse broadening due to intermodal dispersion results from propagation delay differences between modes within a multimode fiber. Using the ray theory model the fastest and the slowest modes propagating in the step index fiber may be represented by axial ray and an extreme ray as in Fig.2 [9].

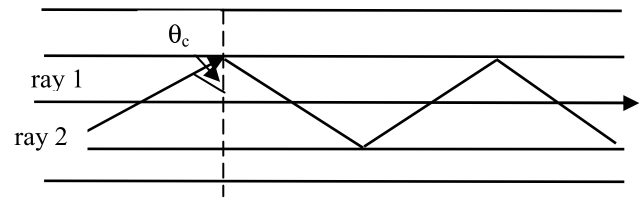

Fig.2. Ray theory model for Intermodal Dispersion

When the waveguide length is L, the difference between refractive indexes of core and the cladding is Δn and the Velocity of light is C, the delay time (Δt) due to intermodal dispersion is given by (5).

$$\Delta t = L\Delta n/C \tag{5}$$

Δn can be estimated using the Numerical Aperture from the fiber specifications.

The Dispersion parameter is very influencing because it can create Inter Symbol Interference in data transmission as seen in Fig.3.Intermodal dispersion may be reduced by propagation mechanisms with in practical fibers [10].Therefore initial measurements of dispersion is crucial. The bandwidth analyzer of this design is capable of analyzing the dispersion of the transmission by measuring the corresponding electrical signal of the transmitted optical signal.

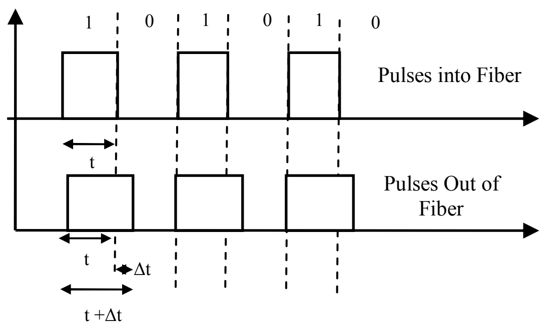

Fig.3. Intermodal Dispersion for a pulse stream

C. Relationship between optical bandwidth and electrical Bandwidth

The modulation bandwidth of an optical source can be defined in either electrical or optical forms. Normally, electrical terms are used because the bandwidth is actually determined via the associated electrical circuitry. Therefore the modulation bandwidth is defined as the frequency where the electrical signal power has drops to half of its lowest DC frequency. Electrical power is proportional to square of the current but the optical power is proportional directly to the electrical current [8].Therefore,-3dB optical Bandwidth point corresponds to -6dB electrical Bandwidth point as shown in Fig.4.

The Bandwidth analyzer integrated in the design can be deployed for laboratory experiments to identify the electrical bandwidth of a modulated LED and hence determine the relevant optical bandwidth. The misunderstanding of these bandwidth concepts of the two forms of signals is a common mistake by many students. The package capacitance of an optical source can also be discovered using this bandwidth analyzer provided it's within the measuring range of the device.

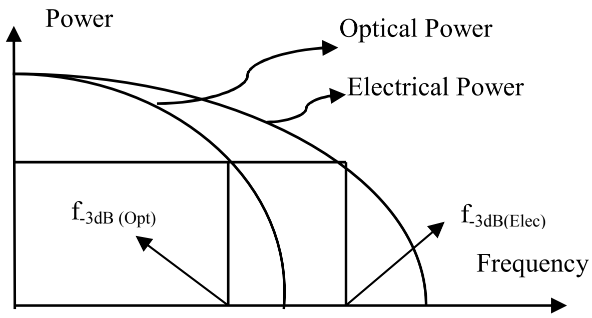

Fig.4. Relationship between Optical and Electrical Bandwidths

III.METHODOLOGY OF THE DESIGN

The development of the optical power meter has employed a logarithmic amplifier that results a very wide dynamic measurement range and higher accuracy. The design of the bandwidth analyzer is based on high frequency design techniques.

A. Optical Power Meter

The usage of logarithmic processing in the analog domain is significant in the design process. With this approach a wide dynamic range can be achieved and simultaneously transformed to a decibel representation. Therefore this allows users to obtain a very wide dynamic range of measurements [11]. A block diagram of the power meter design can be seen in Fig.5

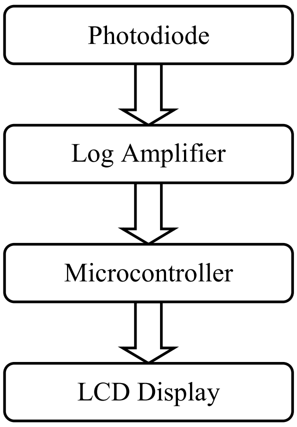

Fig.5. Block Diagram of Optical Power Meter Design Methodology

The photodiode used in the design is ETX100RST by JDS Uniphase Corporation. The main advantage of this photodiode is the integration of photodiode with ST connector receptacle. A 100 µm diameter InGaAs PIN photodiode is mounted inside the Sleeve of an industry standard connector receptacle. This will eliminate the optical loss due to misalignment of components. The other main advantage is the approximately high responsivity (0.8 A/W) of the photodiode for 1310nm and 1550nm optical wavelength. The responsivity for the 850nm light is around 0.2A/W in this photo detector [12].

The logarithmic processing is performed by Analog Devices AD8304 logarithmic amplifier. This is a trans linear logarithmic amplifier which takes advantage of the inherent logarithmic relationship between the collector current of a transistor and the resulting base-to emitter voltage. Eight decades of input currents ranging from 1nA to 1mA can be processed using the IC [13].

The Microcontroller used for the design is ATmega328 which process the analog voltage output from the logarithmic amplifier and converts into digital formats to be displayed in the Liquid Crystal Display. The voltage input is averaged using integration over time to obtain a more stable measurement for time varying optical signals. The integration time period of the design is approximately 2 seconds and can be made to select by the user. The currently operating wavelength and the measured optical power in dBm are displayed using the LCD display.

B. Bandwidth Analyzer

The analyzer design to view the bandwidth of optically modulated signals requires high frequency design techniques. This requires specialized skills and concentration. The base frequency for the design is 500MHz. Texas Instrument Trans impedance amplifier OPA659 possess a sufficient Gain Bandwidth for this purpose.

The high speed InGaAs photodiode used to capture the modulated optic signal is EPITAXX ETX 300T by JDS Uniphase Corporation. This photodiode has high responsivity at 1310nm and 1550nm and sufficient responsivity at 850nm.The device operates up to a Bandwidth of 500MHz.The output from the analyzer circuit can be observed using the spectrum analyzer or oscilloscope. Block Diagram of Bandwidth Analyzer design is shown in Fig.6.

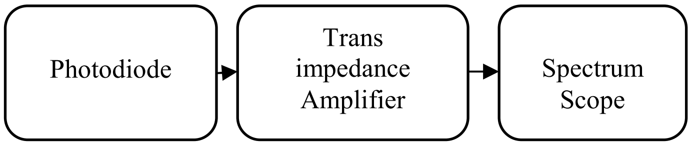

Fig.6. Block Diagram of Bandwidth Analyzer Design

C. Calibration & Testing

The optical power meter was calibrated for 850nm, 1310nm and 1550nm wavelengths. A standard laser source and a standard optical power meter were used. The usage of the Optical laser source was to generate the signals in required wavelengths. One wavelength is considered at a time in calibration. Single mode fiber optic cable and connectors were used to connect the laser source and the power meters. The same fiber cable and connectors were used during the process. Optical power displayed by the standard power meter and designed power meter was matched in the calibration process. The method of Calibration of optical power meter is shown in fig.7.

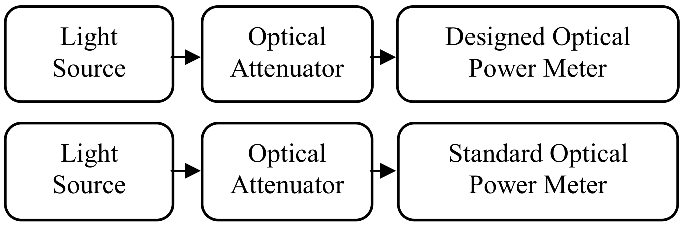

Fig.7. Calibration of the Optical Power Meter

The calibration of the Bandwidth Analyzer was also very crucial since the effect of the device frequency response should be eliminated for reliable and accurate bandwidth measurements. An optical power source that can generate modulated optical signals up to 1GHz was used for calibration of the Bandwidth Analyzer. The Corresponding Electrical signal power for the input optical signal power was recorded during calibration. The effect of the device's frequency response can be eliminated by compensating the frequency response of the photo detector and electronic circuitry. The method of Calibration of Bandwidth Analyzer is shown in fig.8.

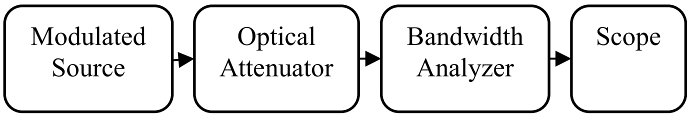

Fig.8. Calibration of the Bandwidth Analyzer

1) *Optical Power Meter Performance*

The power meter was tested by varying the optical power of the light source from its highest optical power available to the lowest optical power achievable by using the optical attenuator and the light source. One wavelength is considered at a time during testing.

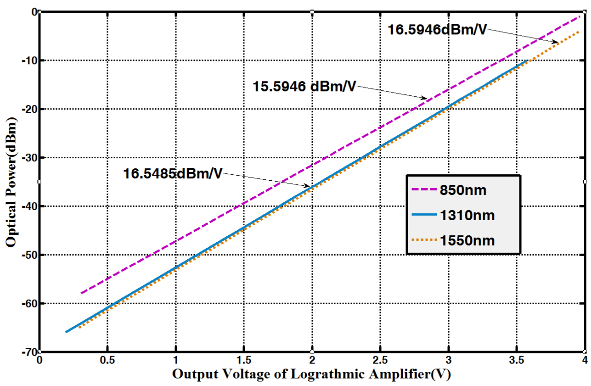

Fig.9. Relationship between Optical Power received at the photodiode and output voltage from the logarithmic amplifier

The output voltage from the logarithmic amplifier is recorded for the corresponding optical power inputs as in Fig.9. This procedure is performed for 850nm, 1310nm and 1550nm respectively. The highest slope of 16.6dBm/V is recorded by 1550nm light since the InGaAs photo detector creates the highest responsivity for 1550nm wavelength. The responsivity of the photo detector for 1550nm light is approximately 0.8A/W. Optical light of 1310 nm wavelength generates a slightly low responsivity on the InGaAs photo detector compared to 1550nm resulting a slope of 16.5dBm/V. The differences in responsivities are reflected in the graph in Fig.9 that gives rise to an offset in the output voltage for a given optical power. The graph exhibits a linear relationship between optical power and the output voltage of the logarithmic amplifier.

The wide dynamic range of the designed optical power meter for the three optical bands is evident from the Fig.9. The measuring accuracy depends upon the logarithmic processing in the analog domain and the resolution of the integrated Analog to Digital Converter of the microcontroller. The resolution of the ADC is 8 bits and encodes the analog input voltage at 256 levels. The power meter circuitry uses decoupling capacitors to reduce noise pickup. The measuring features of the optical power meter for the operating wavelengths can be summarized as in Table 1.

TABLE I. FEATURES OF THE OPTICAL POWER METER DESIGN

Optical Wavelength	**Measurement Range**	**Measurement Accuracy[14]**
850 nm	-63dBm to 6.9 dBm	0.1dB
1310nm	-69.36dBm to 3dBm	0.1dB
1550nm	-70dBm to 2.5 dBm	0.1dB

2) *Bandwidth Analyzer Performance*

The output of the modulated light source is connected to the input of the analyzer circuit. The output from the analyzer circuit which is a high Frequency electrical signal is analyzed using the spectrum analyzer.Fig.10 shows the output signal power of the analyzer against the input optically modulated signal frequencies. By considering this graph it is obvious that the analyzer has a frequency response of nearly 500 MHz. When the frequency increases the optical signal output power decreases due to the bandwidth of the photodiodes and the subsequent electronic stages. The response was flattened calibrating against a standard modulated optical source.

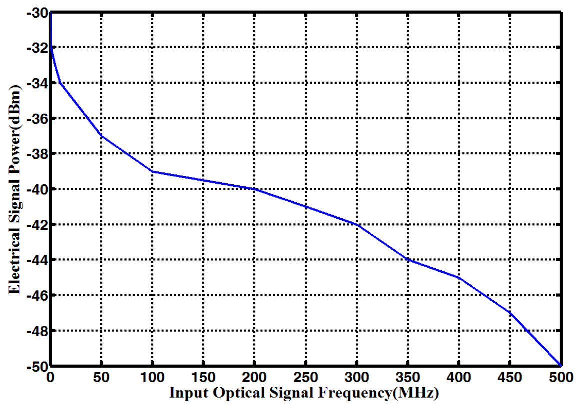

Fig.10. Frequency Response of the Bandwidth Analyzer

IV.ADVANTAGES OVER OTHER DESIGNS

Due to the features of wide dynamic measurement range and high accuracy of the power meter, it can be effectively used as a substitute for commercially available power meter in the market at measurements less than 0.1dB accuracy. Other features such as bandwidth analyzing, measurement logging to memory card and very portable design adds more value to the device. The achievement of these features for the product cost is just below 100 US dollars is a proficient accomplishment. The production cost can be reduced further by producing in mass quantities elevating market demand further.

V. CONCLUSIONS AND FURTHER WORK

This design will be fulfilling a requirement especially in the fiber optic communication laboratories for educational purposes and for the telecommunication industry. Students, scientists and other personnel who engage in research and experimental activities are benefitted by this product.

There are some limitations in this design. The responsivity of the large area INGAAS photodiode used for the power meter is about 0.2A/W for 850nm wavelength. Therefore the dynamic measuring range is lower in the 850nm measurement which is a limitation. To overcome this drawback a separate silicon photo detector can be employed for 850nm light which offers about 0.5A/W responsivity. The accuracy of the optical power meter stands at 0.1dB.This is due to the law conformance of 0.1dB of the Logarithmic amplifier used [14]. The accuracy can be further improved if a logarithmic amplifier with better law conformance can be used. Therefore the limitations of the optical power meter are due to the limitations of both optical detection and electronic processing.

The frequency range can be analyzed by the Bandwidth Analyzer is in the range of 500MHz.This limitation is due to the electronic processing. Usage of a special high speed Trans impedance amplifier IC with a high Gain Bandwidth Product will expand the frequency span of the analyzer circuit enabling wider bandwidth analyzing. The spectrum analyzer or high speed oscilloscope can be used to view the bandwidth of the measured signal. Implementation of an integrated graphical LCD for the product could facilitate the user with viewing Bandwidth with in the equipment.

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