Design of Long Haul Telemetry for the DUMAND Phase II Undersea Array

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This note outlines the salient design parameters for building the longhaul optical telemetry for the DUMAND Phase II undersea neutrino observatory. We discuss limitations in bandwidth, expected optical power budgets, and possible choices for componentry.

Introduction

The DUMAND (Deep Underwater Muon and Neutrino Detector) Phase II array will consist of 8 strings arranged in an octagon (40 meters on a side) with one additional string in the center, for a total of 9 strings. Five strings will have 24 optical modules (OM), 3 calibration modules (CM), and one environmental module (EM). The other four strings will have 24 OMs and one EM. Module spacing on the string is 10 meters, the first module starting 100 meters up from the bottom. Each string will have a bottom processor (SBC) which will record time and pulse height information from each OM on the string. The data links from the OMs to the SBC are via dedicated multimode optical fiber. (These shorthaul multimode links are not discussed here.) These data will be transmitted to a shore station via a 40 km, long haul, 12 fiber, electro-optic cable.(There is one dedicated fast data fiber/string, plus a dedicated fiber for Command Control and Clock signals from shore, plus a dedicated fiber for Command and Control signals from the array to shore. There is one spare fiber.) The array is to be located some 25 km offshore, west of Keahole Point off the Big Island of Hawaii. The array will be situated at an ocean depth of 4.8 km. (fig. 1).

The purpose of this memo is to explain the requirements of the long haul telemetry used in the DUMAND Phase II array, and to justify the approach used to meet these requirements. We demonstrate a design based on commercially available componentry, and give examples, including data sheets, to justify our choice of design. Although components referred to here may not be the actual units chosen for the final design, we believe a design based on these components represents a realistic existence proof for the task at hand.

System Design

There are three primary tasks the long haul optical telemetry system must perform for the Phase II array, they are:

1. High speed data link from SBC to shore at 250 Mbit/s.

This link is repeated 18 times, 2 links/SBC.
2. Provide Command and Control network for array operation.
3. Provide fast clock sync pulse every 16 ms
from shore, to be distributed to each SBC.

All of these tasks rely on transmitting data via the single mode optical fibers in the 40 Km electro-optical cable designed by G. Wilkins (fig. 2). This cable will contain 12 single mode optical fibers (similar to those found in Spec sheet 1 and/or 2). Nine fibers will be dedicated to carrying the high speed data from the SBCs to the shore processor. One fiber will be dedicated to the Command and Control link (hereafter the C^2 link) between shore and each SBC. One fiber will be dedicated to delivery of the rollover Clock (sync) and a redundant Command and Control link (hereafter C^3 link) between shore and each SBC. The twelfth fiber is a spare. The proposed hardware systems needed are discussed below.

The design of the long haul links for the DUMAND array must include not only comfortable optical power margin (to allow for ageing and degradation of components), but also adequate bandwidth margin to insure clean data transmission. All components must be assessed for ten year reliability.

Before discussing the specific requirements for each link, it is usefull to describe some of the well constrained parameters of the design. First, optical PIN-FET recievers for the wavelengths we consider have a sensitivity of $\sim$ -32 dBm (dBm = -10log[P / 1 mW], ie dB w/re 1 mW). The output power of a standard single mode laser coupled into a single mode fiber is typically $\leq$ 1 mW (= 0 dBm). This implies that without the use of special components, the theoretical maximum optical power budget for any link in the array is 32 dB. Fiber losses, connectors, feedthrus, splices, multiplexers, and splitters, must all be accounted for in the optical loss budget to compute the optical power margin for each link. This margin must be comfortable enough to allow for degradation and ageing of components over the 10 year lifetime of the array. Fortunately, many of the components used in the proposed telemetry have indeed been carefully scrutinized by the longhaul telecommunications industry for use in high MTBF (Mean Time Between Failure) systems.

Fast Data Link:

The scheme for digitizing the optical module (OM) data involves 1/2 of the data from a given string, going to digitizer A, and the other half of the data going to digitizer B, in the String Bottom Controller (SBC). Therefore, 14 channels of optical module data go to each digitizer. We assume a raw data rate/(1/2 SBC) of: 14 OMs x 10^5 hits/sec/OM x 2 words/hit x (32 - 40) bits/word = 89 - 112 Mbits/sec, or combining both halves of the SBC, a rate of 188 - 224 Mbits/sec. We take advantage of wavelength division (two color) multiplexing in order to send data from each 1/2 SBC in a different color (λ_1 = 1300 nm, λ_2 = 1550 nm) on the same fiber to shore. This reduces the expected data rate back down to 112 Mbits/sec/color. We plan to run the high speed data link at 256 Mbits/sec/color over the 40 km run. This allows a factor of 2 bandwidth margin, with fluctuations in data rate being taken up by data buffering in the SBC. Active tube rate monitoring and squelching at the SBC level will ensure that the data buffer is never inadvertantly overwritten due to bursts in noise from an individual tube. This will insure the integrity of data words transmitted to shore.

The unidirectional wavelength division multiplexing scheme proposed for the nine fast data links is shown in figure 3. Fast data from digitizer A (B) will drive a 1300 nm (1550 nm) laser (spec sheet 3 and 4). The output from these two lasers are combined onto the single mode fiber by a wavelength division multiplexer (hereafter WDM) located in the SBC (spec sheet 5). This fiber then exits the SBC pressure housing via a high pressure feedthru (Spec sheet 6) and continues as part of the (3 fiber + 2 electrical conductor) umbilical cable, which in turn, is led to the Junction Box. At the Junction Box, each optical fiber in the umbilical cable will be optically coupled to a dedicated fiber in the main cable via a McDonnell Douglas make-and-break single mode connector (fig. 5,6). The fiber will then continue 40 km to the shore station where a wavelength division demultiplexer will again separate the two wavelengths and deliver them to their appropriate recievers (spec sheet 7).

The expected optical losses for this link are as follows. We allow .1 dB loss for each 1 atm. fusion splice (FS = .1 dB). We allow .5 dB for each high pressure feedthru (HPF = .5 dB), and .4 dB/km loss @ $\lambda = 1300$ nm, and .3 dB/km loss @ 1550 nm (using Corning SMF-28 fiber). Typical loss in the wavelength division multiplexer is (WDM = .5 dB), and can be specified to be wavelength independent. The undersea McDonnell Douglas connector gives (McD =.5 dB) loss. For the total loss in the link we get/color: FS + WDM + FS + HPF + McD + Cable + FS + WDM + FS = .1 + .1 + .1 + 1.0 + 16(12) + .1 + .1 + .1 = 17.6 (13.6) dB loss at 1300 (1550) nm. Typical recievers have a sensitivity of -32 dBm at these data rates. Laser transmitters are available with power coupled into a single mode pigtail of ~ 1 mW (= 0 dBm). This implies a system margin of 12.4 (16.4) dB at 1300 (1550) nm.

Color dispersion in this link poses a slight problem. Color dispersion arises in such systems due to the fact that semiconductor lasers have a finite linewidth, typically, $\Delta\lambda =$ 5 - 10 nm. (spec. sheet 3,4). Because the velocity of light in glass is different for different wavelengths, the square edge of a pulse of photons input at one end of a fiber will be smear out slightly over a long run, ultimately limiting the bandwidth for a specified length of fiber. The figure of merit when considering design is then the Bandwidth Length Product (BWLP) given in units of Ghz * km. There is a global minimum dispersion of ~ 2.7 picosec/nm*km in glass, in the spectral region near 1300 nm (fig. 4). Unfortunately, glass has its global minimum for attenuation in a different spectral region near 1550 nm. Therefore, when designing a longhaul system the tradeoff must be made between minimizing attenuation and maximizing bandwidth.

For the fast data links the prudent choice of fiber seems to be a fiber like the SMF-28 fiber, not the SMF/DS (Dispersion Shifted) fiber. The reasons for this choice are somewhat subtle. For the fast data link we require a BWLP of 256 Mbits/s * 40 km or 10.24 Ghz*km. The calculation for dispersion on the SMF-28 fiber, @ 1300 nm, for a spectral width of $\Delta\lambda = 10$ nm gives 14.9 ps/km or 67.1 Ghz*km (adequate). For the SMF-28 @ 1550 nm, $\Delta\lambda = 10$ nm again, we get 5.5 Ghz*km (insufficient). However, for the SMF/DS fiber at 1300 nm, again $\Delta\lambda = 10$ nm, we get (I am guessing here) $\sim$ 5 Ghz*km (insufficient), and 1550 we get 37 Ghz*km (adequate). So, for either choice of fiber, we can not achieve the needed 10.24 Ghz*km at both wavelengths simultaneously. This problem can be solved by choosing a special narrow linewidth laser, the DFB (Distributed FeedBack) laser. These lasers have linewidths typically of .001 nm, thus solving the dispersion problem. (Note: The DFB laser is now commonly used in long haul systems).

The recommendation is then to use a 'normal' laser @ 1300 nm and a DFB laser @ 1550 nm on the SMF-28 fiber. This gives adequate bandwidth, and minimizes the expected system margin difference between the two colors (recall from above, system margin diff: 12.4 db @ 1300 nm and 16.4 dB @ 1550 nm, for a difference of 4 dB. The same calc using the SMF/DS fiber, .5 dB/km loss @ 1300, and .3 dB/km loss @ 1550 gives a difference of 8 dB over the 40 km run).

In sum, we propose a unidirectional WDM scheme, operating at 1300 and 1550 nm to bring the fast data to shore. The link will have one DFB laser @ 1550 nm and another 'normal' laser @ 1300 nm. The total calculated losses are 17.6 dB @ 1300 nm and 13.6 dB @ 1550 nm. For a system with 32 dB of dynamic range this gives a system margin of 14.4 and 18.4 dB respectively.

C^2 and C^3 Links:

As originally proposed, the C^2 and C^3 links are each to have a dedicated fiber (fig. 7). The Clock+Command+Control signals are to be brought out from shore on a single fiber, with the command data being interspersed between the rollover reset clock pulses (rollover every 16 ms). The purpose of the clock is to synchronously reset the clocks in all the nine SBCs, with an accuracy of 1 ns. The expected bandwidth necessary for the command and control signals is $\sim$ 1 Mbit/sec. The bandwidth necessary to insure risetime jitter for clock signals of $<$ 1ns at the SBC, is $\sim$ 1 Ghz, over a 40 km run, or 40 Ghz*km. Again, this bandwidth could be attained with the use of a DFB laser.

The C^3 (C^2) link has an additional loss due to a passive 9 way optical fanout (fan-in) located at the junction box. The 1 : 9 optical splitter will impart an additional loss of 15 dB (1 dB) in the shore-to-SBC (SBC-to-shore) direction. [Note: for the shore-to-SBC link the splitter loss is the equivalent of adding an extra 50 km of fiber to the system @ .3 dB/km !]. The total loss expected for the shore-to-SBC ,C^3, link is 12 dB (cable loss @ 1550, .3dB/km*40km) + 21.5 dB (connector,splitter,feedthru losses) for a total of 33.5 dB. The total loss for the SBC-to-shore, C^2, link is 12 dB (cable) + 7.5 dB (conn + split etc) = 19.5 dB.

Notice that the expected losses for the C^3 link exceed the dynamic range expected from a normal laser/PIN-FET reciever combination of 32 dB. The C^2 link on the other hand has a comfortable margin of 12.5 dB. To solve the C^3 link problem we will need to use a higher power laser on shore. This laser is not standard telecommunications equiptment, and a suitable device has not been located at this time. We require that this laser have an optical output power coupled into a single mode pigtail of at least 10 mw (10 dBm) and a linewidth of $<$ .1 nm to minimize dispersion (ie a high power DFB laser). A laser such as this will give an optical dynamic range of 10 dBm + 32 dBm = 42 dB, and an optical margin for the link of 42 - 33.5 = 8.5 dB. This laser is a specialty item and a search for this device should begin immediately.

Redundancy:

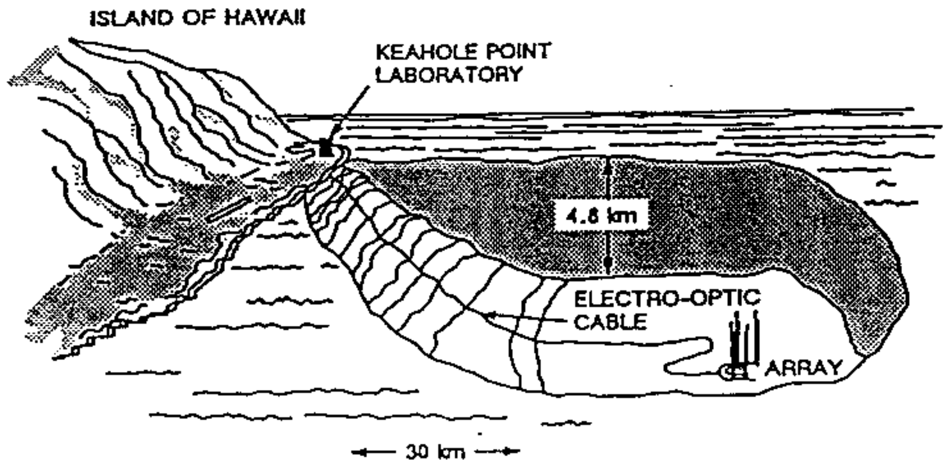
One criticism of the above C^2 and C^3 links is that they do not provide for redundancy should one of the links fail. Although the C^2 link from SBC–shore will indeed be redundantly transmitted on the data channel, the C^3 link, which carries the crucial clock pulse does not have a redundant pathway to the array. For this reason we propose that the full duplex scheme, presented below, be considered as viable option for the C^2/C^3 links. With the addition of WDM equiptment plus the appropriate recievers and transmitters at each end of the C^2 and C^3 links we arrive at a configuration we call the C^{2+3} link. This link can carry both C^3 out to the array and bring C^2 information back from the array (fig. 8).

The C^{2+3} links will be run in a bi-directional wavelength division multiplexed mode. In both links a high power DFB laser @ 1550 nm, C^3 data from shore will be brought out over the 40 km cable and split 10 ways in a 1:10 single mode optical splitter located in the Junction Box (spec sheet 5). Splitting ratios, and insertion losses for this device are essentially wavelength independent, but are directionally asymmetric. For optical power going from shore to SBC, the loss is 15 dB, and for optical power returning from SBC to shore the loss is 1 dB. Because 1550 nm light has lower cable attenuation, .3dB/km, we have chosen this wavelength to be located on shore, so the total system loss is 13.6 (cable + WDM + FS etc) + 15 dB splitting loss = 28.6 dB. This is to be compared with a total system loss of 32.5 dB if the 1300 nm laser were to be located on shore.

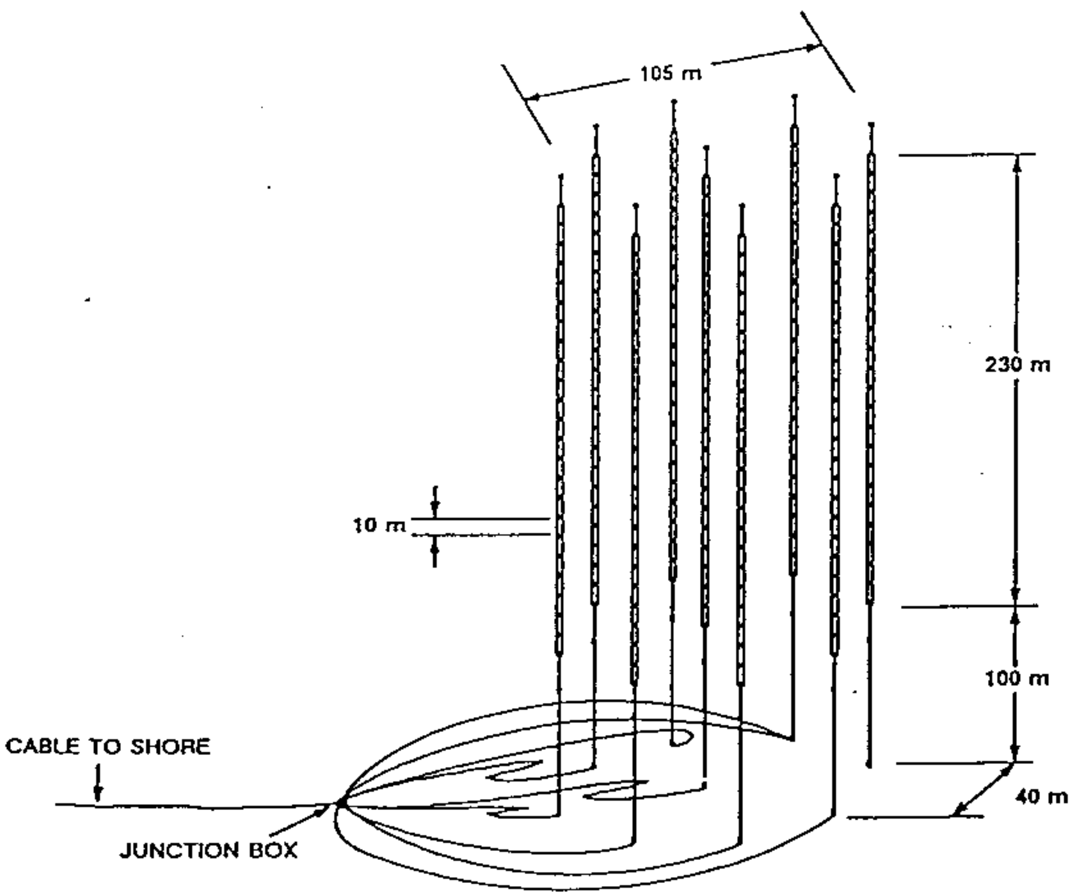
Spare:

The plan for the 12th fiber in the main cable has not been discussed extensively, but it is assumed that the present plan has the spare fiber terminated at the J–Box with a McDonnell Douglas connector. The spare fiber sits dormant at the J–Box until needed. In this configuration the fiber can act as a spare for a single fast data link, but can not act as a spare for the fast clock synch pulses. With this in mind we suggest that the spare be 'wired' with a 1 : 9 optical splitter at the junction box. This would allow the spare fiber to act as a spare for 9 fast data links, or for C^{2+3}. The cost for this redundancy is an extra 10 McDonnell Douglas connectors.

Note: All loss measurements here rely on the value of .3 dB/ km loss for fibers @ 1550 nm, if this value should creep up to .4 dB/km for any one of the fibers in the cable, the quoted margins discussed above would be in serious trouble. This type of requirement should definately be written into cable contacts.

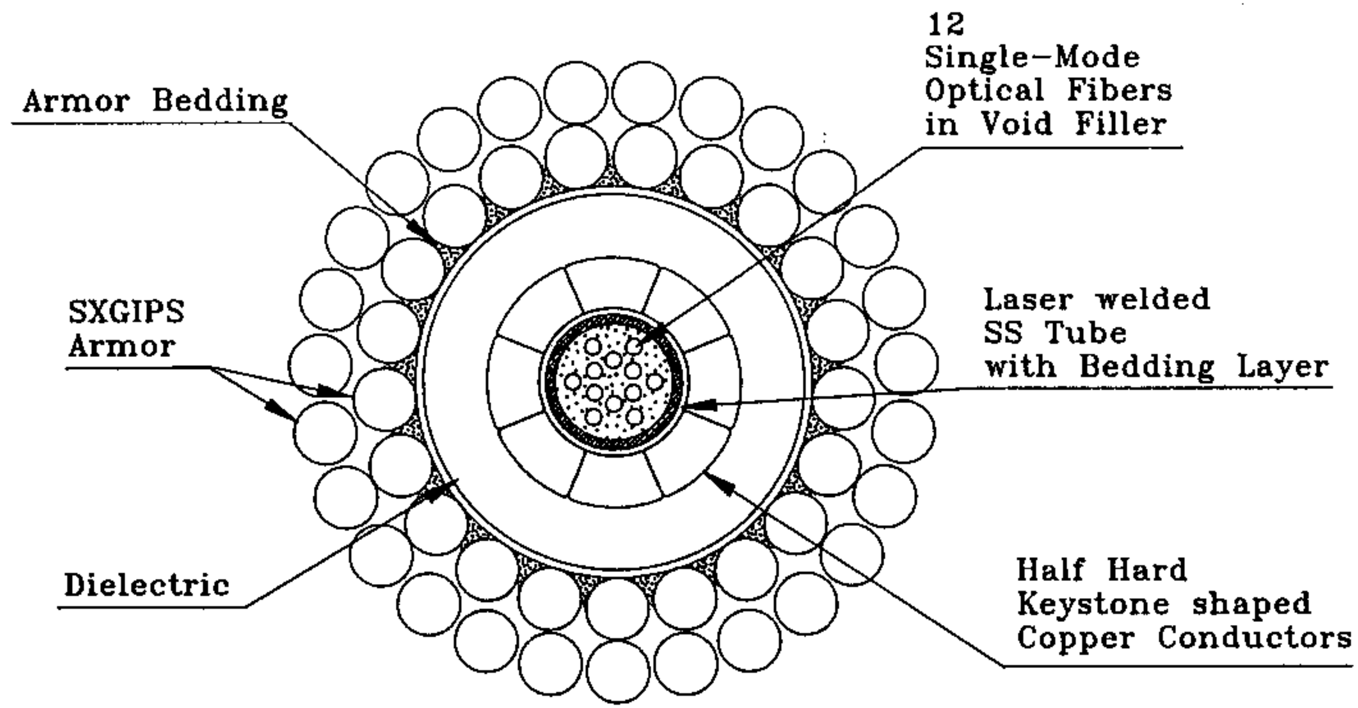


Disposition of the DUMAND detector at 4.8 km depth in subsidence basin ~ 35 km off Keahole Point, island of Hawaii. Armored cables carrying power and fiber-optics communication connect DUMAND to the shore station.



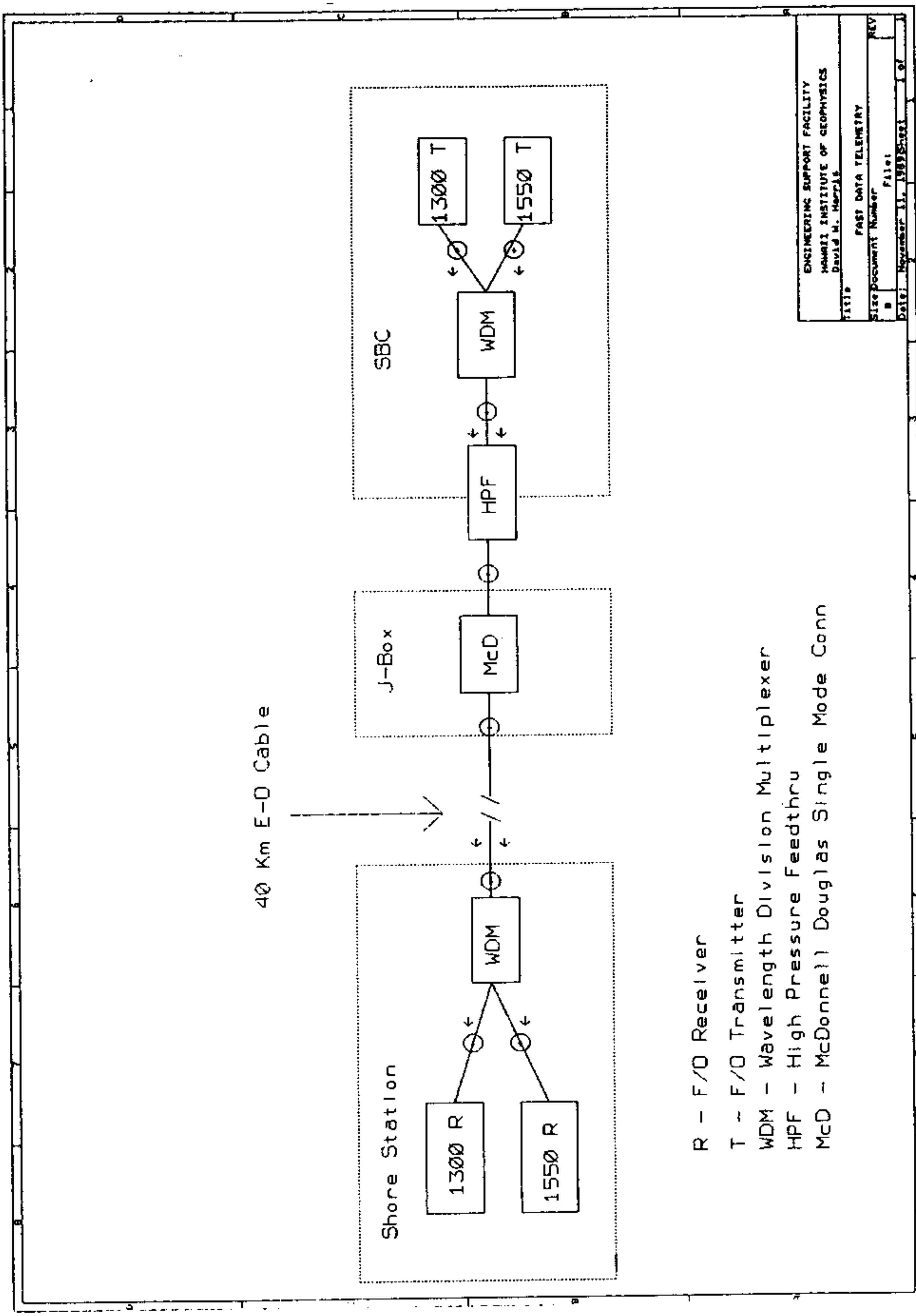
The DUMAND Octogon Array. There are 9 strings, each anchored at the bottom, and held taut by a float. They are spaced 40 m apart on the perimeter, with a ninth in the center. Along each string are 24 detector modues spaced 10 m apart. The strings are independent – they are connected at the bottom.

Figure 1



Model Design of DUMAND DC-Voltage E-O Cable
October 1989

Figure 2


SBC
1300 T
1550 T
WDM
HPF
J-Box
McD
40 Km E-O Cable
Shore Station
WDM
1300 R
1550 R
R - F/O Receiver
T - F/O Transmitter
WDM - Wavelength Division Multiplexer
HPF - High Pressure Feedthru
McD - McDonnell Douglas Single Mode Conn
ENGINEERING SUPPORT FACILITY
HAWAII INSTITUTE OF GEOPHYSICS
David H. Harris
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FAST DATA TELEMETRY
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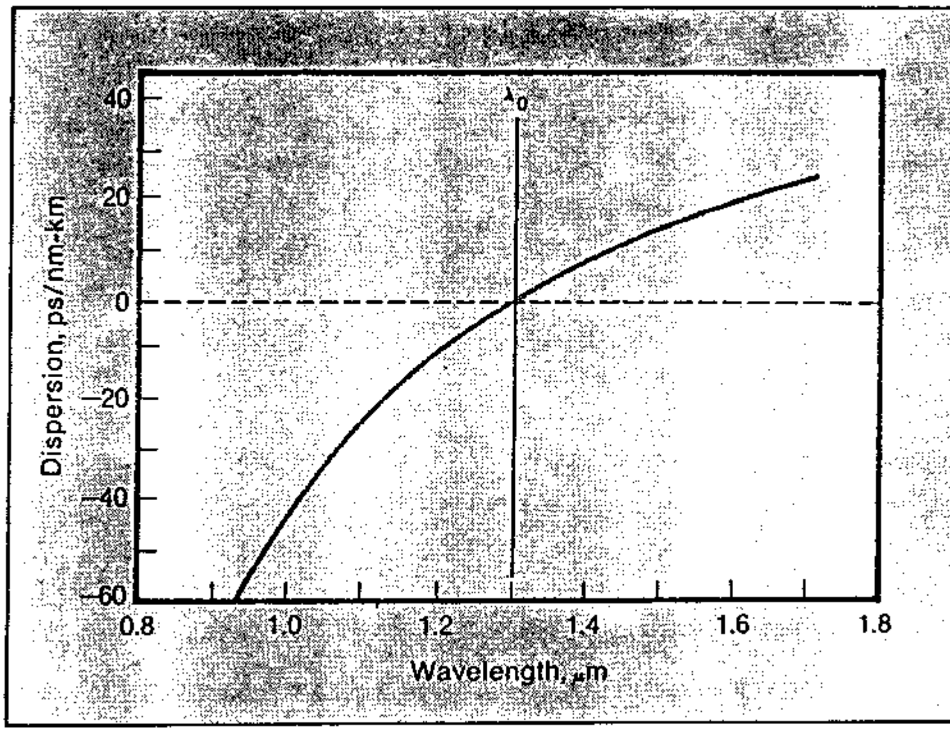
Figure 3



Chromatic dispersion indicates the time-delay difference between two pulses having wavelengths 1 nm apart after traversing a 1-km fiber. At λ_0, no delay difference exists. Data are for a Corning Glass Works single-mode fiber. The zero-dispersion wavelength is 1.33 micrometers.

Figure 4

Figure 5

SINGLE MODE
WET-MATEABLE FIBER OPTIC CONNECTOR

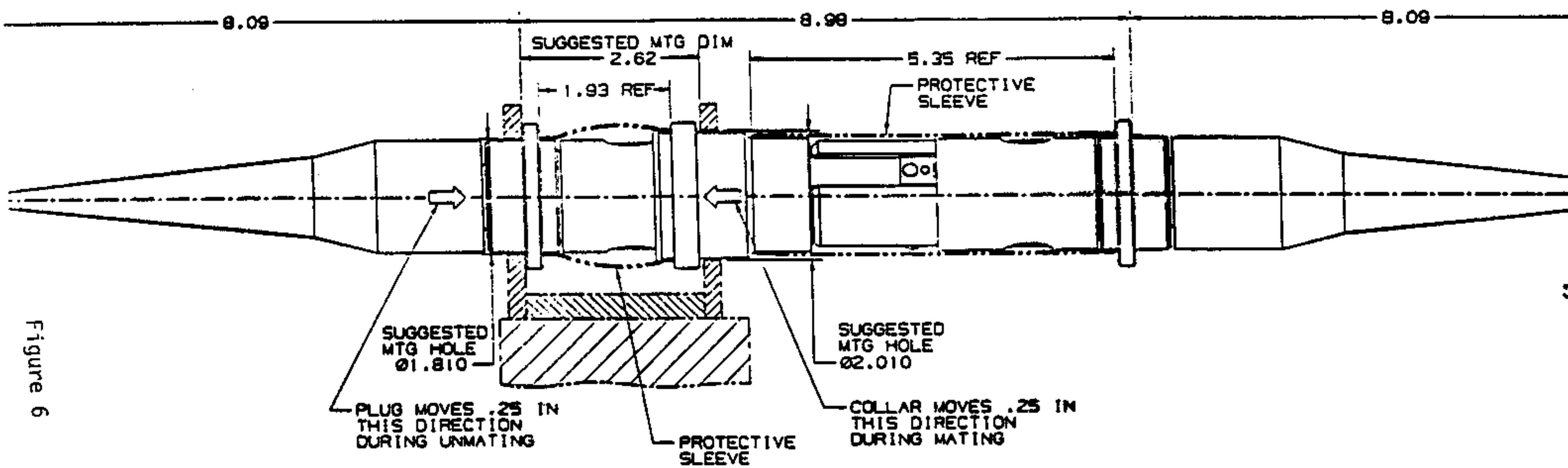


Figure 6

FIG 7
Dedicated
C^2, C^3
Links

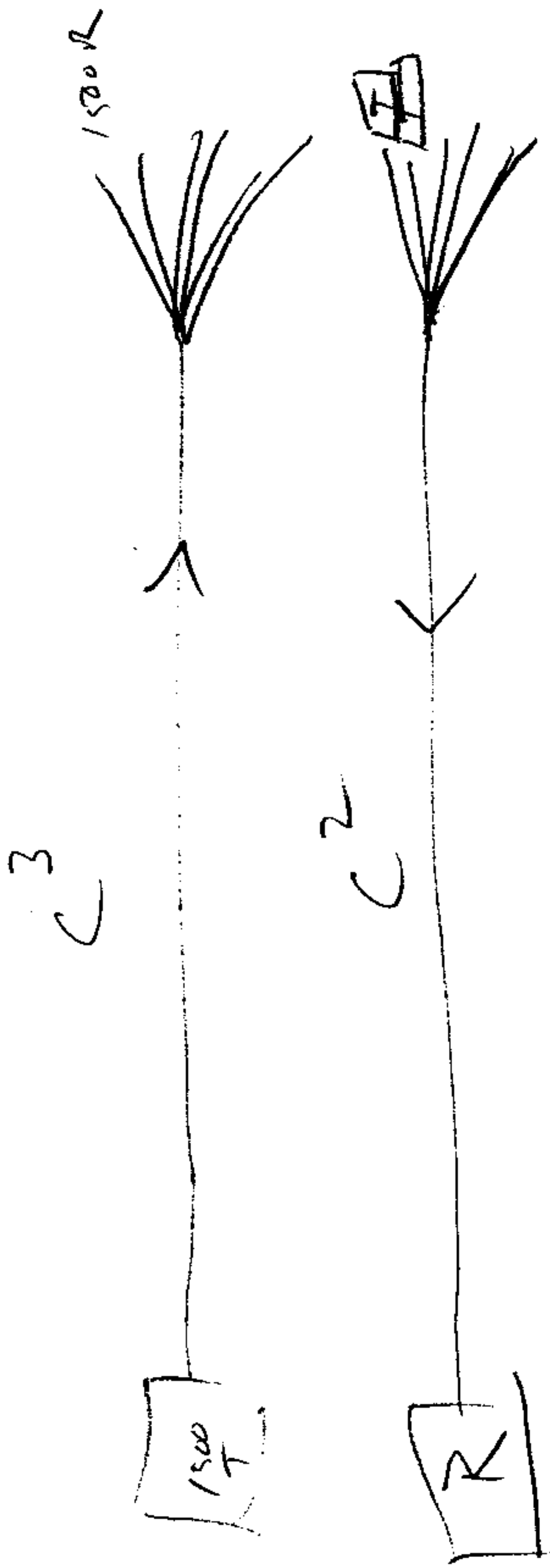
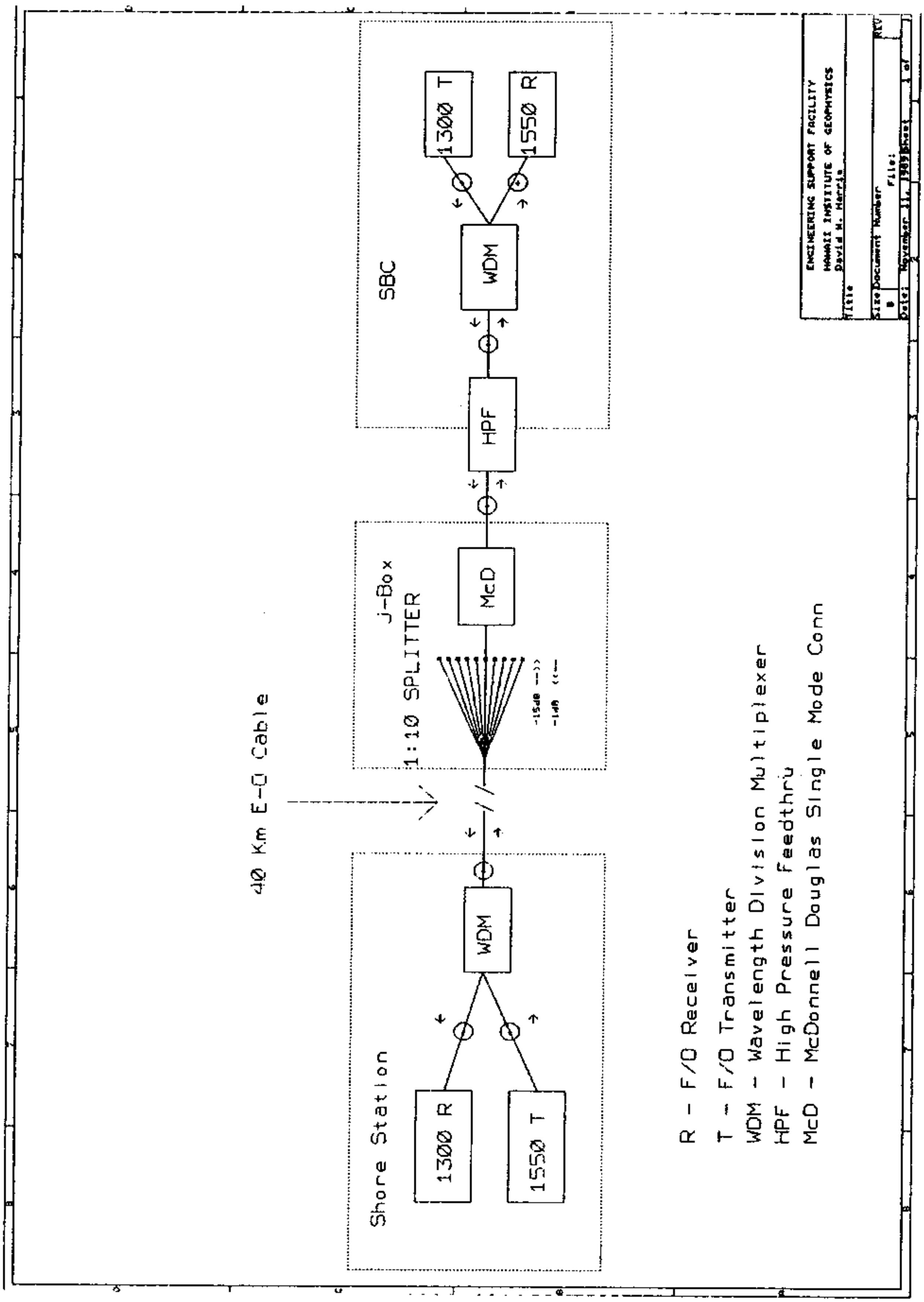


Figure 7



SBC
1300 T
1550 R
WDM
HPF
J-Box
1:10 SPLITTER
McD
40 Km E-O Cable
Shore Station
1300 R
1550 T
WDM
R - F/O Receiver
T - F/O Transmitter
WDM - Wavelength Division Multiplexer
HPF - High Pressure Feedthru
McD - McDonnell Douglas Single Mode Conn
ENGINEERING SUPPORT FACILITY
HAWAII INSTITUTE OF GEOPHYSICS

Figure 8

CORNING

Telecommunications Products Division
Corning Glass Works
Corning, New York 14831, USA
Tel: 607-974-4411
Telex: 932498

Corguide® Optical Fiber

Product Information

SMF-28™ CPC3 Single-Mode Optical Fiber

Issued: 9/87

Supersedes: 2/87

1.0 General

Corguide® SMF-28™ optical fiber is a non-dispersion shifted single-mode fiber with a nominal mode-field diameter of 9.5 μm. The dispersion minimum, where the fiber information carrying capacity is a maximum, is in the 1300 nm wavelength region.

CPC3 is a mechanically strippable acrylate coating with a 250 μm nominal outside diameter. It is primarily used in loose tube and slotted core cable designs.

Corguide SMF-28 CPC3 optical fiber is designed to meet present day requirements of improved 1550 nm performance through enhanced bend resistance. A mode-field diameter of 9.5 μm provides excellent bend resistance in the 1550 nm region where induced attenuation due to excessive bending in splice trays or cables may hamper system performance.

Applications for this product include: long-haul telephony, interexchange, feeder and distribution markets carrying data, voice and/or video services where system upgrading to 1550 nm is a design requirement.

2.0 Optical Specifications

Attenuation:

Standard Attenuation Cells:

Wavelength [nm]	Attenuation Cells [dB/km]		
	A	B	C
1300 nm	≤0.36	≤0.40	≤0.50
1550 nm	≤0.26	≤0.30	≤0.40

Attenuation Uniformity:
No point discontinuity greater than 0.1 dB at either 1300 nm or 1550 nm.

Spec Sht. 1

Attenuation Versus Wavelength:
The attenuation for the wavelength region λ_1 to λ_2 does not exceed the attenuation at λ_3 by more than α dB/km.

Attenuation Vs. Wavelength			
λ_1 [nm]	λ_2 [nm]	λ_3 [nm]	α [dB/km]
1285	1300	1300	0.10
1330	1300	1300	0.05
1380	1300	1300	1.50
1525	1575	1550	0.05

Attenuation With Bending:
The induced attenuation due to 100 turns of fiber wrapped around a mandrel of a specified diameter is as follows:

Mandrel Diameter [mm]	Wavelength [nm]	Induced Attenuation [dB]
50	1300	≤ 0.05
50	1550	≤ 0.10
75	1300	≤ 0.05
75	1550	≤ 0.10

Cut-off Wavelength: 1260 ± 70 nm

Mode-Field Diameter: 9.5 ± 0.5 μm at 1300 nm
10.5 ± 1.0 μm at 1550 nm

Dispersion:

Zero Dispersion Wavelength (λ_o): 1301.5 nm $\leq \lambda_o \leq$ 1321.5 nm
Zero Dispersion Slope (S_o): $\leq$ 0.092 ps/(nm^2•km)
Dispersion Calculation:

$$\text{Dispersion} = D(\lambda) = \frac{S_o}{4}\left[\lambda - \frac{\lambda_o^4}{\lambda^3}\right] \text{ps/(nm}\cdot\text{km), for } 1200\text{ nm} \leq \lambda \leq 1600\text{ nm}$$

3.0 Environmental Specifications

Environmental Test Method	Induced Attenuation [dB/km]	
	1300 nm	1550 nm
Temperature Dependence −60°C to +85°C	≤0.05	≤0.05
Temperature-Humidity Cycling −10°C to +85°C and ≤98% Relative Humidity	≤0.05	≤0.05
Water Immersion, 23°C	≤0.05	≤0.05
Heat Aging, 85°C	≤0.05	≤0.05

Operating Temperature Range: −60°C to +85°C

4.0 Dimensional Specifications

Standard Lengths: 2,200, 4,400, 6,400, 10,500 and 12.600 m

Glass Geometry:

Cladding Diameter: 125.0 ± 2.0 μm
Core to Cladding Offset: ≤1.0 μm
Cladding Non-Circularity: ≤2%

$$\text{Defined as: } \left[1 - \frac{\text{Min. Cladding Diameter}}{\text{Max. Cladding Diameter}}\right] \times 100$$

Coating Geometry:

Coating Diameter: 250 ± 15 μm
Coating Concentricity: ≥0.70

$$\text{Defined as: } \frac{\text{Min. Coating Thickness}}{\text{Max. Coating Thickness}}$$

5.0 Mechanical Specifications

Proof Test:

The entire length of fiber is subjected to a tensile proof stress which is equivalent to 50 kpsi (0.35 GN/m^2) or 100 kpsi (0.70 GN/m^2) for a 1.0 second dwell time.

6.0 Performance Characterizations

Characterized parameters are typical values.

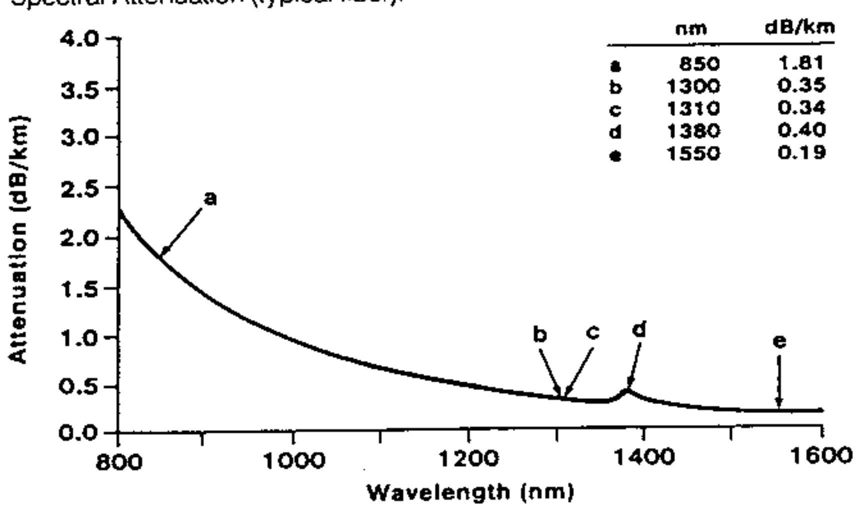
Core Diameter:	8.3 μm
Numerical Aperture:	0.12
Nominal Zero Dispersion Wavelength (λ_o):	1314 nm
Nominal Zero Dispersion Slope (S_o):	0.087 ps/(nm^2•km)
Refractive Index Difference:	0.36%
Effective Group Index of Refraction (N_{eff}):	1.471 at 1300 nm 1.471 at 1550 nm

N_{eff} was empirically derived to the third decimal place using a specific commercially available OTDR.

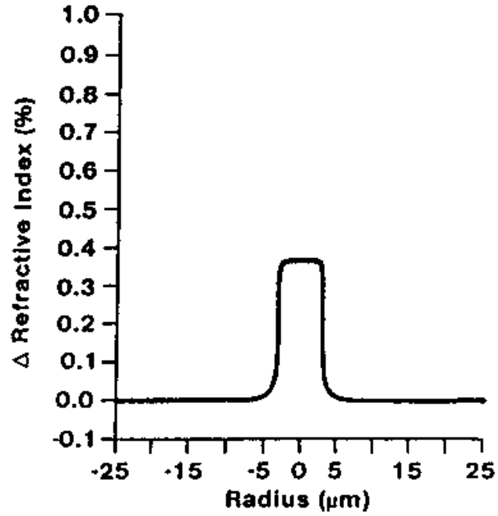
Coating Strip Force:

Coating Strip Force	
Dry	0.67 lbs. (3.0 N)
Wet, 14 days in 65°C water soak	0.42 lbs. (1.9 N)

Spectral Attenuation (typical fiber):



Refractive Index Profile (typical fiber):



7.0 Ordering Information

To order Corguide SMF-28 CPC3 optical fiber contact your sales representative or call the Telecommunications Products Division Sales Department at (607) 974-4270. Please specify the following parameters when ordering:

Fiber Type:	SMF-28 Single-Mode Fiber
Coating:	CPC3 (250 μm outside diameter)
Desired Attenuation Cell:	dB/km
Reel length:	2,200. 4,400. 6,400. 10,500 or 12,600 meters
Total Number of Reels:	—
Proof Test:	50 kpsi (0.35 GN/m^2) or 100 kpsi (0.70 GN/m^2)

CORNING

Telecommunications Products Division
Corning Glass Works
Corning, New York 14831, USA
Tel: 607-974-4411
Telex: 932498

Corguide Optical Fiber

Product Information

SMF/DS™ CPC3 Single-Mode Dispersion-Shifted Optical Fiber

Issued: 9/87

Supersedes: 2/87

What is dispersion @ 1300 for CPC3?

1.0 General

Corguide® SMF/DS™ single-mode dispersion-shifted fiber is designed to operate in the 1550 nm region. A segmented core design has lowered the slope of the dispersion curve while maintaining control of the zero-dispersion wavelength which has been shifted to the attenuation minima point at 1550 nm. This improved performance allows systems transmitting at 565 Mbps to have regenerator spans greater than 80 km. In addition, very long spans without regenerators, over 200 km, are achievable at lower, 140 Mbps, bit rates.

CPC3 is a mechanically strippable acrylate coating with a 250 μm nominal outside diameter. It is primarily used in loose tube and slotted core cable designs.

Applications for this product include: long-haul telephony, optical ground wire and submarine cables where long spans without regenerators and high data rates are required.

2.0 Optical Specifications

Attenuation:

Attenuation Cell: ≤0.25 dB/km at 1550 nm
Attenuation Uniformity: ≤0.1 dB at 1550 nm.
Attenuation With Bending:
The induced attenuation due to 100 turns of fiber wrapped around a mandrel of a specified diameter is as follows:

Mandrel Diameter [mm]	Wavelength [nm]	Induced Attenuation [dB]
40	1550	≤0.05
75	1550	≤0.05

< 17 ps/nm km @ 1300

Attenuation Versus Wavelength:
The attenuation for the wavelength region from 1525 nm to 1575 nm does not exceed the attenuation at 1550 nm by more than 0.05 dB/km. ⇒ use .25 +.05 = .3 dB/km

Cut-off Wavelength: 1220 nm ± 100 nm

ADD .1 dB/km for cabling loss = .4 dB

Mode-Field Diameter: 8.10 ± 0.65 μm at 1550 nm

Total Dispersion: ≤2.7 ps/(nm•km) over the range 1525 to 1575 nm

Spec. Sht. 2

3.0 Environmental Specifications

Environmental Test Method	Induced Attenuation [dB/km]
	1550 nm
Temperature Dependence −60°C to +85°C	≤0.03
Temperature-Humidity Cycling −10°C to +85°C and ≤98% Relative Humidity	≤0.10
Water Immersion, 23°C	≤0.05
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Proof Test:

The entire length of fiber is subjected to a tensile proof stress which is equivalent to 50 kpsi (0.35 GN/m^2) or 100 kpsi (0.70 GN/m^2) for a 1.0 second dwell time.

6.0 Performance Characterizations

Characterized parameters are typical values.

Attenuation at 1300 nm: ≤0.5 dB/km

Refractive Index Difference:

The refractive index difference between the peak of the core and the cladding is 0.9%, and the difference between the peak of the ring and the cladding is 0.3%.

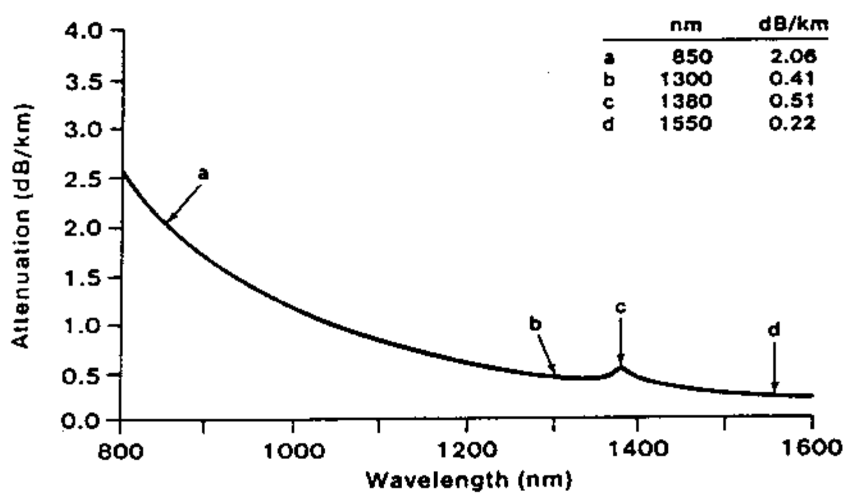
Effective Group Index of Refraction (N_{eff}): 1.476 at 1300 nm
1.476 at 1550 nm

N_{eff} was empirically derived to the third decimal place using a specific commercially available OTDR.

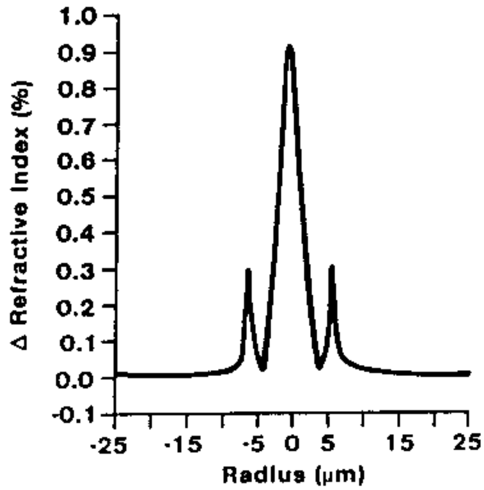
Coating Strip Force:

Coating Strip Force	
Dry	0.67 lbs. (3.0 N)
Wet, 14 days in 65°C water soak	0.42 lbs. (1.9 N)

Spectral Attenuation (typical fiber):



Refractive Index Profile (typical fiber)



7.0 Ordering Information

To order Corguide SMF/DS CPC3 dispersion-shifted optical fiber contact your sales representative or call the Telecommunications Products Division Sales Department at (607) 974-4270. Please specify the following parameters when ordering:

Fiber Type:	SMF/DS Dispersion-Shifted Fiber
Coating:	CPC3 (250 μm outside diameter)
Desired Attenuation Cell:	dB/km
Reel length:	2,200. 4,400. 6,400. 10,500 or 12,600 meters
Total Number of Reels:	—
Proof Test:	50 kpsi (0.35 GN/m^2) or 100 kpsi (0.70 GN/m^2)

Corguide® Optical Fibe

CORNING

Product Specifications

Optical Characteristics	SMF-21™ fiber	SMF-28™ fiber	SMF/DS™ fiber
Attenuation @ 1300 nm	≤0.36 dB/km ≤0.40 dB/km ≤0.50 dB/km	≤0.36 dB/km ≤0.40 dB/km ≤0.50 dB/km	
Attenuation @ 1550 nm	≤0.26 dB/km ≤0.30 dB/km ≤0.40 dB/km	≤0.26 dB/km ≤0.30 dB/km ≤0.40 dB/km	≤0.25 dB/km
Bend Performance @ 1300 nm 100 turns on 75 mm mandrel	≤0.05 dB	≤0.05 dB	
Bend Performance @ 1550 nm 100 turns on 75 mm mandrel	≤0.10 dB	≤0.10 dB	
Temperature Dependence @ 1300 nm	≤0.10 dB/km	≤0.05 dB/km	
Temperature Dependence @ 1550 nm	≤0.15 dB/km	≤0.05 dB/km	≤0.05 dB/km
Temperature Dependence Range	−60°C to +85°C	−60°C to +85°C	−40°C to +85°C
Cut-off Wavelength	1130–1270 nm	1190–1330 nm	1100–1300 nm
Maximum Dispersion			2.7 ps/nm·km 1525–1575 nm
Minimum Zero Dispersion Wavelength	1301.5 nm	1301.5 nm	
Maximum Zero Dispersion Wavelength	1321.5 nm	1321.5 nm	
Dispersion Slope	0.093 ps/nm²·km	0.092 ps/nm²·km	
Mode-Field Diameter	10 ± 1 µm	9.5 ± 0.5 µm	

Corguide® single-mode fibers.
Optical fibers from the
worldwide technology leader.

Telecommunications Products Division, Corning Glass Works, MP-RO-03, Corning, N.Y. 14831, 607-974-4411

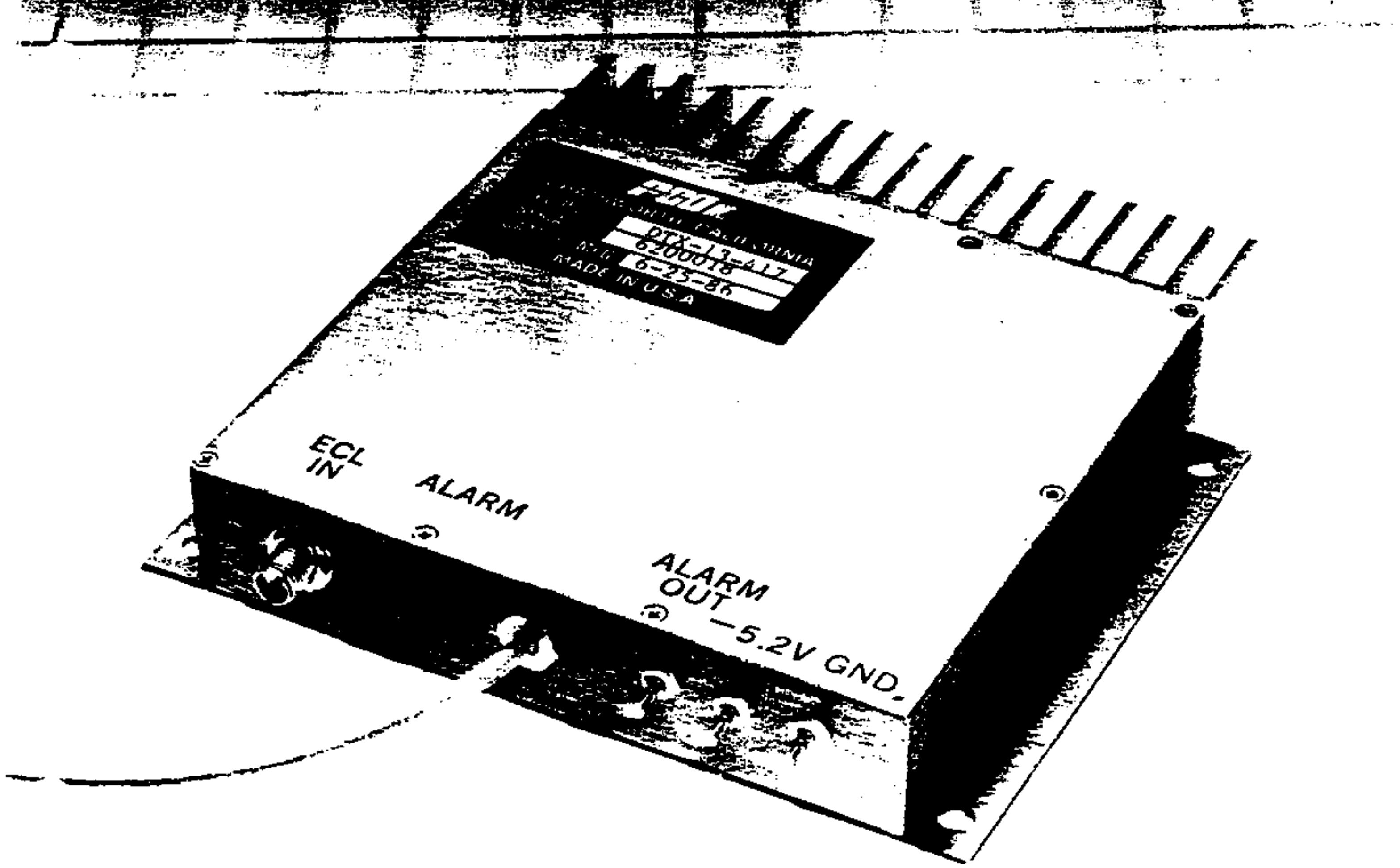
GENERAL DESCRIPTION:

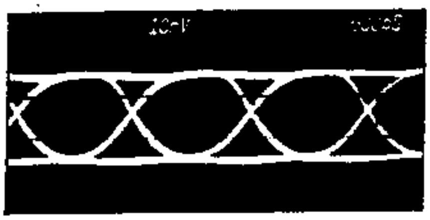
The DTX-13/15-XXX optical transmitter module incorporates an InGaAsP laser diode and associated drive circuitry. An optical feedback loop is used to stabilize the laser output. In addition, the laser temperature is regulated by a thermo-electric cooler (TEC) operated by thermal control loop for high reliability. The drive circuit includes bias control with duty cycle compensation so that an unrestricted input pattern can be transmitted.

The modules are available with 1300 nm or 1550 nm high output, high speed lasers coupled to a variety of fiber pigtails for easy coupling to the transmission fiber. The DTX-13/15-XXX is designed for use in long distance telecommunication systems including those that utilize dispersion-shifted fibers. The module also features a status monitoring LED display and an alarm terminal on the front panel. A fiber optic connector can be provided as an option.

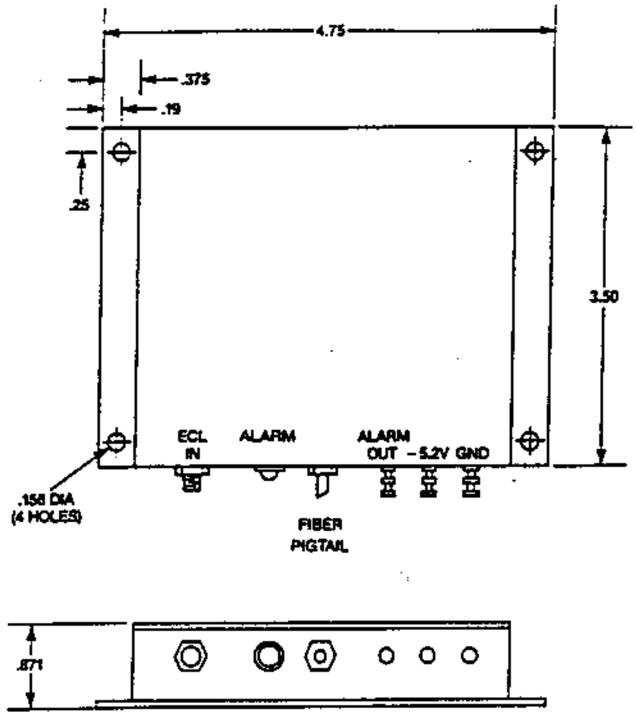
FEATURES:

- 1300 or 1550 nm operating wavelength
- High speed capability (DC to 878 Mb/s)
- High optical power output
- Unrestricted input data pattern
- ECL input logic level
- Optical and thermal stabilization
- Single mode, multimode or dispersion-shifted single mode fiber pigtail
- Various optical connectors available





DTX-13-680
Eye Diagram



MATERIAL: ANODIZED ALUMINUM
DTX-13/15-XXX DIMENSIONS IN INCHES

Operating Characteristics (25°C)								
	DTX-13-XXX			DTX-15-XXX				
	Min	Typ	Max	Min	Typ	Max	Units	Notes
Coupled optical output power Multimode (50/125 micron) Single Mode (9/125 micron)	 −2 −3	 0 −1	 − −	 −3 −3	 0 −1	 −	dBm	1
Threshold current		20	40		20	45	mA	
Peak emission wavelength	1280	1300	1320	1520	1550	1570	nm	
Spectral width (FWHM)	−	3	5	−	5	10	nm	
Extinction ratio	20:1	25:1	−	20:1	25:1	−	−	
Output power stability	−	±0.3	±0.5	−	±0.3	±0.5	dB	2
Supply current	−	0.5	1.5	−	0.5	1.5	Amp	3

Notes:

1. Peak power measured at drive current of 30 mA above threshold with cladding modes completely stripped
2. Measured over temperature range from 0°C to 50°C
3. −5.2V single power supply

DTX-13/15-XXX

Operating Characteristics (25°C)			
Model Number	Recommended Data Rate (Mb/s)	Optical Rise/Fall Time (10-90%;nsec)	
		Typ	Max
DTX-13/15-6.3	6.3	1	1.5
DTX-13/15-17	17	1	1.5
DTX-13/15-45	45	1	1.5
DTX-13/15-90	90	1	1.5
DTX-13/15-140	140	1	1.5
DTX-13/15-200	200	1	1.5
DTX-13/15-417	417	0.7	1
DTX-13/15-565	565	0.7	1
DTX-13/15-678	678	0.5	0.7
DTX-13/15-878	878	0.5	0.7

Notes: 1. Other data rates available on request

Ordering Information:

DTX - 13/15 - XXX

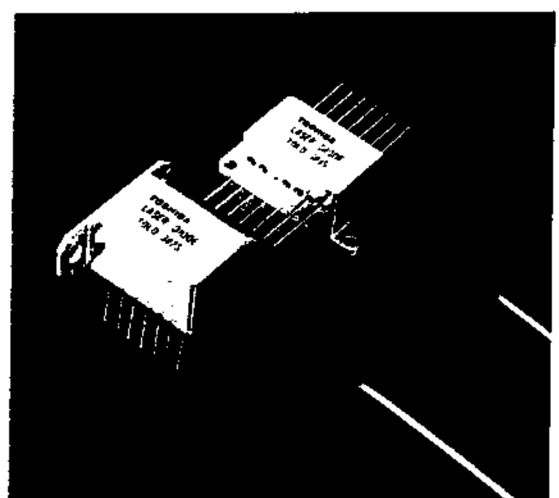
- **Product Code**
- **Wavelength of Operation (1300 nm or 1500 nm)**
- **Data Rate**

TOSHIBA

LASER DIODES
FOR OPTICAL COMMUNICATIONS

DFB Laser Modules
with
Optical Isolator

TOLD332S/333S (1.31μm)
TOLD382S/383S (1.55μm)



TOLD332S/333S
TOLD382S/383S

Applications

- Light source for trunk line, long-distance, large capacity fiber optical communications.
- Light source for optical measuring instruments.

Features

- DFB laser diode modules with built-in optical isolator.
- 1.31/1.55μm wavelengths for lowest-dispersion/lowest attenuation bands.
- Side-mode suppression ratio is greater than 30dB.
- High isolation ratio of 30dB.
- Low RIN of −145dB/Hz.
- High power output of 0.7mW.
- Standard DIL and Butterfly packages.

Optical light reflections created by optical components such as connector surfaces and fiber ends generate noise which degrades the performance of a DFB laser diode.

Toshiba DFB laser diode modules with internal optical isolators provide a practical solution to this problem. These modules feature a high isolation ratio in relation to large side-mode suppression ratio, narrow spectral width, low threshold current, high efficiency, high speed response and low relative intensity noise (RIN).

The TOLD332S/333S/382S/383S are modules with single-mode fiber pigtailed and with oscillation wavelength of 1.31μm/1.55μm. They are available in standard DIL and Butterfly packages.

Each type incorporates a 35dB-optical isolator to prevent noise generation and the degradation of laser diode properties.

Absolute Maximum Ratings (Ta=25°C) (Tentative)

Item	Symbol	Ratings	Units	Notes
Storage temperature	T_{stg}	−20~65	°C	(1)
Operating temperature	T_{opr}	10~60	°C	(1)
Forward current	I_{fl}	150	mA	
Reverse voltage	V_{rl}	2	V	
Optical output power	P_{fl}	2	mW	
PD reverse voltage	V_{rm}	15	V	(2)

Notes
(1) The ambient temperature is equal to the case temperature.
(2) Ge or InGaAs PIN photodiode is available.
(3) Soldering temperature of 180°C and soldering time of 5 seconds should not be exceeded.

Electrical/Optical Characteristics (Ta=25°C) (Tentative)

Item	Symbol	Conditions	Minimum	Typical	Maximum	Units	Notes
Threshold current	I_{th}	CW	—	20	40	mA	(1)
Threshold voltage	V_{th}	$I_f=I_{th}$		1	1.2	V	
Forward voltage	V_f	$I_f=I_{th}+30mA$	—	1.2	1.5	mV	
Optical output power	P_f	$I_f=I_{th}+30mA$		0.7		mW	
Tracking error	ΔP_f	$T_a=10\sim60°C$	—	±0.5		dB	(2)
Peak wavelength	λp	$P_f=0.7mW$	1290	1310	1330	nm	(3)
			1530	1550	1570	nm	(4)
Spectral linewidth (FWTM)	Δλp	$P_f=0.7mW$ *$I_b=I_{th}$	—	0.1	—	nm	(7)
Side-mode suppression ratio	SMSR	$P_f=0.7mW$	30			dB	
Rise/Fall time	t_r/t_f	10~90%, *$I_b=I_{th}$	—	0.3	0.5	ns	(5)
Monitor photocurrent	I_m	$P_f=0.7mW$		0.1	—	mA	(6)
PD dark current	I_d	$V_r=5V$	—	1		μA	(6)
Isolation ratio		$P_f=0.7mW$		30		dB	
Relative intensity noise	RIN	$P_f=0.7mW$		−145		dB/Hz	

*I_b: Bias current

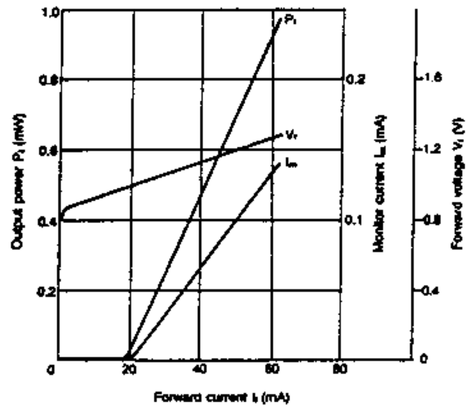
Notes
(1) Threshold current is defined by a second differential method or a linear extrapolation method.
(2) $\Delta P_f=10\log(P_f(T)/P_f(25°C))$, I_m=Const.
(3) TOLD332S/333S
(4) TOLD382S/383S
(5) The modulation current is 30mA.
(6) Ge or InGaAs PIN photodiode is available.
(7) PRBS: 1.8Gbps (NRZ)

Fiber Tail

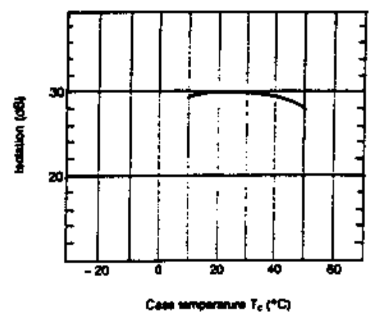
- Fiber type: single mode, self mode stripping
- Cladding diameter: 125±2μm
- Concentricity error: <1μm
- Non-circulation of core: <10%
- Non-circulation of surface: <2%
- Mode field diameter: 10±1μm
- Refractive index difference: 0.3±0.04%
- Length: >1m
- Outer coating diameter: 0.9±0.1mm
- Fiber bendable radius: R>35mm
- Cutoff wavelength: 1.1—1.28μm or 1.13—1.27μm

* Polarization Maintain (PM) fiber is available.
* FC/PC connector is available.

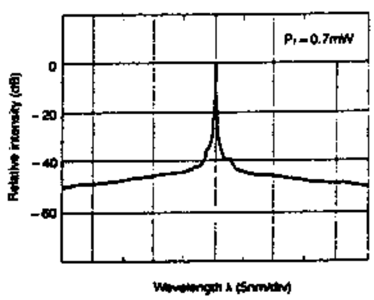
Major Characteristics Curves



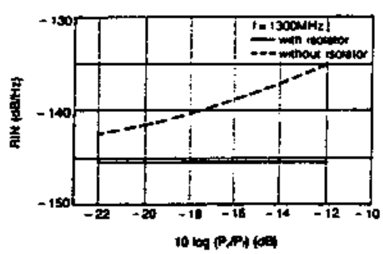
Output power, monitor current and forward voltage VS forward current



Isolation VS case temperature

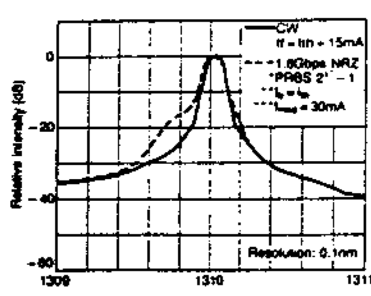


Spectrum

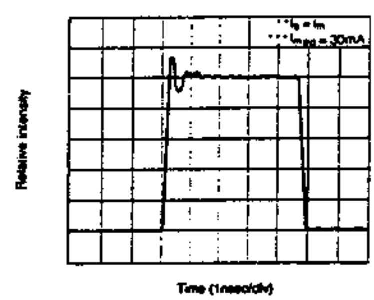


Relative intensity noise

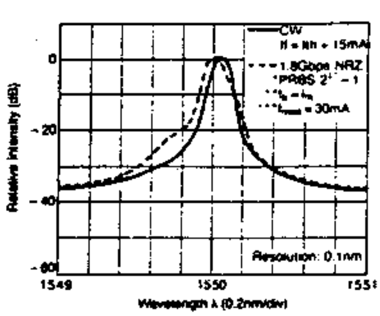
P_r: reflective power



Spectral chirp



Pulse response

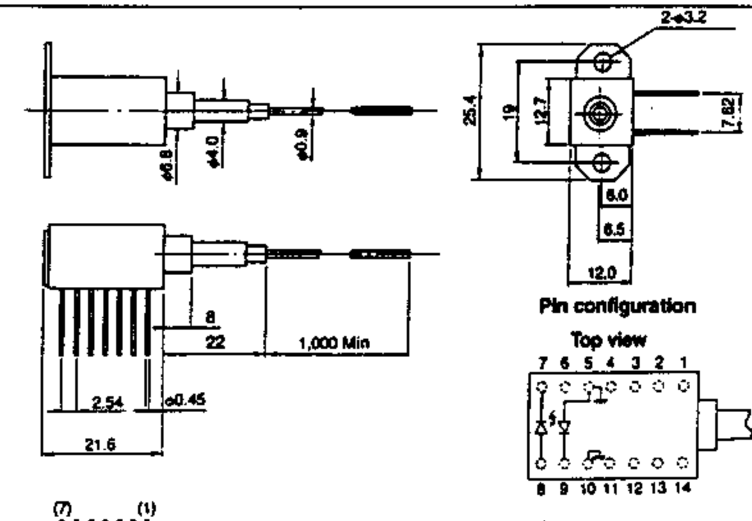


Spectral chirp

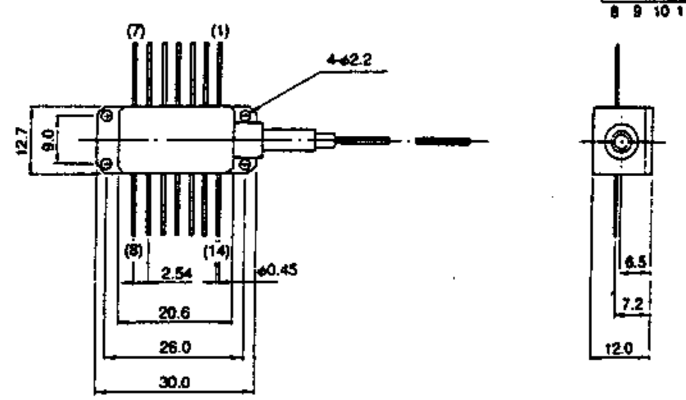
*Mark density 1/2
**I_b: Bias current
***I_{mod}: Modulation current

Dimensional Outlines

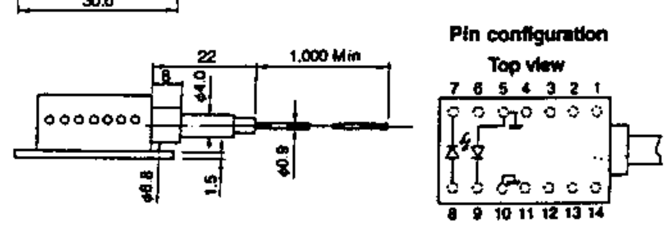
TOLD332S/382S



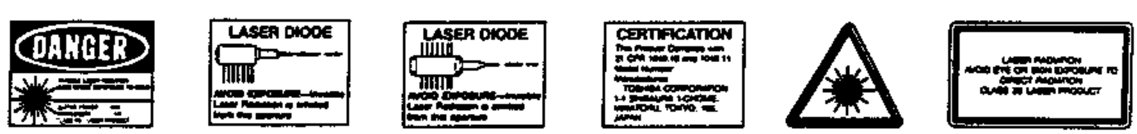
TOLD333S/383S



#	Function
1	N/C
2	N/C
3	N/C
4	N/C
5	Laser anode Case
6	N/C
7	Photodiode cathode
8	Photodiode anode
9	Laser cathode
10	Case
11	N/C
12	N/C
13	N/C
14	N/C



Unit: mm



Precautions

(a) Power supply
Transit voltage may cause the laser output to exceed the absolute maximum ratings.
A surge-free power supply and a slow starter circuit use are recommended.

(b) Safety
The laser light is invisible and may be harmful to human eyes. Don't look directly at the laser emission when the laser diode is operating.

Design and specifications subject to change without notice.

Not working

BT&D British Telecom & DuPont
TECHNOLOGIES

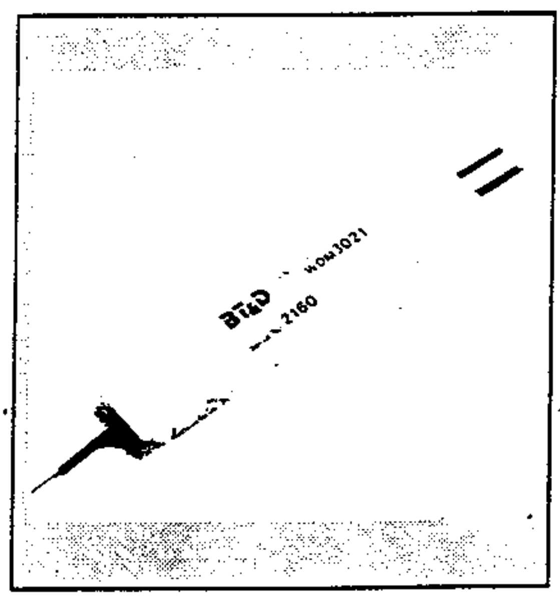
WDM3000
FIBER OPTIC WAVELENGTH DIVISION MULTIPLEXERS

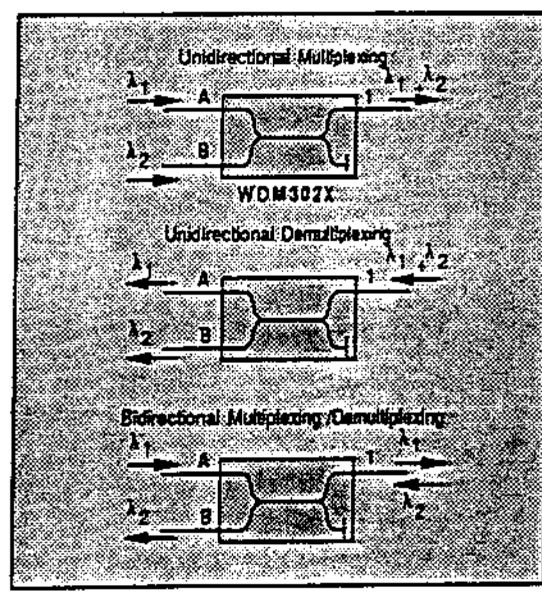
Features

- Superior wavelength isolation -- (>34dB for 20nm bandwidth available)
- Low insertion loss (<0.5dB available)
- Excellent near-end rejection (>60dB)
- Polarization insensitive
- Wide temperature range
- Robust package

Applications

- Dual wavelength transmission systems
- Duplex single fiber links
- Dual wavelength OTDRs
- Low loss signal selection and distribution



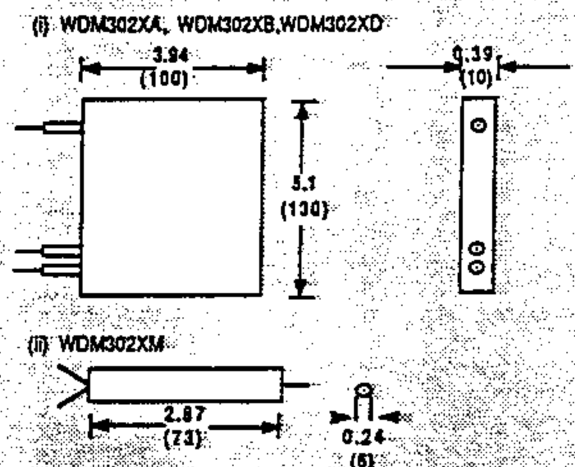


Description

The WDM3000 family of wavelength division multiplexers provides low-loss multiplexing and demultiplexing of two optical wavelengths -- typically 1310nm and 1550nm--in unidirectional or bidirectional single mode transmission systems. Offering superior wavelength isolation, these devices are dual stage versions of the WDM1000 fused biconical tapered multiplexers. They are precision manufactured under computer control and are available in three performance categories to permit cost-effective application in a variety of end uses.

PACKAGE DIMENSIONS

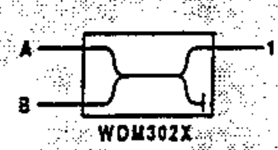
dimensions in inches (millimeters)



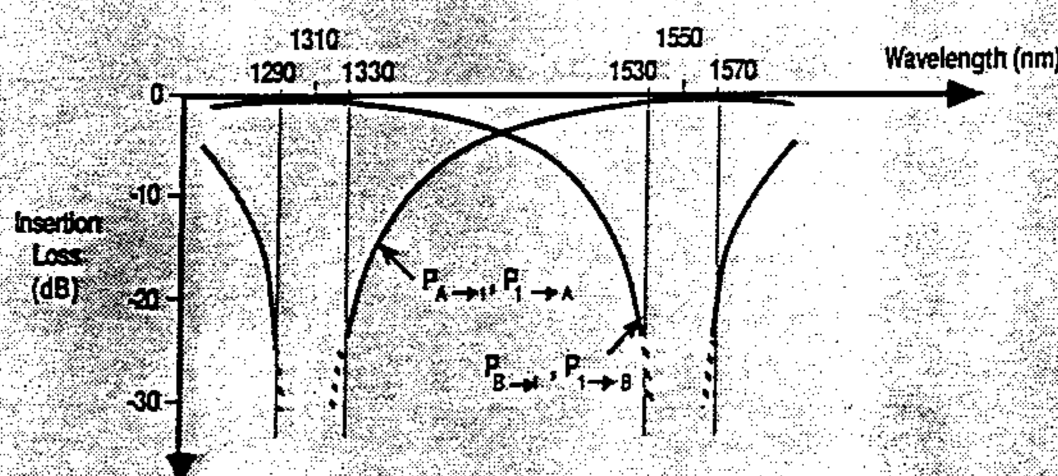
FIBER SPECIFICATION

- Diameter: 125 μm
- Core diameter: 9 μm
- Cutoff wavelength: 1150 to 1200nm
- Mode spot radius: 5 ± .1 μm at 1300 nm wavelength
- Core concentricity: 0.3 μm
- Pigtail length: 1 meter
- Jacket: three types available, see ordering information

PORT CONFIGURATION



TYPICAL SPECTRAL RESPONSE--WDM3022D



APPLICATION NOTES

1. Increased bandwidth optical fiber transmission links

The capacity of an existing optical optical fiber transmission link can be approximately doubled using two WDM couplers to permit multiplexing/ demultiplexing of two wavelengths onto a single transmission fiber (Figure 1). These two wavelengths will typically be 1310nm and 1550nm, corresponding to the two low-loss transmission windows of silica fibers.

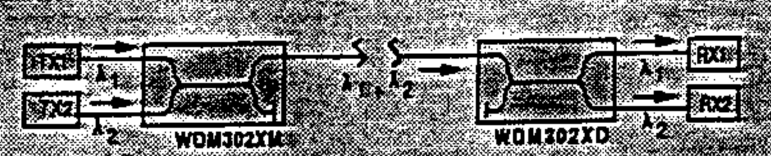
The insertion loss introduced by the WDM couplers is very low -- less than 0.7dB for a WDM3022M/WDM3022D pair at the optimum operating wavelengths. The WDM3000 devices offer excellent wavelength isolation, minimizing crosstalk between output ports at the receiver end.

Optimum wavelength isolation can be achieved only when the WDM operating wavelength is closely matched to the transmission wavelengths. BT&D welcomes inquiries for customer operating wavelength requirements.

For systems requiring less wavelength isolation and lower insertion loss, the WDM1000/WDM2000 devices are recommended.

This use of WDM couplers offers many attractive features. It minimizes fiber usage and offers entirely passive multiplexing of signals without the need for any electronics. Another important feature is the ability to multiplex different signal formats; for example, digital and analog lightwave signals can coexist on a single fiberlink.

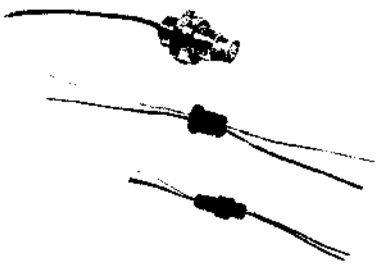
Figure 1: Unidirectional dual wavelength system



35

Transducers, Sensors & Controls

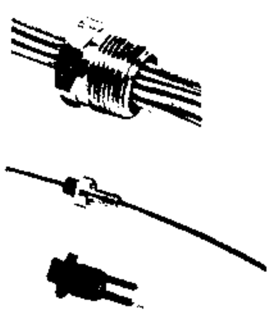
(Sealing your leads from sensor thru controls to actuator)



REQUIREMENTS:	PRODUCTS:
Sealing the electronics cavity	Easy-to install, sealed single or multi-lead feedthrus in NPT plugs or nipples.
Sensor power or signal lead seals	Sealed leads in easy to install housings with 2, 3 or 7 leads (AWG #22 thru AWG #28).
Custom feedthru mounting schemes	Proprietary process allows direct seal-casting of leads to thin wall housings.
Sealed connectors	Connectors of any type can be sealed. We can also provide sealed harness/connectors.

Fluid Filled Devices

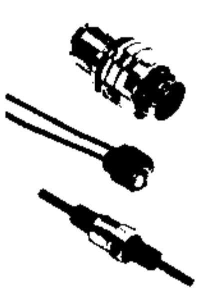
(Transformers, X-ray heads, computers)



REQUIREMENTS:	PRODUCTS:
CT Leads thru wall of oil-transformer	We offer a standard line of 5, 10 and 15 wires, AWG #12 for CT outlets in a 1" NPT housing.
Temperature, alarm & control circuits	Single & Multi-Wire feedthrus (including thermocouples) in standard NPT fittings or in custom housing of any type.
Truly reliable sealing of lead wires thru the wall of x-ray heads.	Single wire or multi-wire 1/4" or 3/8" straight thread fittings.
Multi Conductor Feedthrus	Custom designed harness feedthrus in special housings designed to fit your enclosure.
Fluid filled, sealed transducers.	Metal housings with a wide variety of wires for permanent weld or 'o' ring mounting on sensors to 5,000 PSI.

Pressurized Devices

(Undersea, explosion containment, well head, submersed or sealed motors)



REQUIREMENTS:	PRODUCTS:
High pressure capabilities	We can seal and test virtually any connector(s) to 10,000 PSI.
Undersea applications	Water tight, high pressure, wire and cable penetrations can include connector assemblies.
Fiberoptic cables	Our OptiSeal™ line of pressure sealed fiberoptic cables are readily available in any length with multiple channels.
Multi-conductor cables	Easily accommodated and thoroughly sealed in our broad range of housings.
Heavy current studs	Capacity to 750 amps for hermetically sealed compressors.

We welcome inquiries on new or unusual applications. Challenge us!

Spec Sht. 6

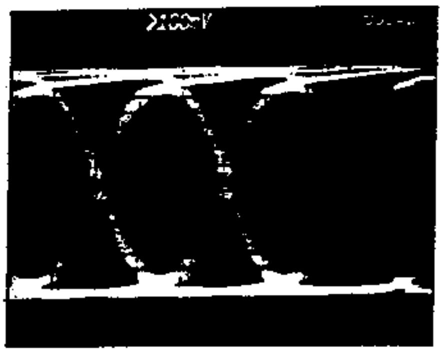
GENERAL DESCRIPTION:

The DRX-13/15-XXX Optical Receiver incorporates an InGaAs PINFET low noise hybrid preamplifier for high detection sensitivity followed by complete associated receiving circuits. These include a main amplifier with automatic gain control, a shaping filter, and a high speed comparator to generate ECL logic signal output. The unit is normally provided with a 50/125 fiber pigtail. Fiber optic connectors and other pigtail sizes may also be specified by the customer.

The DRX-13/15-XXX receiver module is designed for use in high capacity long distance telecommunications and other applications requiring high sensitivity receivers. It can be used over the entire long wavelength region from 1.1-1.6μm. Dynamic range is over 25 dB.

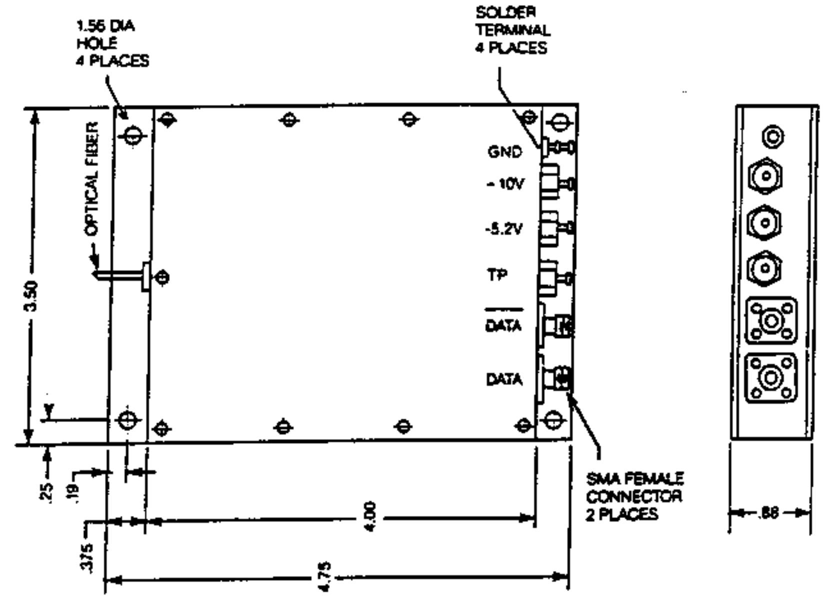
FEATURES:

- Long Wavelength (1.1-1.6μm)
- High speed capability (up to 878 Mb/s)
- High detection sensitivity
- Wide dynamic range
- ECL data and clock output when used with DCR-XXX Clock Recovery Module



DRX-13-678

PINFET Optical Receiver
Eye Diagram



Operating Characteristics (25°C)

Model Number	Data Rate[1] (Mb/s)	Sensitivity[2] (dBm)	
		Min	Typical
DRX-13/15-6.3	6.3	−53	−55
DRX-13/15-17	17	−48	−50
DRX-13/15-45	45	−44	−46
DRX-13/15-90	90	−41	−43
DRX-13/15-140	140	−39	−41
DRX-13/15-200	200	−37	−39
DRX-13/15-417	417	−33	−35
DRX-13/15-565	565	−31	−33
DRX-13/15-678	678	−30	−32
DRX-13/15-678	878	−27	−29

ABSOLUTE MAXIMUM RATINGS:

Operating temperature: −20 to +70°C
Storage temperature: −40 to +80°C

Notes:

1. Other rates available on request
2. Sensitivity is for 10^{-9} BER at 1300 nm. Sensitivity at 1550 nm is typically 0.5 dB better
3. Typical rise and fall times are 1.5 ns for bit rates up to and including 140 Mb/s and 1 ns for higher bit rates.

PCO

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