REPORT ON

The Design of a Medium Range Digital Communications Bus

Submitted to
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By
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Dear Sir:

In following your directions I have prepared the following report entitled The Design of a Medium Range Digital Communications Bus.

The purpose of this report is to examine the design of a medium range digital communications bus. This report will establish the need for such a system and generate alternative designs other than the design used. Following a brief description of the system, several aspects of the design will be discussed. A general conclusion ends the main body of the report.

Sincerely,

Russell J. Baker

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ABSTRACT

The requirements of the medium range digital communciations bus are that it have four channels each ten kilometers in length and each having a bandwidth of one million bits per second.

A bus of this nature has applications at the Nevada Test Site. This bus could be the means by which information is gathered when a nuclear test is being conducted. Another use for this bus is where communications between two points is limited by a natural barrier such as lakes, mountains and caves.

The design of this bus uses fiber optics. A bandwidth of approximately 63 million bits per second is attained while having a total estimated cost of about $60,000. This estimated cost includes loading, labor and components cost.

Report on

THE DESIGN OF A MEDIUM RANGE DIGITAL COMMUNICATIONS BUS

I. INTRODUCTION

The high technology era has brought about faster ways of communicating information. Sometimes this information must go from point A to point B at a rate of one million bits per second.

The conventional method of transmitting data is through a wire usually made of copper. This method of transmitting data is very slow. With modern advances in communications through fiber optics, high bandwidths can be attained easily.

Fiber optics is basically transmitting information on light waves through a thread-like glass fiber. Through the use of fiber optics a digital communications bus ten kilometers in length will be designed. This bus takes information from four electronic devices, sends the information ten kilometers in distance, at a rate of one million bits per second, to four mini computers, which store the information. The availability of very long optical fibers and inexpensive coherent light sources and detectors makes it possible to construct long distance communication systems of this nature.

This report will examine the need for such a system and alternative designs. It will also discuss fiber optics as the basis for the design.

II. NEED STUDY

A medium range digital communications bus of the nature described has many applications. This section of the report will show the system's usefulness as well as give some examples of where and how a system of this nature could be used.

At the Nevada Test Site nuclear testing is being conducted. Information is recorded for each nuclear test. Trailers that contain recording instruments are moved from one test location to another. Moving the trailers is a slow process because of the sensitive recording equipment located within the trailers. Because of the care that is given to these recording trailers the cost to move them is high. The recording instruments also need power. If the location that the trailers are moved to doesn't have power, then power has to be strung to the trailers or a new power station must be built. The predicted cost per man day is $500.00 . This includes loading costs. If power has to be strung out to the trailers then an estimated four to ten man days may be needed. The cost of cable to feed power to the trailers is approximately $1.00 to $2.00 per meter. If a power substation must be built, then an estimated 50-180 man days are needed and an additional $50,000.00 to $200,000.00 for equipment.

If the trailers were located in a permanent central location a communication system like the one described could be used. For example, a nuclear test is going to be conducted ten kilometers away from the permanently located recording trailers. At the site of the test, four electronic information gathering devices will send the information to the recording trailers through the bus. The rate at which these devices transmit information is one million bits per second. A system like the one described could be used in this example.

Another example of a use for this system could be where a natural barrier makes it necessary for the computers or recording equipment to be separated from the sensors or information gathering devices. Examples of natural barriers are mountains, oceans, or valleys.

The preceding examples are just two of the applications that a digital communications bus may have.

III. ALTERNATIVE SOLUTIONS

The first alternative to the given design would be copper wire. Associated with copper wire is a 3.2 us/km delay for every pulse sent.[1] To achieve a bandwidth of one Megabit per second on each of the four channels, we would need 32 copper wires for each channel, or a total of 128 copper wires. The main problem associated with using copper wires is the interfacing circuitry. The amount of money and time that it would take to design proper interfacing circuitry for 128 wires is great.

Another alternative to the given design would be a microwave communications system. With a microwave communications system the required bandwidth and distance of communication could be attained easily.

There are many advantages of fiber optics over microwaves. Bandwidth of fiber optics is limited to theoretically one terahertz while most transponders have

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[1] Hill and Peterson, Digital systems: Hardware Organization and Design, p. 437.

bandwidths of 36, 54, or 72 MHz. Fiber optics are immune to electromagnetic interference where microwaves are not. If the area where the system needs to be used contains stray electromagnetic waves that may interfere with the microwaves, then this system could not be used. Many natural occurences such as storms and lightening also interfere with the operation of microwave communication systems.

The cost of a microwave system that would perform the requirements of the system would be as much if not more than a fiber optic system.

The last alternative would be to design a different type of fiber optic system. The design that is used is not, by any means, the only type of fiber optic system. There are many different types of fiber optic systems. Many things can be changed, such as the operating wavelength, the number of fibers, the source, the transmitter, or even the type of fiber that is used.

Since the design that is used now is a fiber optic system, the choice of the best alternative would be a different fiber optic system, because fiber optics has already been worked with. To change the design entirely would usually require more time. This fiber optic system would be made in such a way that it meets the design requirements. If a fiber optic system could not be used, then the next choice for the system would be a microwave communications system. The copper wire would be a last resort, used only if the fiber optic and microwave systems failed.

IV. THE BASICS OF FIBER OPTICS

There are three basic types of fibers, single mode, multimode, and graded index fibers. Fig. 1 (a)[2] shows the single mode transmission fiber. Only the light which enters perpendicular to the input surface at the center of the fiber gets transmitted, all other light beams are reflected by the input surface. The multimode fiber is shown in Fig. 1 (b)[3]. The multimode fiber consists of a core material and

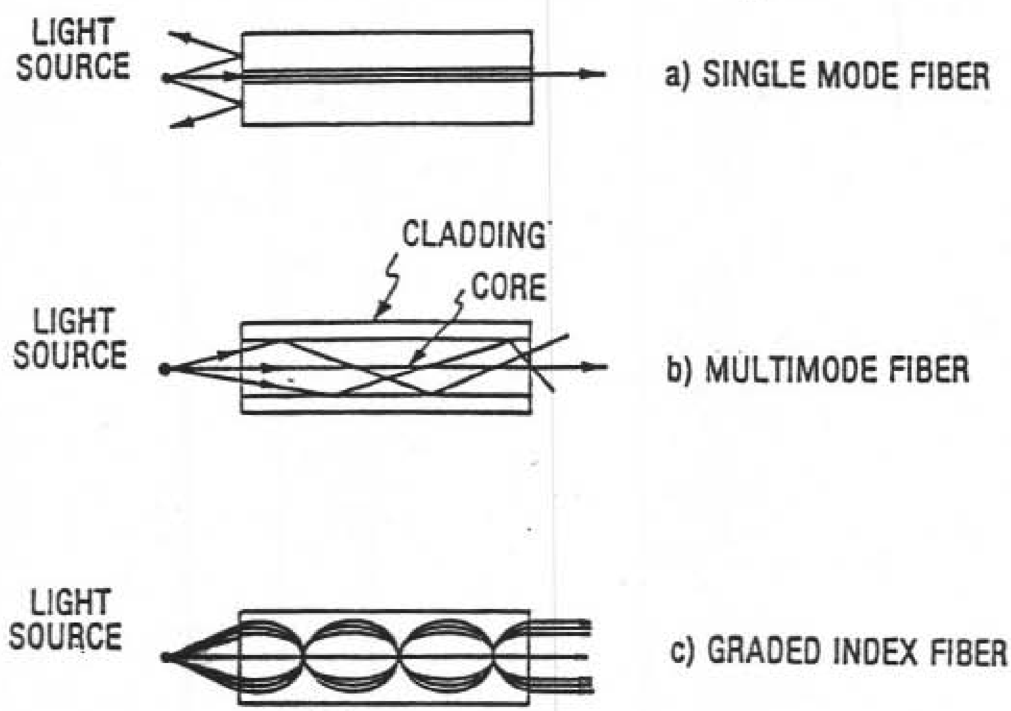

Fig. 1

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2 Buchsbaum, Practical Electronic Reference Data, 473.

3 Ibid.

a cladding which surrounds it. The index of refraction between the core and the cladding is very high. For this reason all of the light beams which strike the cladding at an angle are refracted back into the core. The core material is usually a high quality glass and the cladding may be a different kind of gloss, or plastic, or some other material.

Fig. 1 (c)[4] shows a graded index fiber. The graded index fiber is the fiber that will be used for this design. This fiber provides a gradual transition between the core

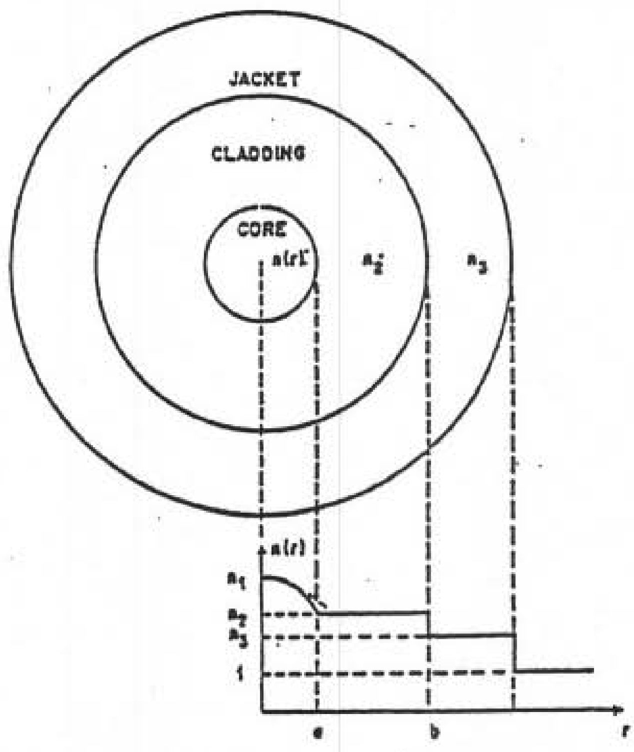

Fig. 2

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4 Ibid.

and the cladding in such a way that the refractive index bends the light rays as shown. Fig. 2[5] shows a cross section of a graded index fiber. The index of refraction versus the radius is shown.

Characteristics of Graded Index Fibers

A graded index fiber usually has a core which measures 50 microns in diameter and a clad which measures 125 microns. The fiber is made of glass throughout. Typically the graded index fiber has low loss and a high bandwidth. The drawback of using a graded index fiber is that it is hard to couple light into the fiber efficiently.

The numerical aperture (NA) of a graded index fiber defines a characteristic of the fiber in terms of its acceptance of the incident light. The numerical aperture[6] is given by the following formula:

$$NA=N_o \sin\theta = N_1 (2\Delta i/(i+2))^{1/2}$$

No is the index of refraction for air, θ is the maximum acceptance angle, n_1 is the index of refraction of the clad, i is the index parameter and Δ is given by $1-N_2/N_1$ where N_2 is the index of refraction of the core. Using this

5 Sharma, Holme, Butusov, Optical Fiber Systems and Their components, p. 3.

6 Okoshi, Optical Fibers, p. 38.

information we can calculate the maximum angle at which light will be coupled into the fiber.

The loss in fibers is measured in decibels and is equal to ten multiplied by the log of the ratio of the power out to the power in. For every component in the fiber optic system there will be an associated loss.

For all fibers used in the system there is an associated material dispersion. Material dispersion is caused by a variation in the refractive index with wavelength. This is the only part of the bandwidth limitation for which compensation is possible.

Material dispersion plays an important part in the extent of pulse spread. For each component in the system there is an associated pulse broadening. The square root of the sum of the squares of each component's pulse spread gives the systems's pulse width[7]. Usually the pulse width is used only with analog systems.

The next step in describing the characteristics of the graded index fiber would be to show how the bandwidth of the fiber is calculated. If the bandwidth of the fiber is

7 Sharma, Holme, Butusov, pp. 89-102.

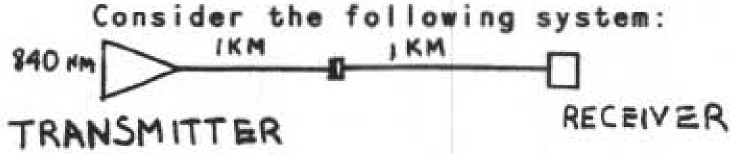
given, then all that is needed is to divide this by the length of the fiber. This will give the bandwidth of all the fiber in the system. If the pulse broadening of the fiber is known, then 0.35 divided by the pulse broadening will give the bandwidth of the fiber. To find the system bandwidth, the bandwidth of each component of the system must be known. The minimum and maximum frequency of the system bandwidth is given by the following equations:

$$\text{MIN. } 1/f_{sys} = 1/f_1 + 1/f_2 + \ldots + 1/f_n$$

$$\text{MAX. } 1/f_{sys}^2 = 1/f_1^2 + 1/f_2^2 + \ldots + 1/f_n^2$$

Example of an Analysis of A Fiber Optic System

Consider the following system:



TRANSMITTER: PULSE WIDTH= τ SOURCE= 75 ps

OPERATING WAVELENGTH: 840 nm

SPECTRAL WIDTH: 2nm

FIBER PIGTAIL: 50/125 GI, NA=0.20

OPTICAL POWER: 30 mW

FIBER: 50/125 GI, NA=0.20

SPECTRAL ATTENUATION: 2.2 dB/km

MATERIAL DISPERSION: 83ps/nm-km at 840 nm

BANDWIDTH: 1.1 GHZ-km at 840 nm

CONNECTOR:

AVERAGE LOSS IS 0.7 dB/mated pair

RECEIVER: PULSE BROADENING $= \tau_{rec} =$ 0.50ns

FIBER PIGTAIL: 50/125 GI, NA =0.20

ASSUME 1 dB LOSS FROM RECEIVER TO FIBER

The first thing that is done in analyzing a fiber optic system is to determine the final pulse width. This is done by the following.

$\tau_{disp}=$ (material dispersion)(spectral width)(distance)

$\tau_{disp}=$ (83 ps/nm-km)(2nm)(10 km)

$\tau_{disp}=$ 1.66 ns

f_{fiber}=1.1GHz-km/10 km = 110 MHz

$_{fiber}$= 0.35/110 MHz =3.2 ns

$\tau_{obs}= (\tau_{source}^2 + \tau_{fiber}^2 + \tau_{disp}^2 + \tau_{rec}^2)^{1/2}$

$\tau_{obs}= ((75\ ps)^2 + (3.20\ ns)^2 + (1.66\ ns)^2)^{1/2}$

$\tau_{obs}=$ 3.64 ns

The secnd procedure in analyzing a fiber optic system is to determine the bandwidth of the system. If the pulse widths of the input and output pulses are known, then the system bandwidth can be calculated as follows:

$$\tau_t = (\tau_{obs}{}^2 - \tau_{source}{}^2)^{1/2}$$
$$\tau_t = ((3.64\ ns)^2 - (75\ ps)^2)^{1/2}$$
$$\tau_t = 3.64\ ns$$
$$f_{3dB} = 0.35/\tau_t = 0.35/3.64\ ns = 96.15\ MHz$$

The final calculation concerns how much power is delivered to the receiver. This is done by summing the losses in the system. The total losses in the system are converted into a percentage loss. This percentage loss is multiplied by the optical power coupled into the fiber which results in the power incident on the receiver.

This example gives the reader of this report a basic understanding of how to analyze a fiber optic system. With this basic understanding the reader should be capable of following the design of the presented fiber optic system.

V. THE SYSTEM

The originally proposed system was a wavelength division multiplexing system. Figure 3 shows the schematic.

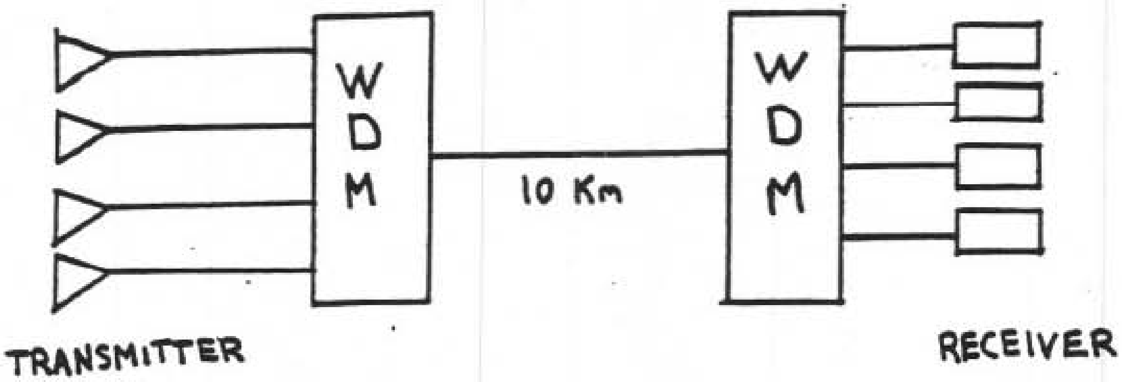


Fig. 3

This system would take the information from the four channels at different wavelengths and multiplex the different wavelengths into a single graded index fiber. At the receiving end the wavelengths would be separated and sent to their respective receivers. The type of multiplexer that was to be used was the OD-8673 made by NEC. The data sheets on this multiplexer are in the appendix.

The system's operating wavelength is between 800-900nm. There is an associated high loss when operating at this wavelength, for distances over two kilometers. The light gets refracted more frequently at this wavelength than at higher wavelengths. Thus the path the light travels is large resulting in more light loss. The obvious solutions to decreasing the loss of the fiber is to increase the wavelength.

The total loss of the system is 50 dB. This large of a loss forces the designer to increase the optical power coupled into the system and the responsivity of the system. The optical power coupled into the system can be increased by using an injection laser diode (ILD). With an ILD the input power could be as high as 10mW. Using an ILD for the transmitter will also raise the cost of the system. With the increased input of optical power the responsivity of the receiver cannot be raised enough to overcome the systems loss. For this reason the multiplexing system will not be used.

The advantage of using a multiplexing system is mainly cost. Graded index fiber cost $0.85 per meter or $8500 per ten kilometer piece. The fiber cost is the greatest of all system components. The multiplexing system employes only one ten kilometer piece of fiber where as another system could employ four, one for each channel.

It has been shown that increasing the wavelength will lower the loss in the system. Thus a system which operates at a higher wavelength will be used.

The Design Used

This design has an operating wavelength of 1300 nm. Operating at this higher wavelength reduces the loss of the system. The cost and therefore the quality of the system components may be smaller.

This design is shown in figure 4.

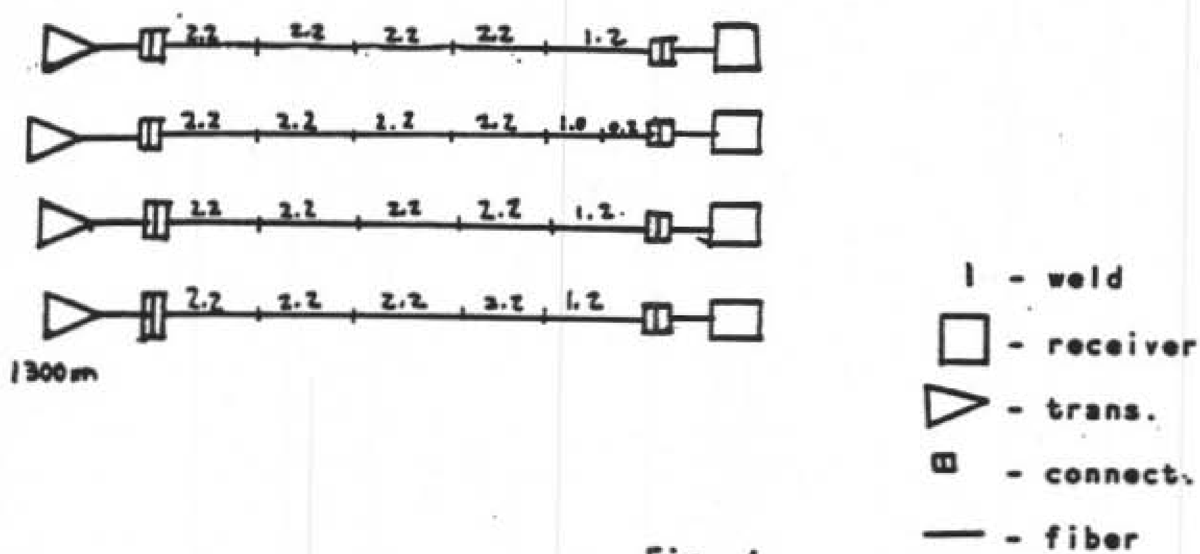


Fig. 4

This graded index fiber is sold in 2.2 km lengths. The 2.2 km lengths are cut in such a way as to optimize their use. Specific details of the design are:

TRANSMITTER:

MA-COM LDT-83004-T

BANDWIDTH: 100 MHZ

OPERATING WAVELENGTH: 1300 NM

RISE TIME: 2.5 ns

FALL TIME: 2.5 ns

OPTICAL POWER: 60 uw

FIBERPIGTAIL: 50/125 GI FIBER, NA=0.20

FIBER:

50/125 GI FIBER, NA=0.20

BANDWIDTH: 1.7 GHZ-KM AT 1300 NM, links are concatenated using welds, assumed to have a loss of 0.1 dB each.

RECEIVER: M-A COM LDT-8300 4-R

FIBER PIGTAIL: 50/125 GI FIBER, NA =0.20

SENSITIVITY: -30 dbm

BANDWIDTH: 100 MHZ

CONNECTOR: NEC 906-110-5014 0.7 dB loss

The data sheets for these components are given in the appendix.

To determine the bandwidth of the system we do the following:

$$f_{fiber} = 1.7 \text{ GHz-km}/10\text{km} = 170 \text{ MHz}$$

$$f_{rec} = 100 \text{ MHz}$$

$$1/f_{sys} = 1/f_{fiber} + 1/f_{rec}$$

$$1/f_{sys} = 1/170MHz + 1/100\ MHz$$

$$f_{sys} = 62.96\ MHz$$

The bandwidth of the system is 62.96 million bits per second. This is far above the required rate of one million bits per second.

The only requirement left for the system is that enough power be incident on the receiver. This means that the loss in the system has to be within the range of responsivity of the receiver. The total loss in the system is calculated as follows:

ITEM	LOSS
2 connectors	1.4 dB
10 km fiber	11.0 dB
4 welds	0.40 dB
	TOTAL LOSS 12.8 dB

$$12.8 = -10 \log \text{(percentage lost)}$$

$$\text{percentage lost} = 94.75\%$$

The optical power incident on receiver is:

$$p_{out} = (100\ uw)(0.0525) = 5.25\ uw$$

This amount of optical power is within the sensitivity of the receiver.

The Bit Error Rate

The error that occurs with this system is less than one bit out of every billion sent. This is shown on the data sheets in the appendix. This error rate is extremely small, which is another attractive feature of this design.

The Cost

The price of the CDT-83004 transmitter and receiver package is $1345.00. The price of the NEC 906-110-5014 is $14.60 and the feedthorough is $3.80. The price of the fiber is $0.85 per meter. The total cost of the materials for the system is $41,170.00. This cost excludes labor needed to build the system.

The labor cost needed to build and test the system is estimated at between thirty and fifty man days. The cost per man day is estimated at $500.00. This includes loading costs such as adminstration buildings, adminstration pesonnel and support costs. The total cost for the system is estimated between $56,170.00 and $66,170.00.

VI. THE REMAINING WORK

The remaining work would be to develop, fabricate, and test the developmental model of the medium range digital communications bus.

This system would be built and tested under conditions similar to those under which it would be operating. Building this system would be a matter of buying the parts and putting them together. The projected cost for the fiber optic parts and assembly of the fiber optic parts is between $56,170.00 and $66,170.00. This includes the parts, loading, and labor costs.

The preceding is all the work that is left uncompleted on this project.

VII. CONCLUSION

The designed bus used fiber optics to achieve a bandwidth of 63 million bits per second per channel. This bandwidth far exceeds the required rate of one million bits per second per channel. The need for a bus of this nature is found at the Nevada Test Site where it could be used for information gathering.

The bus consists of a transmitter, ten kilometers of fiber and a receiver. The operating wavelength is between 1300 nm and 1400 nm. The simplicity of this system makes it easy to maintain and troubleshoot. The error rate is less than one bit out of every billion sent.

The cost of the system which includes loading, personnel and components is about $60,000.

APPENDIX

BIBLIOGRAPHY

Buchsbaum, Walth H. Practical Electronic Reference Data. Englewood Cliffs, N.J.: Prentice Hall, 1978.

Hecht, Jeff. III-V Semiconductor Diode Laser Review. New York: Wiley, 1980. (Information on Transmitters).

Hill, F.J. and Peterson, G.P. Digital Systems: Hardware organization and design. New York: Wiley, 1982

Jaeger, R.E. Optical Fiber Data Transmission. Englewood Cliffs, N.J: Prentice Hall, 1980

Kaniow, Ivan P. An Introduction to Electrooptic Devices. New York: Academic Press Inc., 1983.

Nakazawa, Masataka. "Fiber Gyroscope." Optical Letters. Volume 10. #4 (April, 1985). 193

Palais, J.C. Fiber Optic Communications. Englewood Cliffs, N.J.: Prentice Hall,1984

Safford, Edward L. The Fiber Optics and Laser Handbook. Blue Ridge Summit, Pa: Tab Books Inc., 1984.

Sharma, Halme, Butusov. Optical Fiber Systems and Their Components. Berlin Heildelberg, Germany: Springer-Verlag, 1981.

Thompson, G.H.B. Physics of Semiconductor Laser Devices. New York: Wiley, 1980.

Yariv, Amnon. Introduction to Optical Electronics. New York: Holt, Rhinehart and Winston, Inc., 1979.

PRELIMINARY DATA SHEET

FIBER OPTIC PRODUCTS

M/A-COM

M/A-COM LASER DIODE, INC.
1130 SOMERSET STREET
NEW BRUNSWICK, NJ 08901
(201) 249-7000
TWX 710-998-0597

M/A-COM LASER DIODE, INC.

LDT-83004

1300nm 100 Mbps TRANSMITTER AND RECEIVER

Featuring:

*Data Rates from 100Kbps to 100Mbps

*BER < 10^{-9} at 100 Mbps

*1300 Nanometer Operation

*Distances of up to 12km

*ECL Input and Output

*Hermetic DIP Package

*EMI and RFI Immune

Description: The LDT-83004, fiber optic transmitter and receiver pair, takes advantage of the low attenuation of fiber at a wavelength of 1300 nanometers, to provide reliable data transmission up to 12 kilometers. The hybrid units operate at a data rate up to 100 Mbps with a bit error rate (BER) of less than 10^{-9}. The transmitter utilizes M/A-COM Laser Diode's high performance 1300 nanometer light emitting diodes (LED). The Germanium APD used in the receiver has a sensitivity of -30 dBm (1 microwatts). The receiver tolerates an optical input power of -10 dBm (100 microwatts). This dynamic range of 20dB offers the capacity of operation from 1 meter to 12 kilometers.

The hybrid units are contained in hermetic DIP pacakges, that are capable of operation over a temperature range from 0°C to +60°C. The modules operate with differential ECL input and output. Single ended ECL input and output is available upon request. The transmitter operates on a single -5 volt power supply, the receiver requires a power supply of -5 volts and -25 volts.

LDT-83004

Parameters

	Transmitter	Receiver
Supply Voltage	Ground to -5 volts	Ground to -5 volts Ground to -25 volts
Supply Current	250mA maximum	250mA maximum
Bandwidth	100 MHz	100 MHz
Input/Output	ECL	ECL
Storage Temnerature	0 to +60°C	0 to +60°C
Onerating Temperature.	0 to +60°C	0 to +60°C

LDT-83004

TRANSMITTER

	Min.	Typ.	Max.
Wavelength	-	1300nm	
Rise Time		2.5ns	
Fall Time		2.5ns	
Output Power -			
100μm 0.3NA Fiber		100μW	150μW
50μm 0.2NA Fiber	40μW	60μW	80μW

LDT-83004

RECEIVER

	Min.	Typ.	Max.
Sensitivity	-27dBm	-30dBm	
Maximum Input Optical Power		-10dBm (100μW)	
Dynamic Range		20dB	

M/A-COM

OD-8673-□□□□□

Wavelength Division Multiplexers

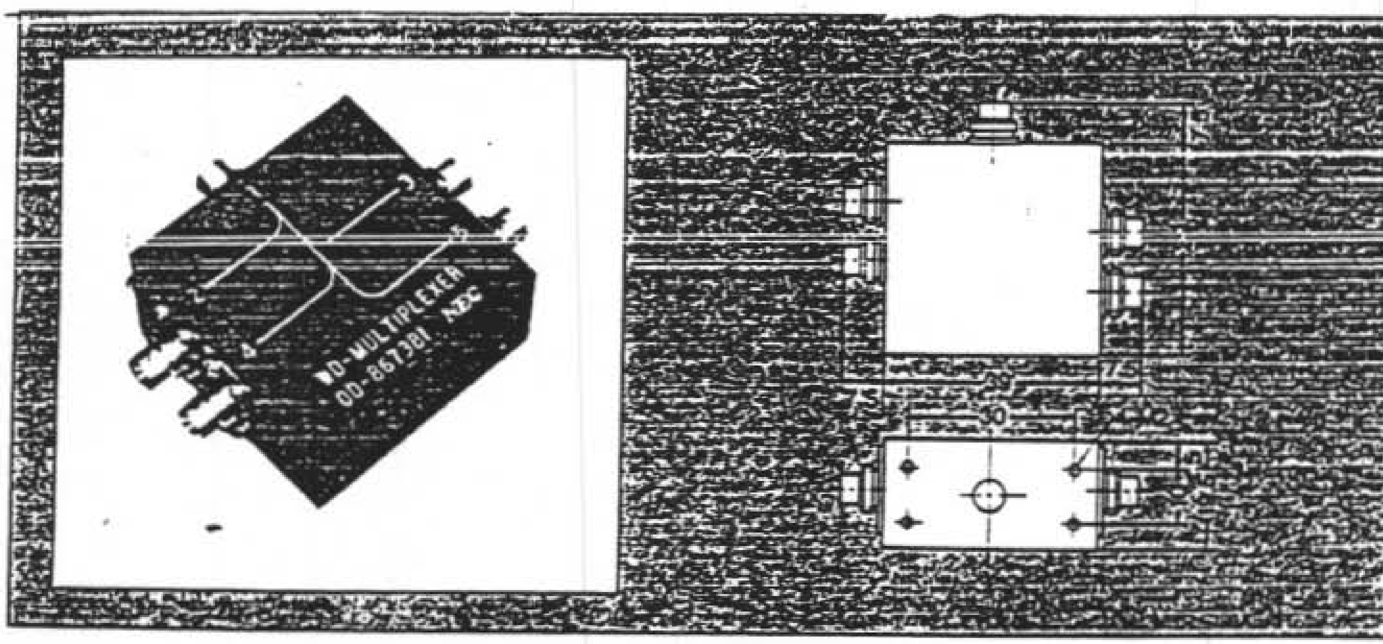
OD-8673 is a multiplexer/demultiplexer used in WDM (Wavelength Division Multiplex) systems to increase transmissic capacity of optical fiber cable.
OD-8673 is applicable to 4-channel WDM system.

FEATURES

- Low insertion loss.
- Sharp separation: wideband and low cross-talk.
- High accuracy of center wavelength.
- Compact and light weight.

APPLICATIONS

- One-way WDM system.
- Two-way WDM system.
- Wavelength characteristics measurement.



MAJOR PERFORMANCES

(Fiber: GI-50)

Items	System type	Specifications	Typical values
Insertion loss of a pair of multiplexer and demultiplexer	1A	6 dB or less	5 dB
	2A	8 dB or less	7 dB
D U ratio	1A	15 dB or more	25 dB
	2A*	15 dB or more	17dB

*In case of 15 dB line loss

MAJOR PARAMETERS

- WDM type :

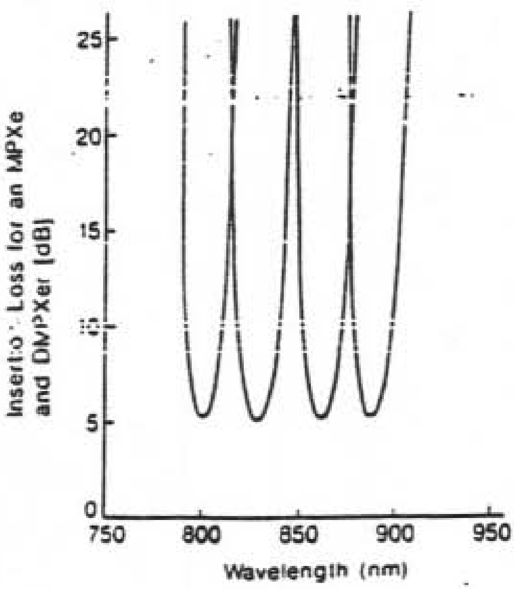
WDM	System	Wavelength			
1AM	One-way LD System	800†† nm	830†† nm	860†† nm	890†† nm
1AD		800 † nm	830 † nm	860 † nm	890 † nm
2AM	Two-way LD System	800 † nm	830†† nm	860†† nm	890†† nm
2AD		800†† nm	830 † nm	860 † nm	890 † nm

† Output †† Input

- Dimensions : 39W x 19.5H x 390 mm
- Weight : 60 g

TYPICAL CHARACTERISTICS.

TYPICAL WAVELENGTH CHARACTERISTICS

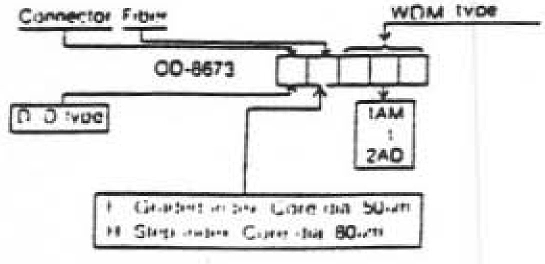


NOTE

1) Standard type is designed for GI-50 fiber and SI-80 fiber
In case of SI-80 fiber, insertion loss increases in comparison with GI-50 fiber
2) Specifications are subject to change without previous notice.

ORDERING FORM

When ordering, please fill in connector type, fiber, wavelength and the other information as follows.



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