Low Cost Optical Power Meter and Bandwidth Analyser with Wide Dynamic Range

Conference Paper · December 2014

2 authors:


Yasantha Samarawickrama
Colombo International Nautical & Engineering College


Rohana Thilakumara
Sri Lanka Institute of Information Technology

Low Cost Optical Power Meter and Bandwidth Analyser with Wide Dynamic Range

Yasantha C. Samarawickrama[#1],Rohana P. Thilakumara[#2]

Department of Electrical Engineering,Sri Lanka Institute of Information Technology, New Kandy Rd,Malabe,Sri Lanka

[1]yasantha.s@sliit.lk,[2]rohana.t@sliit.lk

***Abstract*—Fiber optic communication is a booming technology in the field of telecommunication due to the advantages over traditional communication systems. It is a timely requirement to produce optical equipment at low cost and reasonable measurement accuracy. This research is about designing of an optical power meter and analyser that can be used in laboratories for educational experimental purposes and for optical signal power measurements to troubleshoot connectivity of optical links. Analyser measures the bandwidth of a modulated optical signal up to 500MHz.Both power meter and analyser can be used for 850nm, 1310nm and 1550nm optical wavelengths. Photodiodes, Logarithmic conversion amplifiers, Trans impedance amplifiers are the main components used in the design. Integrated power meter and analyser, low cost, reasonable measurement accuracy and data logging capability are outstanding features.**

***Keywords*—Fiber Optic Communication, Optical Power Measurements, Optical Signal Bandwidth Analyser, Photodiodes, Logarithmic Amplifiers**

I. INTRODUCTION

Fiber-optic communication can be introduced as a way of transmitting information from one place to another by sending pulses of light through an optical fiber. The total internal reflection quality of light is used to transmit data through the Fiber optics. The light forms an electromagnetic carrier wave that is modulated to carry information. Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies.The effect of attenuation and dispersion through optical fibers differs with respect to the wavelengths we are using for the optical communication. Therefore wavelength regions which have less attenuation over distance are used for the optical communication. In the telecommunication field the second window (1310 nm) region and third window C brand (1550 nm) are used due to the low attenuation and dispersion over the distance [1].

Measuring the optical power is an ideal way to determine the attenuation in optical fibers. The most basic fiber optic measurement is optical power from the end of a fiber. This measurement is the basis for loss measurements as well as the power from a source presented at a receiver [2].This research is about a design of an optical power meter and analyzer as a Solution for high cost and the low accuracy in the current market optical measurement equipments.This design can be Used in the telecommunication laboratory experiments as well as in the telecommunication industry for end to end power measurements of a fiber link. The bandwidth analyzing function for a modulated signal that propagate through fiber or any other external optical signal is also added to the design. The optical bandwidth analyzer is integrated with the optical power meter. This analyzer is used for analyzing modulated optical signals. By identifying the bandwidth of a modulated optical signal and thereby clarification of optical source characteristics at the transmitting end can be done.

II. RELATED WORK

Optical measurements grow increasingly complex due to wide dynamic range of measurements and high frequency. To make reliable measurements, the characteristics and interactions of light signals as well as optical-to-electrical signal conversion and the interpretation of electrical signals from the sensor should be considered carefully. Thorough consideration on light sources, detector types, calibration uncertainty, detector saturation and noise, attenuation, back reflection, interference, and beam divergence should be paid during the designs.

Optical measurements can be performed with a wide variety of light sources. A light source can be continuous-wave (CW), modulated, pulsed, or even randomly fluctuating. A laser pulse can be as short as several femtoseconds (fs).But it can be modulated as high as hundreds of gigahertz (GHz).Most importantly it can have kilowatts (kW) of average output or Gigawatts (GW) of peak power[4].Considering the optical power measurements, both absolute and relative measurements are possible. Absolute measurements can be difficult or costly due to the difficulty of collecting all the light. But relative optical power measurements with respect to a reference is easy and a cheap design concept. An optical metering system consists of an optical detector, which converts an optical signal into electrical signal. The most common frequently used optical-signal detectors are photodiodes, thermopiles, and pyro electric detectors. Photodiodes function is the conversion of photon's energy to create an electron-hole pair. The current created by the flow of these electrons is proportional to light intensity. Thermopile and pyro electric detectors convert the photon's energy into heat. The heat subsequently generates a voltage or a current[4]. A silicon photodiode detector is used for visible light. A germanium (Ge) or an indium-gallium-arsenide (InGaAs) detector is used for infrared up to approximately 1.8 µm[5].

Optical measuring systems consist of a computing system which calculates the optical power or energy represented by the electrical signal. For this computing system, Trans impedance amplifiers and logarithmic conversion amplifiers are really vital.Transimpedance amplifiers converts the current output from the photo detectors into voltage while logarithmic amplifiers compress the input parameters at the output of a photo detector enabling a wide measurement range with easy processing. The electrical signal parameters that represent the optical signal parameters can be easily analyzed using a programmed microcontroller. The measurements can be displayed or stored in convenient formats. This display can be done in analog or digital output. For example as a data-collection file or a graphical representation. In order to accurately obtain an absolute measurement, a meter must be calibrated against an accepted reference. For absolute measurements, a detector is supplied with its own conversion table is used. This table specifies the relationship between the optical input and the electrical output. This relationship is called the responsivity (R).Responsivity has units of amps per watt or volts per watt.

Calibration is a very critical step in obtaining accurate optical power measurements. Factors such as the calibration method, the calibration equipment, the facility at which calibration is performed and the processes that enforce repeatability affects the Calibration tolerances. Accurately measuring the power of a CW(Continuous Wave) light source is challenging. Measuring a modulated or a pulsed light is even more difficult. Limitations of the detector's response time and speed of the meter's circuitry are very challenging constraints. Record the raw data and then process it with digital filtering or statistical averaging, rather than reading directly from the detector is done frequently to overcome above constraints [6].

III. OPTICAL SIGNAL POWER MEASUREMENT

A. Concept of the optical power measurements

Traditional techniques for determining optical power have utilized a current to voltage converter known as Trans-impedance amplifiers (TIAs).This amplifier is followed by a low pass filter stages. TIA provides an output voltage proportionally to the current received from photodiode. The typical transfer function of a TIA is shown in Fig.1 which describes its limitations in wide dynamic range measurements. But when a decibel (dB) equivalent is desired, it is essential to perform numeric calculation of the base-10 logarithm of the signal. An alternative to this issue is the usage of logarithmic processing in the analog domain. With this approach a wide dynamic range can be achieved and simultaneously transformed to a decibel representation. Therefore most of the modern world optical measurement equipment designers have employed the logarithmic current to voltage amplifiers great deal allowing the users to obtain a very wide dynamic range of measurements [7].

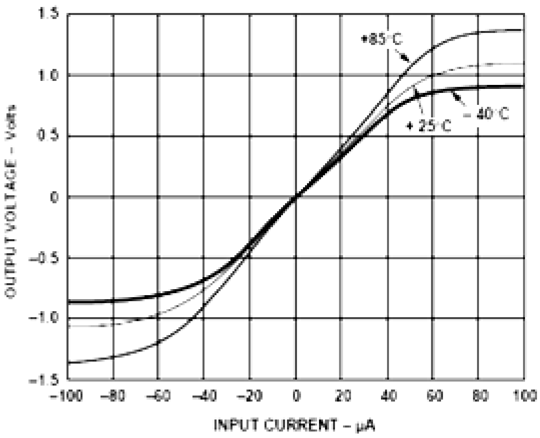

Fig.1 Typical Transfer function of a trans impedance amplifier

The dynamic range limitations of a conventional TIA are obvious. For example, an output voltage swing of 5 V the TIA offers a very less optical dynamic range. For the same 5 V output voltage swing, the logarithmic amplifier provides a very high optical dynamic range with a constant volt-per-dB relationship.

In this optical power meter design Analog Devices AD8304 logarithmic amplifier is used. 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. The basic circuit functions for a single supply application are shown in fig.2.

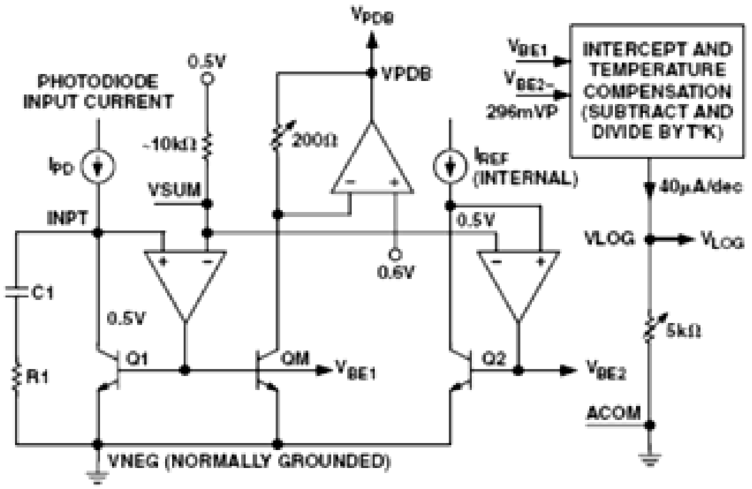

Fig.2 The basic power measurement circuit for single supply application Using AD8304

The input signal current flows into the NPN logging transistor indicated as Q1.This produces a bias voltage (V_{BE}).

$$V_{BE} = V_T \ln(I_{PD}/I_S) \quad (1)$$

Then Q2 generates a second bias voltage using temperature-stable internal reference current (I_{REF}). The highly temperature dependent saturation current is (I_S).This saturation current is Cancelled when two transistors Q1 and Q2 are matched. This can be used to derive the equation 2.

$$V_{BE1} - V_{BE2} = V_T \cdot \ln\left(\frac{I_{PD}}{I_S}\right) - V_T \cdot \ln\left(\frac{I_{REF}}{I_S}\right) = V_T \cdot \ln\left(\frac{I_{PD}}{I_{REF}}\right) \quad (2)$$

$$V_{BE1} - V_{BE2} = V_T \cdot \ln(10) \cdot \log_{10}\left(\frac{I_{PD}}{I_{REF}}\right) \quad (3)$$

$$V_T = kT/q \quad (4)$$

V_T is a temperature dependent term .It can be corrected and re-scaled using maker's proprietary design techniques to provide a final output signal at the VLOG pin.

$$V_{LOG} = V_Y \cdot \log_{10}(I_{PD}/I_Z) \quad (5)$$

When using AD 8304 logarithmic amplifier, compared to this equation V_Y is logarithmic slope which is equal to 200 mV/decade. I_Z is the logarithmic intercept which is equal 100 pA[8-9].

B. Design of the Optical Power Meter

Based on the above mentioned concept for optical power measurements, the design of the optical power meter was performed. The photodiode that was employed in this study was JDSU ETX100RST. The main advantage of this photodiode is the integration of photodiode with ST connector receptacle. A 100 μm diameter InGaAs PIN photodiode is

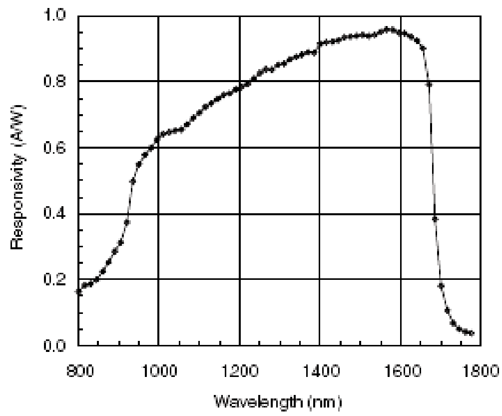

Fig.3 Spectral Response of JDSU ETX100RST

mounted inside the sleeve of an industry standard connector receptacle. When the ST connector is connected to this receptacle, the light emitted from the fiber at ferrule end will match with the active area of the photodiode. This will eliminate the optical loss due to misalignment of these 2 components. The receptacle is also designed for both PCB and backplane mounting.

As seen in from Fig 3, The other main advantage was the high responsibility of the photodiode for 850nm, 1310nm and 1550nm optical wavelengths which are widely used in the fiber optic communications. This enables the power meter to obtain the measurements in main three optical signals that are used with high resolution and wide range of measurements. Typically, the spectral response of photodiode to the light received is not a constant value for all wavelengths. Higher wavelength has higher responsitivity than lower wavelength [10].Analog Devices AD8304 is a trans linear logarithmic amplifier which was introduced previously is used in this study. It is specifically designed for photodiode power measurement applications.

As shown in the Fig.4 the fully function of the optical power meter can be summarized. Optical signal to electrical signal conversion is done by the photodiode. The logarithmic voltage to current conversion amplifier converts the current into voltage while compressing a wide range of the photodiode currents. The optical signal averaging is performed by the microcontroller which is programmed to obtain readings in a pre-configured time period and then average it. The user is given the feature of viewing the calculated optical power real time using the LCD display integrated to the design.

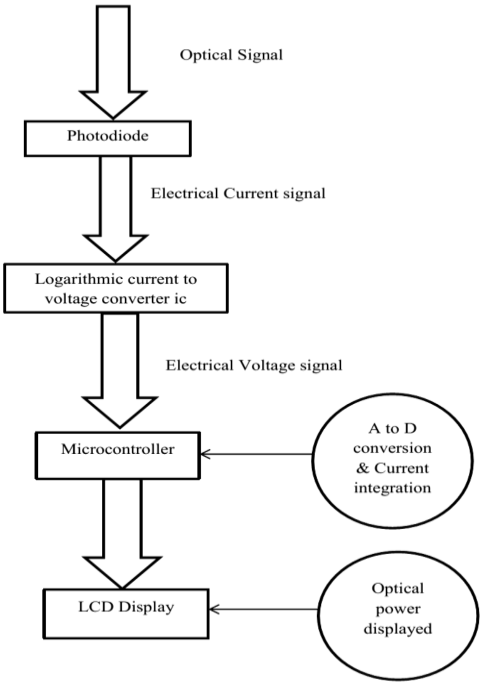

Fig.4 Block diagram of the Optical Power Meter

C. Calculation of the Optical Power

The ideal plot of output V_{LOG} versus I_{PD} is shown in Fig.5.

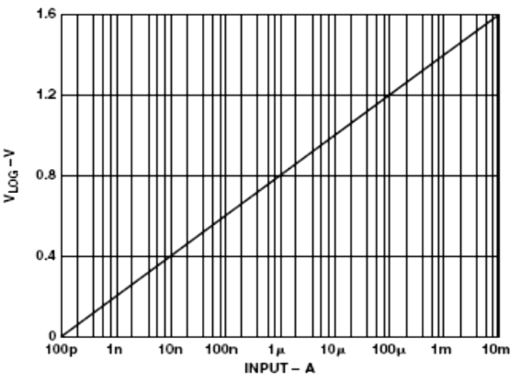

Fig.5 Ideal form of VLOG versus IPD

By considering the above input output graph of the AD8304 IC we can see that 8 decades of input currents can be measured using the ic.Therefore large dynamic range of measurements can be obtained using the logarithmic relationship of this IC. This is an essential feature of measuring equipment. This logarithmic voltage is amplified by a ratio of 3 in order to match the ADC total range. Therefore we can employ the total range of the ADC. For optical calculations the equation (5) derived under A is employed. Using the responsivity, equation (5) can be modified to equation (6).

$$V_{LOG} = V_Y \cdot \log_{10}\left(P_{PD}/P_Z\right) \tag{6}$$

For the AD8304 operating in its default mode, I_Z of 100 pA Corresponds to a PZ of 110 Pico watts. Using analog to Digital Conversion module of microcontroller to read V_{LOG} values and using the above equation the optical power incident on the photo detector can be easily calculated. Averaging of the optical power can be done by the programming the microcontroller to obtain accuracy of the measurements. After designing the optical power meter it was calibrated for 850nm.1310nm and 1550nm wavelengths. Optical laser source that can generate those signals was used for this purpose. Calibration is performed by adjusting the interception of the current to logarithmic voltage output curve. Optical source power is matched with the power displayed in the power meter in the calibration process.

IV. OVERALL PERFORMANCE OF THE POWER METER

The output voltage from the logarithmic amplifier is recorded for the corresponding optical power inputs. A laser source is used which has about 3 different power levels. This procedure is performed for 850nm, 1310nm and 1550nm.Then the optical power that can be detected is plotted against the output voltage from the logarithmic converter IC.

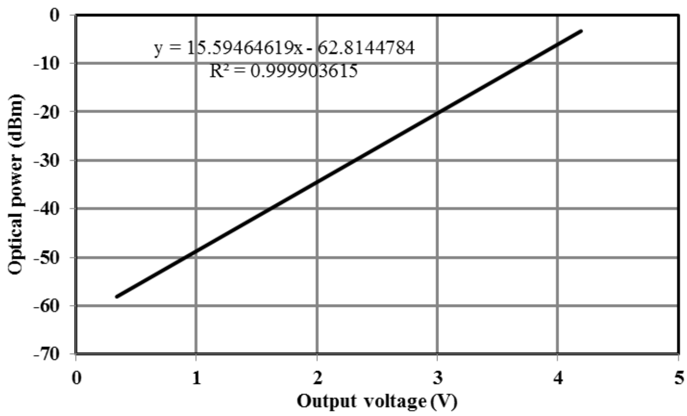

Fig.6 Relationship between optical powers received at photodiode and output voltage from logarithmic amplifier using 850 nm light

As shown in Fig.6 the optical output optical power is obtained using the 850nm light. A linear response is observed. The response has an interception of -62.8144 and a slope of 15.59464.Since 850nm creates a lower responsively for the photodiode than 1310nm and 1550nm light. The slope value obtained here is lower than 1310nm graph and 1550nm graphs and the interception value is also less than Fig.7 and Fig.8 graphs also.

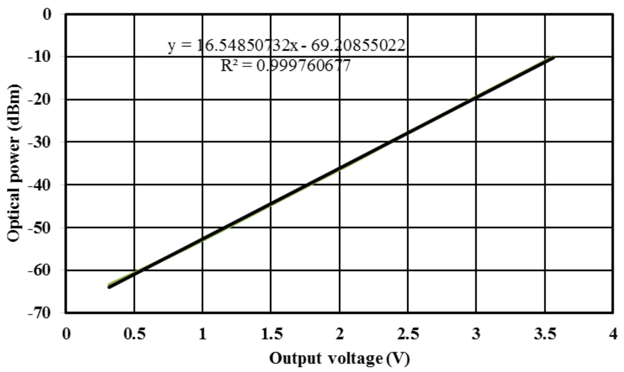

Fig.7 Relationship between optical powers received at photodiode and output voltage from logarithmic amplifier using 1310 nm light.

Fig.7 shows the graph plotted using the 1310nm light. A linear response is observed. The response has an interception of -69.20855022 and a slope of 16.54850.

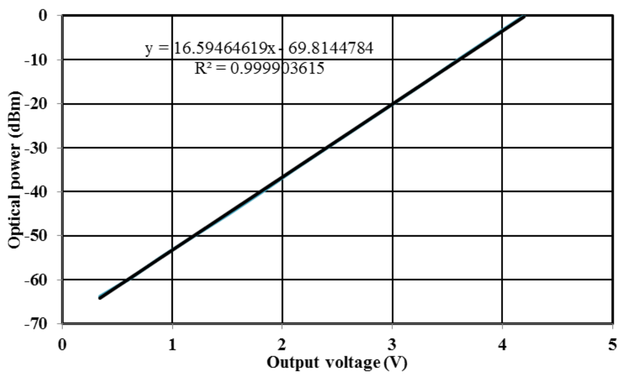

Fig.8 Relationship between optical powers received at photodiode and output voltage from logarithmic amplifier using 1550 nm light.

Fig.8 shows the graph plotted using the 1550nm light. A linear response is observed. The response has an interception of -69.8144 and a slope of 16.59464.Since 1550nm creates a higher responsivity for the photodiode than 1310nm and 850 nm light, the slope value obtained here is larger than 1310nm and 850nm graphs and the interception value is also higher comparison to 850nm and 1310nm graphs. Measurement range of the meter is higher than these ranges in above Fig.6,Fig.7 and Fig.8 graphs. But since the meter is tested only for the available optical powers the graph is plotted in this manner. Actually measureable optical signal power range and the resolution of the device can be seen in the Table1.

TABLE 1
FEATURES OF THE OPTICAL POWER METER

Optical Wavelength	Measurement Range	Measurement Accuracy
850 nm	-63dBm to 6.9dBm	0.001dB
1310nm	-69.36dBm to 3 dBm	0.001dB
1550nm	-70dBm to 2.5 dBm	0.001dB

V. DESIGN OF THE OPTICAL BANDWIDTH ANALYZER

The analyzer design to view the bandwidth of optically modulated signals requires high frequency design techniques which should be performed with plenty of skill and concentration. The base frequency for my design is 500MHz since the used trans impedance amplifier OPA659 possess a Gain Bandwidth Product (GBP) in that range [11]. The high speed photodiode used to capture the modulated optic signal also possess an operating Bandwidth up to 700MHz. Fig.9 shows the schematic of the Bandwidth analyzer circuit that is used in the design.

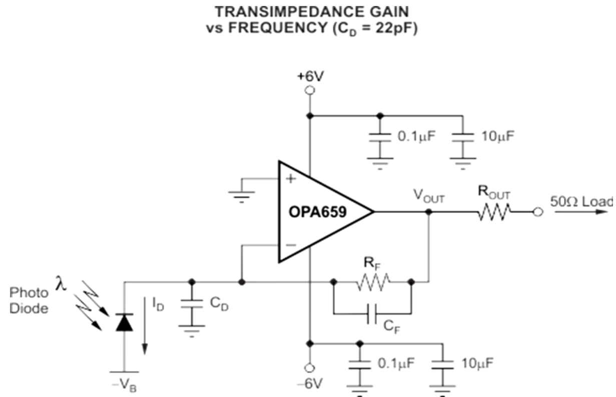

Fig.9 Schematic of the Bandwidth Analyzer circuit

A. *Overall performance of the Bandwidth Analyzer circuit*

To test the analyzer circuit a light source that can be modulated at least up to 500MHz is needed. This design is developed for 850nm, 1310nm and 1550nm light. Therefore the testing should be done for all the three wavelengths. The output from this light source is connected to the input of the analyzer circuit. The output from the analyzer circuit which is a radio Frequency signal is analyzed using the Radio Frequency spectrum analyzer. Spectrum analyzer displays the bandwidth of the optical signal used enabling the identification of the frequency response of the design by plotting the amplitude of the output RF signal against the input signal frequency [12]. 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 considerable frequency response of nearly 500 MHz. When the frequency increases the optical signal output power decreases due to the bandwidth limitations of the electronic devices used in the design.

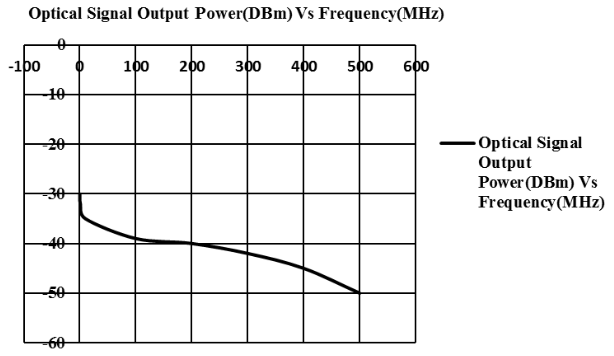

Fig.10 Frequency response of the analyzer for input optical signals

VI. COSTING FOR THE DESIGN

As shown in Table 2 the each and every individual cost incurred for the components and the total actual cost can be found out.

TABLE 2
COSTING FOR THE OVERALL DESIGN

Component	Cost per unit(SLRs)	Quantity	Cost(Rs)
Photodiodes	2500	2	5000
Microcontroller	500		500
LCD module	700	1	700
logarithmic IC	1500	1	1500
High speed op amp IC	500	1	500
Fiber connectors	200	5	1000
Ferrite Beads	800	2	1600
PCB boards(FR4 epoxy)	1000	1	1000
Casing material	1000	1	1000
others	1000	1	1000

Actual Total Cost= Rs.13, 600

Therefore comparing the individual cost incurred for the each components of the design, we can conclude with a total cost of 13,600 Sri Lankan rupees. Comparing the functionalities and advantages of this design this cost is considerably low. When producing in bulk this cost can be reduced further into a very cheaper price which is a marvellous achievement.

VII. ADVANTAGES OVER OTHER DESIGNS

This design is an exceptional achievement compared to current market products which basically do the same function but are very expensive. Due to these facts this product is highly marketable which will attract the customer demand with ease. This low cost of achievement is a timely requirement in the current photonics equipment market because customers are struggling when buying high cost optical equipment for their laboratories and telecommunication companies. The ability to measure the power and analyze the bandwidth up to 500 MHz of three main used optical wavelengths (850nm,1310nm and 1550nm) which are widely used is a very exceptional advantage. Integrated Analyzer with the optical power meter, wide measurement range, high resolution, Portability of the design, long battery life are the other main advantages except for the outstanding advantage of low cost.

VIII. CONCLUSIONS AND FURTHER WORK

The lack of availability of accurate and low cost optical equipment in the Sri Lankan and global market tempted me a lot to design and produce this device. This project will be fulfilling a requirement especially in the fiber optic communication laboratories for educational purposes and for the telecommunication industry. Students, scientists and other persons who engage in researches and practical activities are benefitted by this product. This can be used as the power meter for the end to end power measurements in fiber link testing. Therefore technicians and engineers will be benefited by this project. As this product is made low costly we can offer a low market value. Therefore business people will have a good highly demanded to be sold in their shops.

This product can also be improved further in several ways. Large area InGaAS photodiode is used for the power meter. The responsively of this diode is about 0.2A/W for 850nm wavelength. Therefore the dynamic measuring range is bit lower in the 850nm measurement. To overcome this drawback a silicon photo detector can be employed for 850nm light because it has about 0.5A/W responsivity for 850nm wavelength. Also by using a special high speed trans impedance amplifier IC with a high GBP we can expand the frequency span of the analyzer circuit which would enhance the market value of the product a lot. The spectrum analyzer is used to view the analyzed bandwidth by the analyzer circuit. Implementation of a graphical LCD for product will enhance user friendliness further.

IX. ACKNOWLEDGEMENT

The authors would like to thank the Managing directors and engineers at Sri Lanka Telecom and Dialog Axiata PLC for providing hardware facilities for calibration and testing of the device. Furthermore special thanks go to senior staff of Sri Lanka Institute of Information Technology, Malabe for providing laboratory facilities to accomplish this task.

REFERENCES.

[1] www.researchgate.net. 2014. Why is 1550 nm the most widely used wavelength in optical communication systems?. [ONLINE] Available at: http://www.researchgate.net/post/Why_is_1550_nm_the_most_widely_used_wavelength_in_optical_communication_systems2.

[2] Amaku, A, 2014. Optic Fiber as a Reliable Medium for Metropolitan Area Networking (MAN) Connectivity. International Journal of Engineering and Technology , Volume 4 No. 9, 545,546,547.

[3] Wang , Yajun , 2014. Application of optical fiber sensor technology in building Internet of thing. ournal of Chemical and Pharmaceutical Research,, 6(6):1151-1155 , 2,3,4.

[4] Mitrofanov, A.V, 2012. Physical Methods,Instruments and Measurements. 2nd ed. Moscow,Russia: P.N Lebedev Physical Institute.

[5] Plis, E.A, 2014. InAs/GaSb Type-II Superlattice Detectors. Advances in Electronics, Volume 2014 (2014), Article ID 246769,, All.

[6] Vayshenker, I, 2000. NIST Measurement Services. 1st ed. USA,Washington: Optoelectronic Division,Electronics and Electrical Engineering Laboratary.

[7] Sackinger, Eduard , 2005. Broadband Circuits for Optical Fiber Communication. 1st ed. USA: John Wiley & Sons, Inc.

[8] www.analog.com. 2002. 160 dB Range (100 pA –10 mA) Logarithmic Converter. [ONLINE] Available at: http://www.analog.com/static/imported-files/data_sheets/AD8304.pdf.

[9] Poneprasert, Sira, 2010. Development Of Optical Charachteristics Measurement System For Optical Fiber Coupler Fabrication Using 3-Wavelength Light Simultaneously. Master of Engineering. Electrical Engineering: CHIANG MAI UNIVERSITY.

[10] DSU. 2012. www.jdsu.com. [ONLINE] Available at: http://www.jdsu.com/ProductLiterature/etx100-ds-oc-ae.pdf.

[11] Texas Instruments. 2009. www.ti.com. [ONLINE] Available at: http://www.ti.com/lit/ds/symlink/opa659.pdf.

[12] Thomas, Sibu , 2013. A Study on BASICS OF A SPECTRUM ANALYZER. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering , Vol. 2, Issue 6, 2308,2309.

[13] Sorianello, V, 2009. Guided-wave photo detectors in germanium on optical Chips in silicon on insulator. Journal of European Optical Society, 4, 1,2,3.