Executive Summary

PURPOSE: There is currently an opportunity to acquire and use retiring fiber optic submarine telecommunications cable systems to provide infrastructure for ocean observing systems. The cable systems, with an original capital investment of over $2B, are being retired well before their design lifetime because of conditions in the industry. Economics require the disposal of these systems as quickly as possible after they are retired, thus the academic community must decide quickly whether these assets can and should be acquired. The purpose of this workshop was to obtain the advice of experts with experience in the design and operation of the SL 280/560 cable systems concerning the feasibility and possible methods of using these cable systems to provide power and data infrastructure for observatory networks.

FINDINGS:

1) There appears to be no significant technical roadblocks in re-use of the cable systems for ocean observatory arrays.

2) While the three primary objectives in the implementation of submarine telecommunications systems are reliability, reliability, and reliability, the re-use of these systems for scientific observatories must also allow for considerable flexibility, and the ability to add and upgrade hardware on the ocean floor. This fact will likely degrade the total system reliability, but that decrease is a necessary consequence of the intended use.

3) Repeaters in these systems require that the cable provide a constant current of 1.6 A DC. The PFE (Power Feed Equipment) can supply voltages up to 7.5 kV. If both ends of the cable are powered, two PFEs are used an 15 kV is available to the system. Observatory power systems would be series loads that drop the voltage at each observatory node and provide a voltage source to observatory electronics. A similar supply is currently in use at the Hawaii-2 Observatory.

4) The observatory power supply must convert the constant-current cable power to a constant-voltage power system suitable for electronic systems with variable loads and negative impedance switching power supplies.

5) At least two data telemetry choices are available. Both will require development of a chip set, and the advantages of one over the other have yet to be determined.

6) It is important to preserve the current station hardware and protocols that allow control of the repeaters and identification of cable faults.

7) Wet-mateable electrical and optical connectors at observatory nodes are a critical technology for ocean observatories. These connectors provide the flexibility demanded of a research observatory, but they also represent potential failure points. The engineering community is reluctant to embrace the use of these connectors in critical locations unless high reliability can be firmly established.
8) Acquisition of spares and cable system hardware are important steps in use of these systems for ocean observatories. Re-manufacture of equipment now available for only storage cost would likely be prohibitively expensive.

9) It should be possible to install a prototype observatory node on a retired optical cable within two years.

10) A work force of highly qualified engineers to perform the design and specifications functions for the necessary equipment to utilize these cable systems for observatory networks exists in New Jersey.

9) While funding for construction of an observatory at Station ALOHA connected to the HAW-4 cable has been awarded, it will not cover the expense of design and construction of critical equipment necessary for use of retired optical systems. Careful design of these components will make it possible to install observatories not only at Station ALOHA, but at numerous other locations.

RECOMMENDATIONS:

1) We recommend that all useful hardware and spares available (as determined by industry experts familiar with the re-use possibilities and available funds) be protected from disposal. Initial steps have already been taken in this area.

2) We recommend that a design and construction effort for critical sub-systems necessary for re-use as observatories be begun as soon as possible.

3) We recommend that the highly qualified engineering work force available in New Jersey be utilized for the design and specification of the necessary equipment that will make it possible to re-use all of the retiring systems for scientific observatories.
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AGENDA:

Sept 30

08:00 breakfast
09:00 Introductions
09:10 Welcome
09:15 Purpose and Scope – Duennebier
09:20 IRIS and the Cable Re-use Opportunity – Butler
10:00 Existing Observatories, architectures, and ALOHA – Duennebier
10:15 LEO-15 and Coastal Observatories – Glenn
10:30 Duennebier cont.
11:05 Power systems for constant-current observatories- Harris
12:00 lunch
13:00 Communications to observatories: Tremblay
15:30 Break-out groups
   A) Communications (Tremblay)
   B) Power (Harris)
   C) Node connection mechanical (Duennebier)

Oct 01

08:00 breakfast
09:00 summaries of break-outs
11:00 break-out again
12:00 lunch
13:00 summaries
14:00 next step in development
14:30 adjourn

SYSTEM ARCHITECTURE

The AT&T SL280/560 Sub marine Cable Systems were originally engineered to maximize end-end system traffic availability as required in telecommunication networks. This goal was achieved by designing an extremely reliable wet-plant, incorporating automatic undersea regenerator span and laser restoration switching via SCOUT (System for Control Of Undersea Transmission), automatic system/terminal line PFE (Power Feed Equipment) switching, and automatic TTE (Terminal Transmission Equipment) protection. In addition, terminal equipment is designed to support a Mean-Time-To-Repair (MTTR) of 1-hour (staffed station) and 4-hours (non-staffed station). Telecommunication systems also incorporate detection and logging of fault and performance information on a timely basis (typically 1-second).

Since this high availability level is not required for undersea observatory data communications and, indeed, the fact that there are no net revenues involved, directs the focus
towards a minimum cost approach (funding is usually at a premium). This does not mean that reliability can be compromised, however; just that automatic protection/restoration with its associated cost overhead need not be considered. Minimum cost would include minimizing both design and maintenance costs. Note that with the exception of communication support equipment in the undersea observatory nodes, the wet-plant costs are not affected (recovering and moving undersea cables are considered separate issues).

The attendees generally agreed to a wet-plant architecture consisting of an Observatory Node, a Junction Box containing both data and power conditioning sub-systems (in separate bottles), and the Observatory, containing access to the system for experiments (FIGURE 1). These sub-systems are discussed below. Architecture options presented in pre-meeting documents by Mark Tremblay were used as a basis for discussion. These documents are presented in the appendices.

![Diagram](image)

**Figure 1:** Functional concept of a 280/560 Observatory Connection. The cable is cut and a hybrid connector is installed at each end. When not in use, the two ends are connected by an umbilical (see Figure 2).

One important feature of this node architecture is its flexibility. For example, an in-line node location could initially be operated as an end-node by bringing in a Sea Ground assembly and

Experts Workshop on Sl 280/560 Cable Re-Use for Observatories
leaving the rest of the system unconnected; it can then be reconnected as an in-line node (retrieve the Sea Ground) when other in-line nodes and/or an end-node are added to the system. When used as an End Node, each fiber pair is looped-back in the Junction box. Also note that a malfunctioning Junction Box can be bypassed if a replacement is not immediately available and that the overall system remains operational.

**OBSERVATORY NODE**

The Observatory Node is the cable connection to the observatory. There are many issues to consider in the design and operation of the observatory connection to the 280/560 systems. The series electrical connection must pass the current to the observatory where power is removed by dropping the voltage on the cable. The Observatory Node must also pass the data from at least one fiber to the observatory for detection of commands, timing, and addition of data from experiments. The remaining fibers could pass through the node without going to the observatory. Several options for the node connection were discussed, including systems requiring no wet-mateable connectors that were deemed too restrictive and inflexible for the observatory application. In another plan, a branching unit split out the power and one fiber for use by the observatory, but installation and repair costs were deemed considerably higher than the plan below. Since wet-mateable connectors are required for both power and fiber communications, the most flexible system passes all fibers and power to the observatory. In this case it will be possible in some situations to install observatories without using large cable ships. Installation could proceed as follows:

1) The cable is cut on the ocean floor using an ROV or cable cutter.
2) The cable is grappled and brought to the surface about 1 water depth back from one of the cut ends.
3) The cable is cut, terminated with a connector, and lowered back to the bottom (Figure 2).
4) The other cut end is recovered and a section of cable long enough to reach the other end is spliced on.
5) A connector termination is added, and the cable is lowered to the bottom with the end as close as possible to the other end.
6) A ROV takes an umbilical to the bottom and connects the two ends (Figure 2) restoring full functionality to the cable.

The above Observatory Node scenario has many advantages over concepts that add branches to the cable:

- In many situations, no cable ship will be required.
- Minimal extra cable is added to the original system.
- A faulty connector can be recovered and replaced with a new (and possibly improved) connector without requiring a cable ship.
- Hardware development is minimal.
- All fibers are available at each node.
- Connectors can be easily made accessible to ROVs.

In shallow water (continental shelf depths), it will be possible to design a node connection that can be easily brought to the surface for servicing and connection to the junction box without the
use of wet-mateable connectors. This is particularly important where biofouling is likely to make wet mating of connectors difficult. Nodes in shallow water will be easier to maintain and repair than deep-water nodes, greatly improving long-term reliability. Shallow nodes must also be protected from storm and fishing damage using technology developed for observatories such as LEO-15.

![Figure 2. Observatory Node Option](image)

In this option, the cable is cut, both sides are terminated with a connector, and the connectors are co-located and connected by an umbilical if an observatory is not ready for installation.

There was considerable discussion of wet-mateable connector reliability. Even if they have reasonably high reliability, the connectors will still likely represent the weakest link in the observatory system. The above scenario relieves some of that concern, since all connectors will be recoverable without a cable ship. In this research application, loss of data because of a failure, while very undesirable, does not have a huge cost, as it does in the telecommunications application. Thus, high reliability can be cost-effectively be traded for loss of data and a much lower cost. Ship time for repairs will not be easily obtained, however, and every attempt should be made to improve reliability as the budget allows.

POWER MODULE SUB-SYSTEM

The Power Module will be housed at the Junction Box, but removable by ROV for repair or upgrade. The critical requirement of the Power Module is to transform the constant-current cable power to a constant-voltage supply for observatory hotel and experiment loads. It was generally accepted that the user power interface would be a 48 VDC power bus protected by (programmable) circuit breakers, with a much higher voltage bus when there is considerable distance between the Junction Box and the Observatory. 48 VDC is the same value chosen for the NEPTUNE user
system, thus hardware (observatories and experiments) developed for NEPTUNE could also be operated on the re-used cables.

A power system currently in use at the Hawaii-2 Observatory (H2O) utilizes a shunt regulator system to locally convert the constant-current cable supply to a constant-voltage source for the observatory (Petitt et al, 2002, Harris and Duennebier, 2002). This system, developed by David Harris at the University of Hawaii, was heavily discussed in one of the break-out groups.

Creating a power interface between the SL280/SL560 cable systems and Cabled Ocean Bottom Observatories presents intricacies beyond what would be expected for power systems and “bench” electronics. The basic reasons are four-fold:

1) Telecommunications cables are so long that cable resistance and capacitance become very important circuit elements.
2) The telecommunications cable power system was designed to be extremely stable and uniform, while the science community and their power needs tend to be highly variable and unpredictable by the very nature of the experimental process.
3) The SL280 cable system operates from a regulated current source, while observatory systems will require a constant voltage power source. Supply of constant voltage power from a constant current source is fundamentally unstable. While stability can and must be locally imposed at the observatory node, this instability is never far below the surface.
4) The consequences of this instability are more serious than might be expected. In a typical power system, a transient load may only produce a transient in the power bus. In the cable-observatory power configuration, a transient load can easily produce a collapse of the power bus even if the original transient is only of short duration. A transient from one Observatory Node could trigger the collapse of the power bus in an adjacent observatory. If the observatory system control channel is incapacitated by the collapse, then the only way to recover could be to power down the cable.

The very nature of the supply, with multiple switching converters and shunt regulators, cannot be made as reliable as a Zener diode, the low voltage power source used for the repeaters, but a significant level of serviceability and flexibility is needed for the observatories. The converters themselves can be made and tested to fairly high reliability (they are after all the ultimate in simplicity, being unregulated and independent) and the configuration can survive multiple module failures with only marginal loss of functionality, so the power modules should be able to be engineered to “second tier” levels. Also, with the multiple converter modules, they will be switching about 100 volts each, which vastly improves the reliability.

There seemed to be general agreement that these issues are real and of legitimate concern. Specific questions raised in the power system working group concerning the steps needed to address problems when designing the power system for the 280/560 systems are presented below:

1) Throughout the open session and the power group meeting, there was considerable emphasis on the desirability of basic simplification to enhance ultimate reliability. The H2O design provides substantial backup provision with no increase in circuit complexity beyond that already required for power increment adjustment, however, the stack switches which allow power increments to turn on and off have had considerable reliability problems in H2O. At
some point the simplification process begins to compromise the flexibility of the system for controlling stability and the ability to monitor and diagnose problems. In areas where “soft” failure modes make system failure much less likely, flexibility and monitoring should prevail. Trade-offs among flexibility, reliability, and simplification need further evaluation. Avoidance of “feature creep” – the temptation to add features that may add some functionality, but at the cost of increased complexity and lower reliability - is important.

2) Since there is the potential for one user to collapse the power bus by error or electrical failure, it will be important to define specifications for the User Power Interface and provide access to a system test bed. Specifications could include limits on peak-to-average current drain and/or a requirement for using local DC-DC converters with under-voltage (brown-out) protection, and the use of programmable circuit breakers. There must be established procedures for qualifying a user instrument prior to deployment.

3) The H2O power supply has switches to turn on and off power supply stacks and thus control the power dissipated by the observatory. It was suggested that the switches add complexity and cost reliability, and that a fixed-wattage power module configuration would be more reliable. The maximum power could be hardware-configured prior to deployment.

4) An increase in the overall observatory power to accommodate added instruments could be accomplished by swapping the power module at the time the instruments are deployed. A consequence of this design is the necessity to dissipate unused power. Even spare modules must be kept powered, and all power up to the anticipated maximum load that is not used by the observatory must be dissipated. Heat is a concern, particularly within titanium pressure vessels. A “heat tube” could be devised to take the excess heat out of the pressure vessel and dissipate it from an oil-filled tube.

Managing experiment power dynamics should be accomplished by careful choice of hardware:

° All users should be prohibited from using "wide range" converters since they have a larger transient current at start-up. The power bus will be well regulated, so there is no need for such converters. On the other hand, converters with "brown-out protection" generally ramp up their reference voltage to limit inrush current, protecting the power system.

° Programmable circuit breakers can be set to provide headroom above the experiment operating point. A fault on a user's equipment will trip that breaker without collapsing the system. If the observatory power is configured to handle the total programmed breaker load, then even simultaneous overloads by all users would not affect system stability. Since simultaneous faults are extremely unlikely, some compromise in terms of Observatory reserve may be reasonable.

5) A design review should include a vigorous review of test procedures, results of previous tests and failures, and power management procedures.

6) A suggestion evolved to provide a Power Module control channel from the observatory Module to eliminate the need for communications between the Junction Box and the Power Module. This can be as simple as a RS-422 channel in the power cable (RS-422 is viable up to 10 kms at 9.6 kb/s; 20 kms at 4.8 kb/s; 40 kms at 2.4 kb/s, etc). This RS-422 line is already at sea ground potential and it affords the maximum flexibility for the power and observatory modules to negotiate power issues.

7) The repeaters are capable of surviving a fault current of over 100 Amps. Since the observatory load is in series (like a repeater), the question arose as to whether the Power Modules could also survive a similar event. The difference is in the relative voltage drop (800
V for an observatory vs. 22 V (43 V for 560-system repeaters) Volts for a repeater). This makes it considerably more difficult to afford the same degree of protection to the observatories as are present in the repeaters. On the other hand, such fault currents could only be caused by a highly unlikely cable breakdown. Also, the Power Module is far more easily and cheaply retrievable and repairable. A breakdown in the power module itself could cause a fairly large fault current and incapacitate the system. (The cable surge impedance was said to be about 27 ohms.) Protection can be provided by a TVS (Transient Voltage Suppressor), protecting the circuits from transients up to several kW.

8) A 25 Hz tone at about 100mA is superimposed on the 1.6 A line current for location of buried cables out to about 500km. Will the power supplies affect or disrupt this capability? This capability could be very important for coastal observatory installation. Should this capability be needed, it should be possible to switch off all observatories between the affected area and the cable station prior to testing.

9) It is critical that power modules input circuits fail in a shorted mode to maintain continuity to the remaining cable. The power converter and output portions of the power module can have lower reliability because their failure effects only the local experiment and not the entire system.

10) The power-up ramp is an unregulated PWM ramp until the current feedback takes over. The effects of “undefined” voltage mode at low currents should be explored, but are probably not significant.

11) Development of a 400 volt power supply to extend the distance between the Junction Box and the Observatory should be deferred until the need arises for an observatory at significant distance from the cable route. Addition of such a module could involve just adding a voltage multiplier/rectifier module to generate the higher voltage.

There are several items to be addressed for the power system:

1) Further define Power Module interface and control issues.
2) Evaluate Power Module fault protection options. Even if the Power Module does not survive a fault, it must maintain the continuity of the line.
3) Specify the user power interface and procedures for full experiment qualification prior to deployment.
4) Specify guidelines, recommendations and limitations on user power dynamics to educate the science user group and ease power management problems.

COMMUNICATIONS MODULE

The optical communications on the 280/560 systems is accomplished using a single wavelength of light that is regenerated periodically (about every 70 km). The signal travels one-way along a fiber, with a pair of fibers constituting a complete bidirectional path. Six fibers are present in all SL cables configured as two working fiber pairs and one protection fiber pair. Each repeater has the ability to loop-back fibers or to switch from a working fiber pair to the protection fiber pair.

The present SL280 and SL560 line signal formats provide two major functions: 1) line maintenance support; and, 2) the transport of 140 Mb/s PDH traffic (note that the 140 Mb/s traffic
transport is “clear channel”; that is, the information content is never examined with only Code-Mark-Inversion and clock recovery taking place. The former will still be required to maintain the wet-plant and, thus, the SCOUT and TTE will be kept as-is with no modifications (keeping development costs low). The latter 140 Mb/s traffic transport function is no longer required. Instead, a new 100 Mb/s Ethernet traffic transport “clear channel” function is required in its place (only layer 1 Ethernet processing is performed; that is, optical to electrical conversion and clock recovery). This new function is shown as the CHANNEL MULTIPLEXER connecting directly to the TTE regenerator in Figure 3 and as the COMMS LINK (shorthand for the complementary regenerator/multiplex function) in the Junction Box in Figure 1. While we will include the basic line supervisory channel capability (24B1P; 24 data-1 parity) in the line format associated with the CHANNEL MULTIPLEXER at essentially no additional development cost, the remaining TTE functions supporting this capability will not be developed at this time since the original TTE is already available (if warranted, this can be visited years down the road).

There were discussions on Ethernet protocols and the less than maximum efficient use of the available line system bandwidth. It must be emphasized that the approach presented above makes the line system communication transport function independent of the Ethernet communications between the end-user and the observatories. This approach also allows line people to focus on the line transmission, and Ethernet communication people to focus on end-user to observatory communications. This leaves only the 100Base-FX layer 1 protocol as being common between the two efforts.

Communications between the observatories and scientists and system operators require that data from the observatory are sent to shore from each experiment, and commands to the observatory nodes and experiments be interpreted and acted on by the appropriate devices in the observatories. On the shore-end it appears that the most efficient way to disseminate data and enter commands into the system is via Ethernet protocol.

A corresponding terminal architecture for the above system is shown in Figure 3 below, depicting the basic terminal components: PFE, SCOUT, TTE and the new Channel Multiplexer. The original SL280 terminal subsystems are used (without modification) for line powering and for line maintenance. The Channel Multiplexer line rate signals replace the TTE multiplexer working line rate signals for node communications. Note that the TTE PDH (Plesiosynchronous Digital Hierarchy) interfaces are not used at any time. The architecture for the terminal equipment is further specified in APPENDICES 1 and 3.
OBSERVATORY MODULE

The Observatory Module is where scientists can plug in their instruments and send their data back to shore. Observatory Modules can be built in many configurations, the simplest having access to one 100 Mb/s Ethernet link, a 48 V power bus, and connections for many experiments. A power module capable of supplying 800 W to an observatory is well within current capabilities, and modules to increase the available power could be added at a later time. The only constraints on the Observatory Module are that it must conform to the Junction Box architecture requirements of power and communications. Observatory Modules were not discussed in detail at this workshop, since they are not part of the backbone infrastructure. It will be highly desirable to conform connections between the Junction Box and Observatory Modules with the architecture of NEPTUNE and other observatories.

RELIABILITY:

In the architecture above, reliability concerns decrease from top to bottom. The Observatory Nodes must have very high reliability, since failure (in deep water) would result in either an expensive repair. The primary reliability concern in the Observatory Node design as envisioned is the wet mateable connection to the Junction Box. The rated reliability of these connectors would certainly be unacceptable to the commercial telecom industry, but the required flexibility of a research observatory appears to require the connectivity function. Discussions with vendors and acquisition of reliability data are needed.

Reliability of the Junction Box and Observatory Nodes is important for science, but these components will be designed such that Junction Box failure will be unlikely to cause failure of the cable system. Since these systems can be recovered, repaired, and replaced using ROVs, their reliability is considerably less critical than that of the Observatory Node. It was agreed that allowing decreases by factors of 10 in each layer of the system as one move from the Observatory Node down to the Observatory would be acceptable given that we can keep the Observatory Node FIT rate in the low hundreds.
SUMMARY

There appear to be no roadblocks in the development of observatory systems using retired 280/560 SL cable systems as infrastructure. It is possible to design systems with any number of observatory nodes on a cable up to the excess power available, which in turn depends on the cable length. Since each node will have a fixed amount of power available, independent of that used by other nodes, power control should be relatively simple. Reliability will depend mainly on the reliability of the hybrid wet mateable connectors used, although no repair should require a cable ship. Costs of the required infrastructure hardware development should be less than $4M.
Appendix 1

UNDERSEA NODE ARCHITECTURES AND MAINTENANCE CONSIDERATIONS USING AT&T SL280 SYSTEMS

M. D. Tremblay

INTRODUCTION

The node architecture depicted in this appendix shows how a generic set of node building blocks could be used to obtain different node configurations for use of AT&T SL280 Submarine cable systems for scientific studies. The major issue in this approach is the reliability of wet-mateable connectors.

BACKGROUND

The AT&T SL280 Submarine Cable Systems were originally engineered to maximize end-end system traffic availability as required in telecommunication networks. This goal was achieved by designing an extremely reliable wet-plant, incorporating automatic undersea regenerator span and laser restoration switching via SCOUT (System for Control Of Undersea Transmission), automatic system/terminal line PFE (Power Feed Equipment) switching, and automatic TTE (Terminal Transmission Equipment) protection. In addition, terminal equipment is designed to support a Mean-Time-To-Repair (MTTR) of 1-hour (staffed station) and 4-hours (non-staffed station). Telecommunication systems also incorporate detection and logging of fault and performance information on a timely basis (typically 1-second).

Since this high availability level is not required for undersea observatory data communications and, indeed, the fact that there are no net revenues involved, directs the focus towards a minimum cost approach (funding is usually at a premium). This does not mean that reliability can be compromised, however; just that automatic protection/restoration with its associated cost overhead need not be considered. Minimum cost would include keeping down both design and maintenance cost. Note that with the exception of communication support equipment in the undersea observatory nodes, the wet-plant cost are not affected (recovering and moving undersea cables are considered separate issues).

This paper provides the system architecture of the terminal to observatory node communication path with the objectives of a) minimizing node and terminal communication electronics, and b) keeping the ability to maintain the SL280 wet-plant. This document can then be used as source material for detail specifications suitable for equipment procurement.

SYSTEM ARCHITECTURE

System deployments are expected to fall into two categories: a) systems powered to sea ground and, b) systems with end-end powering. The first type would support (0 – N) in-line observatory nodes and (1) end-node; while the second type would support (1-N) in-line observatory nodes. In both
cases, the value \( N \) is determined by the system power available for observatory use. This architecture was chosen to minimize wet-plant node and dry-plant terminal development while keeping the existing imbedded SL280 system maintenance capabilities.

**FIGURE 1: TYPICAL SYSTEM DEPLOYMENTS** provides a pictorial representation of both deployment types. End-end powered systems would usually employ transmission loopbacks at the repeater following the last node controlled by a particular terminal. This insures that the round-trip communication path is no longer than the original end-end communication path (the reasons are discussed later). Note that an end-end powered system is essentially operated as two independent systems from the communication point view with Ethernet access at each terminal location. In either case, it is possible to test prototype observatory communications at cable stations prior to deployment by utilizing the TTE connectivity and wet-plant repeater loopback capabilities.

![SINGLE-ENDED-POWERING](image1)

![DUAL-ENDED POWERING](image2)

**FIGURE 1: TYPICAL SYSTEM DEPLOYMENTS**

**Node Architecture**

**FIGURE 2: GENERAL NODE ARCHITECTURE** depicts the basic node components: Junction Box, Connector (passive), Sea Ground (passive) and Observatory. The various components are interconnected via umbilical cables consisting of fiber and power conductors. Junction Boxes provide the 100 Mb/s Ethernet to optical line data rate translation, as well as, constant-current to constant-voltage power conversion between the repeatered line and the Observatories. Each
Observatory has access to two 100 Mb/s Ethernet channels associated with one of the two working fiber pairs (the spare fiber pair is reserved for repeater span switching as per the original SL280 design). It is also possible to have multiple Junction Boxes/Observatories at any node subject to the available overall system power..

Terminal Architecture

**FIGURE 2: GENERAL NODE ARCHITECTURE**

**FIGURE 3: TERMINAL ARCHITECTURE** depicts the basic terminal components: PFE, SCOUT, TTE and the new Channel Multiplexer. The original SL280 terminal subsystems are used (without modification) for line powering and for line maintenance. The Channel Multiplexer line rate signals replace the TTE multiplexer working line rate signals for node communications. The TTE PDH (Plesiosynchronous Digital Hierarchy) interfaces are not use.
Major Features

Overall, this architectural approach was chosen to maintain adequate repeater span margins; to minimize development and fabrication cost; to provide deployment flexibility; and, to minimize installation and maintenance cost.

The major effects on terminal architecture are that:

1) No changes to the terminal subsystems are required;
2) Full SL280 system maintenance functionality retained;
3) The TTE can easily be converted from one mode of operation to the other;
4) 400 Mbit/s total communication system capacity is supported.

The major effects on node architecture are that:

1) **There is no branching device with its associated costs;**
2) In-line node locations can be realized with a minimum of additional cable (less than 0.5 kms) as compared to what is required for branching device technology (approximately 2.5 time the site water depth);
3) The in-line node thru fiber path loss is approximately 3 dB, this is 2-4 dB less than a branching device architecture thus maintaining adequate repeater span margin;
4) There is no differentiation between in-line and end node equipment types,
5) On-site node fiber-pair assignment;
6) On-site node bypass capability;
7) On-site node type reconfiguration (e.g.: operating an intended in-line node as an end-node);
8) Essentially identical deployment and maintenance procedures can be use for both in-line and end nodes.
One very important feature of this node architecture is that configurations may be altered at will, subject to overall system constraints such as power, system length, data channel utilization, etc. For example, an in-line node location could initially be operated as an end-node by bringing in a Sea Ground assembly and leaving the rest of the system unconnected; it can then be reconnected as an in-line node (retrieve the Sea Ground) when other in-line nodes and/or an end-node are added to the system. Also note that a problem Junction Box can be bypassed if a replacement is not immediately available and that the overall system remains operational for failed or missing Observatories.

More detail information on the terminal subsystems, including the new channel multiplexer, is provided in Appendix 1A: Terminal Subsystems.

More detail information on the node architecture is provided in Appendix 1B: Detail Node Architecture.

Appendix 1C: Alternate Node Architectures reflects the use of more expensive wet-plant branching devices similar to that present used on some SL280 systems. These architectures are included in this document for historical and completeness reasons.
Appendix 1A: Terminal Subsystems

There are four primary terminal subsystems comprising the SL280 System: PFE, SCOUT which is sometimes called the Home Supervisory Unit (HSU), TTE and TML (Transmission Monitor Logger). A modified version of the HSU, called a Remote Supervisory Unit (RSU) was also used on systems having a mid-ocean meet with non-AT&T system segments (e.g.; the TAT-8 and TPC-3 Systems). And, finally, Mini-SALT (System for Laying and Testing) is available for ship repair and laying operations and can also be used in terminals when appropriate.

Let us look at each of these in turn:

**PFE:** The PFE can be used as is. Some operational cost may be reduced by powering down redundant equipment. However, in some cases one may see a slightly higher equipment failure rate due to not load-sharing. The PFE can also be replaced by commercially available power supplies in some applications and/or as PFE spare parts become unobtainable.

**SCOUT (HSU):** Wet-plant transmission fault location and subsequent restoration through regenerator laser switching and regenerator span switching are provided via the SCOUT computer. The SCOUT computer can be used as is in concert with the standard TTE (the system data base will have to be edited, however, to reflect the any system reconfiguration). The SCOUT computer and associated TTE support functions could be removed if one is willing to rely only on Mini-SALT for wet-plant fault location (not recommended; see mini-SALT comments, below). The SCOUT computer software has recently (within the last three years) been ported to a desktop workstation substantially increasing its maintainability. This effort also included SALT capabilities. The latter is extremely important since the standard SCOUT computer software was designed to support automatic wet-plant fault location and restoration with many user safeguards which would not be applicable in this situation.

**TTE:** Cannot be used as is to support Ethernet communications; that is, interfacing at the PDH (Plesiosynchronous Digital Hierarchy) 140 Mbit/s level. Doing so would result in maximum design effort and substantial amounts of new equipment for both the terminal and the observatory nodes. In turn, this would reduce the amount of scientific equipment at the nodes and/or reduce the number of available nodes on a cable. Finally, it would result in higher operational cost.

Observatory data communications can best be achieved by only utilizing the TTE optical transmit/receive equipment which were specifically designed for the SL280 systems (actually incorporated many of the same components used in the repeaters). Minimum development is realized by keeping the existing TTE to support line maintenance with the SCOUT computer running the SALT software (it’s possible to actually use the automatic fault location feature of the SCOUT software for a system with only in-line nodes and landings at both ends; however, it is not recommended). Note that most TTE fault and performance parameters can still be monitored in both TTE configurations (certain connections being established) and that it is also possible to provide some monitoring of any new terminal function.
New terminal function:

Communications to the observatories attached to the SL280 cable systems will be via the Fast Ethernet protocol for data transmission at 100 Mb/s.

**Clear Channel Multiplexer:** This circuit will multiplex two 100Base-FX Ethernet signals (let’s denote them as communication channels 1 and 2) to the 295.6 Mbit/s line rate (line supervisory support formatting is not included since the original TTE will be used for that function). The term “Clear Channel” is used to denote that only optical to electrical conversion and clock recovery functions are performed, thus keeping the terminal and node communication electronics to a minimum. The Clear-channel Multiplexer will include a pseudorandom bit scrambler to insure sufficient transition density, a frame marker different than that used in the standard SL280 line format, overhead bits for data bit-stuffing and overhead bits for node regenerator laser switching. The different line formats are used to control node operation in support of normal data transmission or line maintenance activity. The FX Ethernet interface version is chosen to provide complete electrical isolation to the observatories (F stands for fiber interface) and ease in making the entire SL280 repeatered system transparent to the Ethernet data format.

**Figure 1** depicts how the new Clear-Channel Multiplexer interfaces to the existing SL280 TTE with connection to fiber pair 2 shown. Connection to fiber pair 1 would be via a second clear channel multiplexer. Connecting the fiber pair 1 or fiber pair 2 Clear-Channel Multiplexer to the protection fiber pair would only be done if a shore repeater span transposition switch is in effect. Manually disconnecting the Clear-Channel Multiplexer via the already existing front panel coaxial jacks automatically applies the standard SL280 signal in support of wet-plant maintenance activity.

NOTE: Some of the TTE equipment could be removed in the interest of minimizing floor space. However, since the equipment can be powered down, the decision should be delayed until a later date
**TML:** The TML is eliminated as a separate physical entity with the software having been ported to the new SCOUT platform. The function, or parts thereof, can still be used, especially for PFE line current and voltage monitoring and TTE/overall system monitoring with appropriate interpretations.

**Mini-SALT:** Portable equipment that provides line transmission and supervisory for one fiber pair and connects directly to the optical line. Can be permanently kept in or brought to the cable station as desired. Many of the Mini-SALT components are the same as those in the TTE and SCOUT; thus, one could use TTE/SCOUT components for Mini-SALT or vice-versa. **NOTE:** AT&T has disliked using and has not kept this equipment up to date. Its use may be relegated to certain ship activities and may require some upgrade effort.
Appendix 1B: Detail Node Architecture

Undersea nodes must contain 100 Mb/s data transport equipment to support communications to and from the scientific observatories. For the most part, the data transport equipment mirrors the Clear-Channel Multiplex used in the terminal. However, it must mimic a 100 Mbit/s bus and also support passing the standard SL280 signal for line fault location. Some long systems may physically have both cable ends terminated on shore for powering purposes; however, transmission connectivity would be configured as having end-nodes as seen from the shore ends. In either case, it is possible to test prototype observatory communications at cable stations prior to deployment by utilizing the TTE line access points and wet-plant repeater loopback capabilities.

**Figure B1: Node Communication Architecture** depicts the node transmission functional components and connectivity. Any node can be configured:

- a) connector to connector;
- b) Connector to Sea Ground;
- c) Connector to Junction Box;
- d) Junction Box to Junction Box and
- e) Junction Box to Observatory.

The basis for all this flexibility is in the design of the single umbilical cable type used between the various node components. **Figure B2: Umbilical Conductor Assignment** illustrates one possible implementation of the fiber and electrical conductor assignment. The umbilical consists of (6) fiber and (2) electrical conductors with the plug assignment arranged, as shown, in a circular pattern at 45 degrees intervals. Umbilical applications on the line side utilize all (6) fiber and (1) electrical (at a time) conductors; applications on the Observatory side utilize (4) fiber and (2) electrical conductors. Junction Box line fiber pair assignment is achieved by inserting the umbilical oriented at 0 or rotated 180 degrees at the Junction Box end. The Junction Box to Observatory connection always presents both data channels with channel selection being an Observatory function.

Returning to **Figure B1**, which illustrates a typical configurations, we see that the in-line node has both Junction Box line side connections in the 0 degree position and, thus, is connected to fiber pair #1 (solid line). The end-node has both Junction Box line side connections in the 180 degree position and, thus, is connected to fiber pair #2 (dotted line). The double reversal achieved in the 180 degree position insures that fiber pair #1 and #2 line assignments and spare line pair transmit/receive directionality are maintained. Transmission availability is optimized if the node connections are split between fiber pairs. Note that the Sea Ground connection point includes fiber pair loopbacks; otherwise, this function would have to be included as an option in the Junction Box.

**Figure B1** shows both nodes as having their Observatory-side connections in the 0 degree position; however, the 180 degree position is not supported since, while it would reverse the channel #1 and #2 assignments, it would unfortunately reverse the power polarity. Observatories can be designed to have one or two data channel ports as desired with two ports being recommended due to the ability of surviving a single port failure (either in the Junction Box or Observatory) thus diminishing the need for repair activities.
The components depicted in Figure B1 allow for node reconfiguration in support of node deployment alternatives and node fault bypass capability. An interesting example is one in which the only way to restore traffic over a repeater span containing an in-line node utilizing that particular fiber pair is to perform a span switch to the protection fiber pair. Such a condition results in completely isolating that particular node from a communication point of view. While doing a line repair would restore connectivity, communications to that node can be more easily and less expensively restored by reconnecting the Junction Box line side umbilicals to select the other working fiber pair.

Other supporting node architecture items are:

1) An Umbilical Cable technology with the desired optical and electrical connectivity is commercially available. While including more fibers and/or electrical conductors than what is required in any given connection increases the basic cost, having only one umbilical type, larger purchase quantities of a single type and requiring fewer spare units should actually result in an overall cost savings for umbilical cables.

2) All Connectors are identical regardless of their use: in-line or end-node applications. Connectors always mate to the standard SL cable and do not need dual power conductors as is the case with branching units.

3) The Sea Ground connection hardware can be the same as that used for the Connectors. It may be possible to leverage the Connector hardware in the Sea Ground function described herein.

4) The Junction Box complexity is kept at a minimum. In other words, there are no options other than a unit address code applied at manufacturing which is required to perform regenerator laser switching from the shore station.

5) The Junction Box connections require dual keying capability. This is possibly a new feature associated with the presently available commercial product.

6) While there are more connectors and more expensive connection hardware (items 2-5), this cost is more than compensated for by not using branching devices and other factors such as higher installation and maintenance cost. The commercially available wet-mateable connection hardware is rated to 10K psi, greater than 100 matings (certified to 200 matings) before recommended refurbishing, and 25-year life.

7) It is possible to have more than one Junction Box/Observatory at a given node location by connecting Junction Boxes in tandem (series?) at the same observatory node.

A relative comparison of the node architecture detailed above and an architecture utilizing a branching device and a combined Junction Box/Observatory is as follows:

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DEVELOPMENT/UNIT COST</th>
<th>DEPLOYMENT/MAINTENANCE COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector (2)</td>
<td>low</td>
<td>low/med</td>
</tr>
<tr>
<td>Ocean Ground</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Junction Box</td>
<td>med</td>
<td>low</td>
</tr>
<tr>
<td>Observatory</td>
<td>n/a*</td>
<td>n/a*</td>
</tr>
<tr>
<td>Branching Device</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Connector (1)</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

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Timing Jitter and Increase Span Loss Effects on Bit Error Performance:

Junction Box regenerator laser redundancy:

Junction Box communication equipment reliability:

The Junction Box communication hardware availability is maximized by first utilizing the highly reliable SL280 regenerator for the T and R functions which also provides access to all line clock and data signals required for the multiplexing function. Secondly, the synchronous nature of the 100Base-FX interface protocol reduces the amount of bit-stuffing control electronics; that is, all the overhead bits, including bit-stuffing, can be passed straight through.

Junction Box regenerator laser redundancy:

Junction Box regenerator transmitter laser switching is provided via the standard SL280 SCOUT System. The only modification required is the establishment of unique repeater/regenerator addresses for the regenerator physically located in the Junction Box (addresses are set via simple jumpers on the regenerator unit) and editing the SCOUT database to include the new addresses.

Timing Jitter and Increase Span Loss Effects on Bit Error Performance:

At first glance, it would appear that timing jitter would increase due to looping the line signal at the end-node location which, in turn would increase the bit error rate. One should note, however, that the actual round-trip path length would not be significantly longer than the
original commercial path length due to the nature of expected typical observatory deployments. Most commercial systems will be segmented to form two or more smaller systems terminating at one shore only. This is also true for an end-end power feed arrangement whereby transmission loopbacks would be established in the middle of the system forming two functionally independent transmission systems. In-line and end nodes would introduce timing jitter equivalent to one regenerator for the appropriate fiber pair. The small additional jitter may be considered insignificant considering the approximate square-root-of-N jitter addition, where N equals the number of regenerators.

**Junction Box Power Supplies:**

Two power functions are required in the Junction Box: 1) regenerator/multiplexer ensemble power; and, 2) observatory power. The first power supply utilizes low wattage highly reliable series powering similar to that used in SL280 repeaters. The second power supply will have a 800 Watt capacity for observatory use and is realized via a constant-current to constant-voltage DC/DC switching power supply generating isolated 400 Vdc. Load-side isolation prevents observatories from having to withstand line voltages in excess of 10kV, a potentially costly endeavor. Note that a failure of the second less reliable power supply that does not involve the primary side results in losing that particular node’s observatory while the rest of the system remains operational.

**Node communication faults:**

There are two general types of node communication faults: single node and all nodes.

A single node communication fault would most likely be an Observatory fault with the Junction Box and umbilical cabling to the Observatory being less likely possibilities.

An all node communication fault would most likely be a Junction Box multiplexer (D/M) or a regenerator (R/T) fault with the Connector, Branch, umbilical cable and fiber cables being less likely; a span failure elsewhere in the system or a system power fault. Manually switching to the standard SL280 line signal would quickly verify that a multiplexer is at fault if the standard TTE demultiplexer goes in-frame. Determining the faulty node for a multiplexer fault is accomplished by manually making (through SCOUT) a repeater span switch for all spans that contain a node until the faulty node is identified (procedure would include going back and forth between line signal types to verify multiplexer operation). Determining the location of all other faults (including Junction Box power supply) is accomplished by using standard SL280 fault location procedures. A repeater span switch over a span containing an in-line node or a loopback switch for an end-node that results in through transmission would indicate that the failure is in that node (the next action to then take would be to do a Junction Box laser switch). Note that both types of node failures can result in isolating the failed node from the system thus keeping other nodes operational while waiting for repair activities.
Overall Node Reliability:

The node is defined as being comprised of two Connectors (or one Connector and one Ocean Ground), the Junction Box, the umbilical cables between the Connectors or Ocean Ground and the Junction Box (the umbilical between the Junction Box and the Observatory is deemed as being part of the Observatory). The use of the extremely reliable AT&T SL regenerator hardware in the Junction Box assures that the majority of the node failure allocation is reserved for the Junction Box multiplexer and node power supply, the primary new hardware components that need to be designed.

As a basis for discussion, let us assume that any given Observatory has to be visited at least every two years for whatever reason. Setting the node reliability objective to be approximately ten times better than the Observatory visit rate would insure that the majority of node visits would be for scientific and not node maintenance activities. Based on this goal, a system with four nodes would thus be expected to have a node failure approximately every 5 years. During that time period there would likely be 10 or more Observatory visits for a four-node system.

The calculated node FITs (Failure in Time (per 1B years)) based on the discussion above is approximately 6000. This value is between one and two orders of magnitude less stringent than the values associated with the SL repeater technology and should be achievable without the need for the extensive costly qualification efforts normally undertaken in submarine cable systems. Previously qualified components should be used where applicable and cost effective. And, finally, careful observance of established engineering practices in all areas should make the node reliability objective an achievable goal.
**FIGURE B1: NODE COMMUNICATION ARCHITECTURE**

- **R**: REGENERATOR
- **D**: DEMULTIPLEXER
- **T**: TRANSMIT LASER
- **M**: MULTIPLEXER
- **I**: NORM CLOSED ELEC RELAY
- **X**: NORM OPEN ELEC RELAY

*NOTE: SOLID/DASHED LINES IN THE JUNCTION BOX AND OCEAN GROUND DEPICT SIGNAL PATHS ONLY; ACTUAL FIBER CONNECTIONS WITHIN EACH UNIT DO NOT CHANGE.*
**FIGURE 5: UMBILICAL CONDUCTOR ASSIGNMENT**

<table>
<thead>
<tr>
<th>Option</th>
<th>Conductor:</th>
<th>PA</th>
<th>PB</th>
<th>1A</th>
<th>1B</th>
<th>2A</th>
<th>2B</th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Pair #1 to Junction Box</td>
<td>0</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>thru</td>
<td>thru</td>
<td>thru</td>
<td>thru</td>
</tr>
<tr>
<td>Fiber Pair #2 to Junction Box</td>
<td>180</td>
<td>-</td>
<td>X</td>
<td>thru</td>
<td>thru</td>
<td>X</td>
<td>X</td>
<td>thru</td>
<td>thru</td>
</tr>
<tr>
<td>Data ch #1 &amp; #2 to Observatory</td>
<td>0</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
</tbody>
</table>
APPENDIX 2:

NODE 100BASE-FX ETHERNET CLEAR-CHANNEL MULDIX REQUIREMENTS

M. D. Tremblay

Purpose

This document presents the functional requirements for the Node (Junction Box) 100BASE-FX Ethernet Clear-Channel Muldex used for undersea scientific observatory applications over retired AT&T SL280 Line System.

1 Overview

The Node 100Base-FX Ethernet Clear-Channel Muldex (the term “Muldex” denotes a multiplexer/de-multiplexer pair) is the complement of the Terminal Muldex (see document: Terminal 100Base-FX Ethernet Clear-Channel Muldex Requirements). The approach of performing only 100BASE-FX optical to electrical conversion allows the entire reused SL280 line system to be transparent to Ethernet communications to/from the undersea observatories; thus, the system operates essentially as a 100BASE-FX Ethernet ring.

While the Node Muldex requirements do not include all of the Terminal Muldex requirements, there are two node-specific requirements: a) original SL280 pass-thru capability to support line fault location using the standard embedded SL280 maintenance capabilities; and, b) tributary (Ethernet) pass-thru to maintain overall communication for a failed or missing Node Observatory.

The requirements contained here are consistent with and in support of document: Junction Box Requirements.

The nomenclature used in this document is as follows:

1) \textit{Rxxx} denotes a specific requirement that must be met. As a rule, only one function will be included in any one requirement statement;
2) \textit{Oxxx} denotes an objective that is deemed nice to have but not absolutely necessary;
3) \textit{Ixxx} denotes an information statement that may be useful in interpreting requirements and objectives;
4) Each section starts numbering at the x10 where x is 0 for the first section and 1 plus the last number used in the previous section for subsequent sections;
5) \textbf{R} statement numbering initially increments by 10 starting at \textbf{R010} to allow for inserting additional statement (\textbf{Rxx1-Rxx4}) in subsequent document releases;
6) \textbf{O} statement numbering initially increments by 10 starting at \textbf{O015} to allow for inserting additional statements (\textbf{Oxx6-Oxx9}) in subsequent document releases;
7) \textbf{R} and \textbf{O} statement numbering are in combined increasing order;
8) \textit{I} statements use the same number as the corresponding \textbf{R} or \textbf{O} statement;
9) Any deleted statements will remain in the document and have the term \textit{(deleted)} entered immediately after the statement number.
2 Document References

The following document references are either cited directly or may be useful in interpreting requirements, objectives and information statements contained herein (NOTE: AT&T refers to AT&T, AT&T Bell Laboratories or AT&T Laboratories; and, documents originally issued by AT&T may now be indicated as being tycom or tycotelecom documents):

1) SL280 Terminal Transmission Equipment Reuse Requirements, prepared for the Research Corporation of the University of Hawaii, School of Ocean, Earth, Sciences and Technology
2) Terminal 100Base-FX Ethernet Clear-Channel Muldex Requirements, prepared for the Research Corporation of the University of Hawaii, School of Ocean, Earth, Sciences and Technology
3) Node Junction Box Requirements, (pending)
4) Node Junction Box Regenerator Requirements, (pending)
5) IEEE 802.3-2002 IEEE Standard for Information Technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications

3 Node Muldex Functional Requirements

This section provides the functional requirements for the Node (Junction Box) 100Base-FX Clear-Channel Muldex (heretofore referred to as “Node Muldex”). Note that since the Node Muldex performs the inverse function with respect to the Terminal Muldex and to keep with the transmission flow, the Node Muldex de-multiplexer requirements are presented before the Node Muldex multiplexer requirements. This approach is reflected in FIGURE 1: Node Muldex Interfaces.

3.1 Node Muldex Unit Requirements

This section provides physical and environmental requirements for the Node Muldex Unit.

R010: The Node Muldex Unit shall consist of a single unit with dimension that facilitates interfacing to the SL280 Regenerator.

I010: SL280 Regenerator Assembly is approximate 17 inches long, 6 inches tapering down to 3 inches wide and 6 inches deep (six such assemblies are mounted in a circular arrangement around a central hub in a standard repeater). Having some Node Muldex Unit dimensional commonality with the regenerator should facilitate coaxial and power wiring routing between the two; and, should enable the use of common physical mounting within the Junction Box.

R020: All Node Muldex Unit coaxial connections to/from the Node Regenerator shall be made with 50-Ohm RG-402, or equivalent, semi-rigid coaxial cable using 50-Ohm SMA (Sub-Miniature-A) plugs.
I020: The SL280 Regenerator has a number of clock and data signals which must be connected to the Node Muldex Unit.

R030: The Node Muldex Unit shall physically share a common chassis ground with the SL280 Regenerator Assembly whose interconnection resistance is less than 0.01 Ohms.

I030: This allows the SL280 Regenerator and Node Muldex Unit to be treated as one functional entity for all electrical signals including power.

R040: The Node Muldex Unit shall operate over a temperature range of 0 – 30 °C (to be confirmed).

I040: While the deep water operating temperature range is expected to be less than 10 °C, testing at the assembly stage is performed at nominal room temperature. The design must, of course, be verified over the entire temperature range.

R050: (reserved for voltage isolation)

R060: (reserved for shock and vibration)

3.2 **Node Muldex Interface Requirements**

This section provides the input and output interface requirements for the Node Muldex Unit. The requirements are generally presented in the order of transmission.

R110: The Node Muldex Unit shall operate off the SL280 Regenerator power supply $+14.0 \times 0.6$, $+7.0 \pm 0.3$ or $-7.0 \pm 0.3$ Voltage sources.

I110: SL280 Regenerator power supply, which was designed to power three regenerators, should have more than enough capacity to power both the single regenerator and the Node Muldex Unit. DC-DC converters will most likely be required if lower voltage values are required.

R120: The Node Muldex de-multiplexer shall accept a 295.6 MHz ± 880 Hz AC-coupled 88-142 mV p-p line clock signal terminated into a 50-Ohm impedance having a minimum return loss of 20 dB.

I120: The SL280 Regenerator has a clock signal (CK MON) available at J2. Care should be taken with the receive line clock and line data signal phase relationship (usually achieved by setting the rising clock edge in the middle of the data pulse) to insure proper data re-clocking. This can be achieved by adjusting the coaxial cable length if the Node Muldex de-multiplexer does not include an internal means of adjusting clock phase.

R130: The Node Muldex de-multiplexer shall accept the following SL280 Regenerator 295.6 Mbit/s AC coupled 260-450 mV p-p data signals terminated into a 50-Ohms impedance having a
minimum return loss of 20 dB and having a rise time of $\square$ 1.4 ns (10-90% amplitude points) with a maximum ripple of 20%:

- $\overline{D}1$ (J1 on SL280 Regenerator)
- $\overline{D}2$ (J2 on SL280 Regenerator)
- $D2$ (J4 on SL280 Regenerator)

**I130:** $D1$ and $\overline{D}1$ are used to provide connectivity directly to the SL280 Regenerator transmit lasers when the Node Muldex is in an out-of-frame condition (see **R240** for additional information). $D2$ is used as the input signal to the Node Muldex demultiplexer.

**R140:** The Node Muldex shall physically terminate two IEEE 802.3 100Base-FX Ethernet channels via SC optical connectors using single-mode optical fiber.

**I140:** Multi-mode fiber is normally used for 100Base-FX Ethernet. Single mode fiber capability is specified to support having a single fiber type for all undersea node optical connections.

**R150:** The Node Muldex multiplexer shall output both $DATA$ and $\overline{DATA}$ 295.6 Mbit/s AC coupled signals at 260-450 mV p-p amplitude into 50-Ohms and $\square$ 1.4 nanoseconds (ns) rise time (10-90% amplitude points) with less than 20% ripple.

**I150:** The objective is to provide an electrical line signal compatible with that provided by the receive portion of the SL280 Regenerator and to insure proper operation with the transmit portion of the SL280 Regenerator. The line data signals are applied to the SL280 Regenerator connectors J17 ($OUT$) and J16 ($\overline{OUT}$) inputs associated with the redundant transmit laser.

### 3.3 Node Muldex De-multiplexer Requirements

This section provides the de-multiplexer functional requirements.

**R200:** The Node Muldex de-multiplexer framing algorithm shall be as specified in document: *Terminal 100Base-FX Ethernet Clear-Channel Muldex Requirements*.

**O210:** The Node Muldex de-multiplexer shall provide a loss-of-frame indication.

**I210:** The indication would be used for testing only and is in common with the Terminal Muldex requirements. The indicator may be via a LED (Light Emitting Diode) as is done by the Terminal Muldex or by any other simple locally accessible means.

**O220:** The Node Muldex de-multiplexer shall provide an isolated line parity error test point via a 50-Ohm SMA connector.

**I220:** The requirement may serve as an aid in testing the Node Muldex. It is also in common with the Terminal Node Muldex de-multiplexer.
R230: The Node Muldex de-multiplexer framing state shall control the Node Muldex multiplexer output signal selection as follows:
   1) Out-of-frame: SL280 Regenerator $D_1$ and $\overline{D_1}$ line data signals identified in R130;
   2) In-frame: line $DATA$ and $\overline{DATA}$ from the multiplexer.

R240: The Node Muldex de-multiplexer shall provide a line clock signal to the Node Muldex multiplexer as to meet the requirements in Section 4.4 below.

R250: The Node Muldex de-multiplexer shall pass the, at a minimum, the tributary data signals to the Node Muldex multiplexer.

I250: This requirement helps supports overall system communications for a failed or missing Node Observatory.

R260: The Node Muldex de-multiplexer shall output no tributary signals (no light) whenever the de-multiplexer is in an out-of-frame condition.

I260: Having no-light when in an out-of-frame condition increases the lifetime of the 100Base-FX light sources. This requirement is also in common with the Terminal Muldex.

3.4 Node Muldex Multiplexer Requirements
This section provides the Node Muldex multiplexer functional requirements.

R200: The Node Muldex multiplexer shall use the clock (R240) and data signals (R250) from the Node Muldex de-multiplexer in support of its multiplexing functions as appropriate.

R210: The Node Muldex multiplexer shall perform optical-to-electrical conversion, clock recovery and data retiming on the two IEEE 802.3 100Base-FX Ethernet channels independently (no other signal processing is required).

R220: The Node Muldex multiplexer tributary incoming signal loss state shall control the tributary input signal selection as follows:
   • Loss of tributary incoming signal:: pass through the appropriate tributary data signal from the Node Muldex de-multiplexer;
   • Tributary incoming signal present: multiplex the incoming tributary signal into the line signal format.

R230: The Node Muldex multiplexer line format shall be as specified in document: Terminal 100Base-FX Ethernet Clear-Channel Muldex Requirements.

I250: This requirement can be met by using a copy of the incoming line data signal from the Node Muldex de-multiplexer or by creating the format anew as is done in the Terminal Muldex.
4 Reliability
This section provides reliability requirements for the Node Muldex.

R410: The Node Muldex shall not have more than one failure for the expected 15-year lifetime of the equipment with 95% confidence.

I210: This requirement may seem overly restrictive and potentially costly. However, it is about two orders of magnitude less restrictive than the original requirements for the SL280 Regenerator.

5 Documentation
R510: Documentation in the form of appropriate schematic, equipment and/or handbook drawings and certification/qualification procedures shall be provided to support engineering, manufacturing, procurement, installation, operation and maintenance functions.

FIGURE 1:
APPENDIX 3

TERMINAL 100BASE-FX ETHERNET CLEAR-CHANNEL MULDEX REQUIREMENTS

M. D. Tremblay

Purpose

This document presents the functional requirements for the Terminal 100BASE-FX Ethernet Clear-Channel Muldex used for undersea scientific observatory applications over retired AT&T SL280 Line System

1 Overview

The line format used on the AT&T SL280 Systems does not allow for a cost-effective approach for providing 100 Mbit/s Ethernet connectivity to undersea scientific observatories. Considerable hardware, combined with an extensive development effort, would be required for both the terminal and observatory node locations. The alternative is to provide a simple 100 Mbit/s Ethernet clear-channel multiplex that has the primary advantage of keeping observatory communication hardware to a minimum (the term “clear” is used to denote that the actual Ethernet data content is not examined in the multiplexing processed).

The Terminal 100Base-FX Ethernet Clear-Channel Muldex (the term “Muldex” denotes a multiplexer/de-multiplexer pair) multiplexes two 100 Mbit/s Ethernet channels, along with sufficient housekeeping overhead bits, to form a new 295.6 Mbit/s line signal. The approach of performing only 100BASE-FX optical to electrical conversion and clock recovery allows the entire reused SL280 line system to be transparent to Ethernet communications to/from the undersea observatories; the system operates essentially as a 100BASE-FX Ethernet ring. A Node 100Base-FX Ethernet Clear-Channel Muldex provides the corresponding multiplexer functions at the undersea observatory node locations.

The requirements contained here are consistent with and in support of document: SL280 TERMINAL TRANSMISSION EQUIPMENT RESUSE REQUIREMENTS.

The nomenclature used in this document is as follows:

1) Rxxx denotes a specific requirement that must be met. As a rule, only one function will be included in any one requirement statement;
2) Oxxx denotes an objective that is deemed nice to have but not absolutely necessary;
3) Ixxx denotes an information statement that may be useful in interpreting requirements and objectives;
4) Each section starts numbering at the x10 where x is 0 for the first section and 1plus the last number used in the previous section for subsequent sections;
5) R statement numbering initially increments by 10 starting at R010 to allow for inserting additional statement (Rxx1-Rxx4) in subsequent document releases;
6) O statement numbering initially increments by 10 starting at O015 to allow for inserting additional statements(Oxx6-Oxx9) in subsequent document releases;
7) **R and O** statement numbering are in combined increasing order;
8) **I** statements use the same number as the corresponding **R** or **O** statement;
9) Any deleted statements will remain in the document and have the term **(deleted)** entered immediately after the statement number.

## 2 Document References

The following document references are either cited directly or may be useful in interpreting requirements, objectives and information statements contained herein (NOTE: **AT&T** refers to **AT&T, AT&T Bell Laboratories** or **AT&T Laboratories**; and, documents originally issued by **AT&T** may now be indicated as being **tycom** or **tycotelemc** documents):

1) **SL280 Terminal Transmission Equipment Reuse Requirements**, prepared for the Research Corporation of the University of Hawaii, School of Ocean, Earth, Sciences and Technology
2) **Node 100Base-FX Ethernet Clear-Channel Muldex Requirements**, prepared for the Research Corporation of the University of Hawaii, School of Ocean, Earth, Sciences and Technology
3) **Node 100BASE-FX Ethernet Clear-Channel Muldex**, prepared for the Research Corporation of the University of Hawaii, School of Ocean, Earth, Sciences and Technology
4) **IEEE 802.3-2002 IEEE Standard for Information Technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications**
5) **Network Equipment Building System (NEBS), Telecordia Technologies**

## 3 Terminal Muldex Functional Requirements

This section provides the functional requirements for the Terminal 100Base-FX Clear-Channel Muldex (heretofore referred to as “Terminal Muldex”). Some requirements are also in support of the Node 100Base-FX Clear-Channel Muldex (heretofore referred to as “Node Muldex”). Requirements and are so noted. This approach is reflected in **FIGURE 1: Terminal Muldex Interfaces**.

### 3.1 Terminal Muldex Shelf Requirements

This section provides functional and physical requirements for the equipment shelf containing the Terminal Muldex Shelf.

**R010**: The Terminal Muldex Shelf shall support mounting in a 19-inch wide and 10-inch deep bay with a height allowance of 8-inches and front-back adjustable mounting brackets.

**I010**: The usable dimensions are 16-inches wide by 9-inches deep by 8-inches high. These dimensions are chosen to support optionally mounting the shelf in the AT&T SL280 TTE.

**R020**: The Terminal Muldex Shelf shall have the capability to contain four Muldex units.
I020: While two Terminal Muldex units are initially required, allowance is made for future expansion.

R030: All Terminal Muldex Shelf electrical connections shall be made via the side of the shelf using appropriate connectors; and, all optical connections shall be made via the front of the appropriate Muldex.

R040: The Terminal Muldex Shelf shall include in-line shelf power filtering with the power return isolated from the Terminal Muldex Shelf frame ground.

R050: The Terminal Muldex Shelf shall include a shelf frame ground metallic bolt connection point suitable for mounting a wire lug, washer and nut.

I050: While the Terminal Muldex Shelf mounting brackets and bolts may provide some frame grounding, they cannot be relied on to provide a quality frame ground due to paint and/or metal oxidation.

R060: The Terminal Muldex Shelf shall provide an isolated relay closure (mechanical or solid-state) suitable for connecting to the SL280 TTE (details to be determined)

R070: The Terminal Muldex Shelf shall comply with the following NEBS Level 2 criteria:
1) All of Level 1
2) ESD Normal Operations
3) Emissions an Immunity
4) Ambient Temperature and Humidity (operating)

I070: This requirement is a compromise between Level 1, the minimum required for experimental and non-communications network equipment; and, Level 3 which applies to communications network equipment.

3.2 Terminal Muldex Interface Requirements
This section provides the input and output interface requirements for the Terminal Muldex Shelf.

R110: The Terminal Muldex shall operate of a nominally -48 Volts power source with a voltage range capability of 36-72 Volts.

I110: The voltage range specified is an industry standard with circuit board-mounted DC-DC converters readily available from many manufacturers.

R120: The Terminal Muldex shall physically terminate two IEEE 802.3 100Base-FX Ethernet channels via SC optical connectors using single-mode optical fiber.
I120: Multi-mode fiber is normally used for 100Base-FX Ethernet. Single mode fiber capability is specified to achieve commonality with the undersea communication Node Muldex.

R130: If an internal clock source is not provided (O210), the Terminal Muldex multiplexer shall accept a 295.6 MHz $\times 880$ Hz AC-coupled line clock signal with an amplitude $\geq 250$ mV p-p (milliVolt peak-peak), less the attenuation of approximately 20 feet of RG-59B/U or equivalent cabling, terminated into a 75-Ohm impedance having a minimum return loss of 20 dB ($\geq 104$ mV p-p into 50-Ohms when measured via a minimum loss 75-50 Ohm pad).

I130: A line clock is readily available from the SL280 TTE Multiplexer. The Node Muldex will not include an internal clock source; instead, it will use the receive line clock signal available from the node receive regenerator for all Node Muldex functions.

R140: The Terminal Muldex multiplexer shall output a 295.6 Mbit/s AC coupled data signal having a 640-1027 mV p-p amplitude into 75-Ohms (345-80 mV into 50-Ohms measured via a 75-50 Ohm minimum loss matching pad) and $\geq$ 1.4 nanoseconds (ns) rise time (10-90% amplitude points) with less than 20% ripple.

I140: The objective is to provide an electrical line signal compatible with that provided by the TTE multiplexer to insure proper operation with the TTE line regenerator.

R150: The Terminal Muldex de-multiplexer shall accept a 295.6 Mbit/s AC coupled data signal having an 845-1086 mV p-p amplitude into 75-Ohms (400-50 mV into 50-Ohms via a 75-50 Ohm minimum loss matching pad), less the attenuation of approximately 20 feet of RG-59B/U or equivalent cabling, and having a rise time of $\geq$ 1.4 ns (10-90% amplitude points) and maximum ripple of 20%.

R160: The Terminal Muldex de-multiplexer shall accept a 295.6 MHz $\times 880$ Hz AC-coupled line clock signal with an amplitude 200-400 mV p-p amplitude, less the attenuation of approximately 20 feet of RG-59B/U or equivalent cabling, terminated into a 75-Ohm impedance having a minimum return loss of 20 dB (83-166 mV p-p into 50-Ohms when measured via a minimum loss 75-50 Ohm pad).

I160: Care should be taken with the receive line clock and line data signal phase relationship (usually achieved by setting the rising clock edge in the middle of the data pulse) to insure proper data re-clocking. This can be achieved by adjusting the coaxial cable length if the Terminal Muldex de-multiplexer does not include an internal means of adjusting clock phase. Also note that the requirement reads that the line clock signal must be accepted; not that it has to be used. It is possible to use the transmit line clock signal for the demultiplexer since the receive line clock is at the same exact frequency as the transmit line clock due to the line being in a looped back configuration; however, low frequency litter jitter and or wander may make this approach unusable.

O170: The Terminal Muldex de-multiplexer shall provide a front panel isolated line clock test point via a 50-Ohm BNC connector.
**I070:** This purpose of this objective is to have commonality with the Node Muldex which must past a line clock signal from the de-multiplexer to the multiplexer. The only advantage of having this capability in the terminal is that the line frequency can be verified without dropping transmission. That is, breaking the receive clock path identified in R160.

**R180:** The Terminal Muldex de-multiplexer shall provide a front panel isolated line parity error test point via a 50-Ohm BNC connector.

### 3.3 Terminal Muldex Multiplexer Requirements

This section provides the Terminal Muldex multiplexer functional requirements.

**O210:** The Terminal Muldex multiplexer shall include an internal 295.6 MHz line clock generator accurate to ± 3 ppm (parts per million) with a maximum SSB (Single Side Band) phase noise of –80, -115, -125 and -135 dBc/Hz at 10, 100, 1000 and 10000 Hz, respectively. If not implemented, then the alternative outlined in R130 must be provided.

**I210:** Including an internal clock source decreases external cabling congestion for slightly higher development and equipment costs. However, it does make the Muldex more independent and allows one to power down the TTE multiplexers.

**R220:** The Terminal Muldex multiplexer shall perform optical-to-electrical conversion, clock recovery and data retiming on the two IEEE 802.3 100Base-FX Ethernet channels independently (no other signal processing is required).

**R230:** The Terminal Muldex multiplexer shall provide front panel incoming channel loss-of-signal indicators via red LEDs (Light Emitting Diode).

**I230:** A simple data transition or loss of clock detector having a time-constant of 10 microseconds is sufficient. This specification is negotiable depending on available technology.

**R240:** The Terminal Muldex multiplexer shall insert a 1010 pattern for the appropriate tributary upon a loss-of-signal condition; and, the multiplexer shall remove the 1010 pattern for the appropriate tributary upon receiving a valid signal.

**R250:** The Muldex multiplexer frame format shall meet the following criteria:

1) **Line Rate:** 295.600 Mbit/s ± 0.0003%
2) **Number of Tributaries:** 2
3) **Tributary Rate:** 125 Mbit/s ± 0.005%
4) **Frame Length:** any length other than 1400 bits
5) **Frame Marker:** any pattern having 50% 1/0 density that excludes <msb>1111101000 or subsets thereof, all ones, all zeroes and alternating patterns such as 1010…, 1100…, 111000…, etc
6) **Parity:** Even parity over all bits in the frame using one or more bits
7) Scrambling Pattern: \((2^7 \square 1)\)-bit maximal-length pseudorandom sequence of polynomial \(X^7 + X^6 + 1\) reset to \(1111111\) at the start of every frame

8) Scrambling: Exclusive-OR over all bits except the frame marker

(See Demultiplexer Requirement R310 for additional specifications.)

I250: While the multiplexer frame format supports communications to the undersea observatories, the TTE frame format is used to maintain the SL280 repeatered line. The restriction is to insure that the Muldex frame format does not mimic the TTE frame format. Data scrambling is include to minimize baseline wander and maximize data transitions which, in turn minimize line jitter and maximize error performance

Note: It may be advantageous to perform all multiplexing processes at half the line rate and then combining to obtain the full line rate signal.

3.4 Terminal Muldex De-multiplexer Requirements

This section provides the de-multiplexer functional requirements.

R300: The Terminal Muldex de-multiplexer shall provide a front panel incoming channel loss-of-frame indicator via a red LED (Light Emitting Diode).

I230: Only a loss-of-frame indicator is required since both a loss of clock and a loss of data result in a loss-of-frame condition.

R310: The de-multiplexer framing algorithm shall have the following capabilities:

1) Mean time between loss of frame alignment at \(BER = 10^{-4}\): \(> 30\) days
2) Maximum error burst length to cause loss of frame alignment: \(> 10\) \(\mu s\)
3) Time to detect loss of frame alignment (no valid data): \(< 50\) \(\mu s\)
4) Time to re-acquire frame alignment and verify (no errors): \(< 50\) \(\mu s\)
   (with 90% probability)
5) Mean time between incorrect de-justification at \(BER = 10^{-4}\): \(> 10\) days
6) Minimum error burst length to cause incorrect de-justification: \(> 2\) \(\mu s\)

I310: The framing/de-justification requirements are similar to the TTE de-multiplexer specifications. The stated lower or upper bounds allow for some latitude in implementation taking into consideration the multiplexer requirement (R250).

R320: The Terminal Muldex de-multiplexer shall output no tributary signals (no light) whenever the de-multiplexer is in a loss-of-frame condition.

R330: The Terminal Muldex de-multiplexer shall output a pulse for each detected parity error via a 50 Ohm BNC connector.
4 Reliability
This section provides reliability requirements for the Terminal Muldex.

R410: The Terminal Muldex shall not have in more than three failures for the expected 15-year lifetime of the equipment with 95% confidence.

I210: This requirement may seem overly restrictive and potentially costly. However, it is expected that the core Muldex functions will incorporate the same device(s) used in the node Junction Box Muldex (wet-plant device failure rates have to be kept low to minimize costly ship repairs). Also note that this requirement is in the same range of the original AT&T SL-280 multiplex equipment which incorporated technology many integration levels lower than what is presently available.

5 Documentation
R510: Documentation in the form of appropriate schematic, equipment and/or handbook drawings and certification/qualification procedures shall be provided to support engineering, manufacturing, procurement, installation, operation and maintenance functions. Duplication shall be kept to a minimum between the documents and by referring to existing AT&T TTE documentation where applicable.

FIGURE 1:
Appendix 4

SL280 TERMINAL TRANSMISSION EQUIPMENT REUSE REQUIREMENTS

M. D. Tremblay

1 Purpose

This document presents the functional requirements and procedures for modifying the SL-280 Terminal Transmission Equipment (TTE) to support undersea scientific observatory applications over retired AT&T SL280 Submarine Cable Systems.

2 Overview

The SL280 TTE provided the interface between the domestic telecommunications network and the SL280 undersea cable. Two or four 140 Mbit/s Plesiosynchronous Digital Hierarchy (PDH) signals are multiplexed to a 295.6 Mbit/s proprietary undersea application line formats. Optical/Electrical (O/E) conversion is provided for interfacing to the undersea repeatered line at 1310 nanometers (nm). The TTE also includes equipment protection and unit fault isolation, as well as, end-end maintenance functions in support of telephony applications.

Utilization of the TTE multiplexer, as is, would result in an inordinate quantity of corresponding equipment at undersea observatory nodes which, in turn, would have deleterious effects on development cost, deployment capabilities and maintenance. The approach, then, is to incorporate a new separate multiplexer supporting 100 Mbit/s Ethernet clear channels (the term “clear’ is used to denote that the actual Ethernet data content is not examined in the multiplexing processed). The TTE line regenerators are then used to directly apply the new multiplex signal to the repeatered line. The “modified” TTE can be easily converted between its new configuration in support of node observatory communications and the original configuration for repeatered line maintenance. This approach does not require any SL280 TTE redesign thus focusing all efforts on equipment directly supporting undersea node communications.

The nomenclature used in this document is as follows:

1) \textit{Rxxx} denotes a \textbf{specific requirement} that must be met. As a rule, only one function will be included in any one requirement statement;
2) \textit{Oxxx} denotes an \textbf{objective} that is deemed nice to have but not absolutely necessary;
3) \textit{Ixxx} denotes an \textbf{information} statement that may be useful in interpreting requirements and objectives;
4) Each section starts numbering at the x10 where x is 0 for the first section and 1 plus the last number used in the previous section for subsequent sections;
5) \textit{R} statement numbering initially increments by 10 starting at \textit{Rx10} to allow for inserting additional statement (\textit{Rxx1-Rxx4}) in subsequent document releases;
6) \textit{O} statement numbering initially increments by 10 starting at \textit{O015} to allow for inserting additional statements(\textit{Oxx6-Oxx9}) in subsequent document releases;
7) \textit{R} and \textit{O} statement numbering are in combined increasing order;
8) \textit{I} statements use the same number as the corresponding \textit{R} or \textit{O} statement;
9) Any deleted statements will remain in the document and have the term *(deleted)* entered immediately after the statement number.

3 Document References

The following document references are either cited directly or may be useful in interpreting requirements, objectives and information statements contained herein (NOTE: AT&T refers to AT&T, AT&T Bell Laboratories or AT&T Laboratories; and, documents originally issued by AT&T may now be indicated as being *tycom* or *tycotelecom* documents):

2) SD-5G221-01: AT&T SL280 Terminal Transmission Equipment Application Schematic
3) X-80025: AT&T SL280 Terminal Transmission Equipment Manufacturing Testing Specifications (J68969A, B, C and D Bays)
4) G.703: ITU (International Telecommunications Union) Recommendation
6) Terminal 100BASE-FX Ethernet Clear-Channel Muldex Requirements

4 Functional Requirements

This section provides the specific requirements and objectives for modifying the AT&T SL280 TTE to support undersea observatory node communications while retaining existing line maintenance capabilities. Note that this section is organized in such a way that it can essentially be used to support initial installation, configuration conversion and maintenance support.

4.1 TTE Configured for Line Maintenance

This section provides the specific requirements and objectives for configuring the AT&T SL280 TTE to retain existing PFE (Power Feed Equipment), repeatered line and TTE maintenance, as well as, performance monitoring capabilities. For the most part, the TTE is operated as initially installed for telecommunications services. All changes are permanent with exception of the line side connections.

**R010:** All equipment in the TTE bays shall be kept operational with the possible exception of the OrderWire Termination Shelf.

**I010:** Keeping the TTE subsystems operational suppresses TTE alarms, maintains PFE and TTE performance logging functions and insures that the SCOUT Computer functions properly during line maintenance activity.

**O015:** The OrderWire Termination Shelf, including the orderwire cabling between the TTE and PFE, shall be operational for a system utilizing dual-ended power feed; that is, the cable ends terminate at cable stations.

**I015:** Having the OrderWire Termination Shelf operational for end-end powered systems facilitates end-end maintenance (helps reduce the need for commercial telephone facilities).
R020: Both Multiplex-1 and -2 shall be provided with 140 Mbit/s input signals (normally referred to as tributaries 1 and 2) conforming to the ITU G.703 Recommendation and obtained from one or more 140 Mbit/s transmission test sets and/or from the corresponding Demultiplex-1 and -2 140 Mbit/s outputs as follows:

Test Set #1 OUT to TTE top of A-Bay: DT4IN1
TTE top of C-Bay: DT4OUT1 to Test Set #1 IN
Test Set #2 OUT to TTE top of A-Bay: DT4IN3
TTE top of C-Bay: DT4OUT3 to Test Set #2 IN
Test Set #3 OUT to TTE top of A-Bay: DT4IN5
TTE top of C-Bay: DT4OUT5 to Test Set #3 IN
Test Set #4 OUT to TTE top of A-Bay: DT4IN7
TTE top of C-Bay: DT4OUT7 to Test Set #4 IN

or

Test Set #1 OUT to TTE top of A-Bay: DT4IN1
TTE top of C-Bay: DT4OUT1 to TTE top of A-Bay: DT4IN3
TTE top of C-Bay: DT4OUT3 to Test Set #1 IN
Test Set #2 OUT to TTE top of A-Bay: DT4IN5
TTE top of C-Bay: DT4OUT5 to TTE top of A-Bay: DT4IN7
TTE top of C-Bay: DT4OUT7 to Test Set #2 IN

or

Test #1 Set OUT to TTE top of A-Bay: DT4IN1
TTE top of C-Bay: DT4OUT1 to TTE top of A-Bay: DT4IN3
TTE top of C-Bay: DT4OUT3 to TTE top of A-Bay: DT4IN5
TTE top of C-Bay: DT4OUT5 to TTE top of A-Bay: DT4IN7
TTE top of A-Bay: DT4OUT7 to Test Set #1 IN

or (least preferred)

TTE top of C-Bay: DT4OUT7 to TTE top of A-Bay: DT4IN1
TTE top of C-Bay: DT4OUT1 to TTE top of A-Bay: DT4IN3
TTE top of C-Bay: DT4OUT3 to TTE top of A-Bay: DT4IN5
TTE top of C-Bay: DT4OUT5 to TTE top of A-Bay: DT4IN7

(Connections are to be made using RG-59B/U 75-Ohms coaxial cable, or better, equipped with an appropriate coaxial plug compatible with 633A (Lucent) coaxial jacks.

I020: Test set signals (required to suppress TTE alarms) are preferred; however, test sets do require floor space if said equipment is not already located in the TTE miscellaneous bay and they do require power (the option using one test set is probably the most viable option based on test set availability). While the connections could be made at the more easily
accessible front of the bay access jacks on the Multiplexer and De-multiplexer Switch Shelves, using the top of the bay interconnect jacks decreases front of the equipment cable congestion. Note that 50-Ohm BNC connectors will most likely be required for connecting to the test sets. Also note that with the exception of the first option, the 140 Mbit/s signals are daisy-chained which will result in cascading alarms for certain fault conditions.

**R030:** The existing connections between the TTE and SCOUT (System for Control Of Undersea Transmission) shall be kept operational.

**I030:** SCOUT communications to the undersea plant is via the TTE. The TTE also provides line system error performance data to SCOUT that it uses to support repeater section fault location.

**R040:** The existing telemetry connections between the TTE and PFE (Power Feed Equipment) shall be kept operational.

**I040:** PFE line voltage and current, as well as, some PFE alarms are routed to the TML (Transmission Monitor Logger) via the TTE. Note that the TML function is separate software running concurrently on the SCOUT computer.

**O045:** Remote TTE maintenance dial-up access shall be provided.

**I045:** Modem dial-up access at 1200 baud was initially provided to support remote access to the TTE OA&M (Operations, Administration & Maintenance) Panel. This feature allows complete TTE maintenance access to an off-site “TTE expert”. Communication rates can be as high as 9600 baud and may already have been implemented.

**R050:** The existing TTE office alarm connections shall be maintained.

**I050:** TTE office alarm operation can be disabled at any time by disengaging the Office Alarm Interface circuit pack in the TTE D-Bay OA&M (Operations, Administration & Maintenance) Shelf. This should be done during installation, fault location, repair and terminal configuration changes to minimize audible alarm activation.

### 4.1.1 TTE Alarm Echoing

Line signal loopbacks at an end-node or at an intermediate repeater in an end-end powered system and, any tributary side daisy chaining, will result in system alarm states being echoed 1-2 seconds after a status change. Alarm echoing is due to the built in TTE (near-terminal) to TTE (far-terminal) embedded maintenance communications channel. This maintenance channel carries both alarm and performance information that is updated on a 1-second basis. Since the near-terminal is its own far-terminal, alarms will appear to momentarily clear, come up again for one second and then clear. Thus, one should wait 2-3 seconds after any maintenance activity to determine the steady-state system alarm conditions.
Note that the same behavior occurs when the TTE line side multiplexer signals are looped back directly to their associated de-multiplexers. These connections are used to suppress TTE alarm conditions when the TTE is configured for node communications using the Ethernet clear-channel multiplexer signals.

4.2 TTE Configured for Node Communications

This section provides the specific requirements and objectives for configuring the AT&T SL280 TTE to support Ethernet communications over the SL280 repeatered line. For the most part, the TTE alterations are non-intrusive. All changes are permanent with exception of the line side connections.

R110: The new Ethernet Clear-Channel Multiplexer Shelf shall be installed in the Miscellaneous Bay adjacent to the TTE.

I110: While it is possible to install the new Ethernet Clear-Channel Multiplex Shelf in the TTE D-Bay if the OrderWire Termination Shelf is removed (except possibly in an end-end powered systems), the Miscellaneous Bay is more convenient for interconnecting to other Ethernet equipment such as routers. The only advantage for using the OrderWire Termination Shelf position is readily available -48 Volt power; on the other hand, either AC or DC powering can be supported in the Miscellaneous Bay.

R120: The new Ethernet Channel Multiplexer Shelf shall be powered from -48 Volts present in the Miscellaneous Bay.

R130: If the new Ethernet Clear-Channel Multiplexer does not include an internal clock source, obtain the ≥ 250 mV p-p (milliVolt peak-peak) line clock signals from the appropriate TTE Multiplexers using RG-59B/U 75-Ohms coaxial cable, or better, equipped with an appropriate coaxial plug compatible with a 560B (Lucent) coaxial jacks with the cables being routed via the overhead racks. The cables shall be affixed to the style strip between the TTE A and B bays.

<table>
<thead>
<tr>
<th>Eth Ch Multiplexer</th>
<th>TTE Multiplexer Shelf</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>#1, LIN MUX Circuit Pack, LINE CLOCK jack</td>
</tr>
<tr>
<td>#2</td>
<td>#2, LIN MUX Circuit Pack, LINE CLOCK jack</td>
</tr>
</tbody>
</table>

I130: It would be preferred that the coax cabling be hidden behind the TTE style strips; however, the location of the line clock signal jacks prohibits doing so. Clock signal measurements should be made via a 75-50 Ohm minimum loss attenuator which results in a signal amplitude of ≥ 104 mV p-p.

R140: Each new Ethernet Clear-Channel De-multiplexer shall accept a 200-400 mV p-p (83-166 mV p-p when measured via a 75-50 Ohm minimum loss attenuator) receive line clock signal from the TTE C-Bay Interconnect Panel connectors routed via the station overhead cable racks using RG-59B/U 75-Ohms coaxial cable, or better, terminated with a Lucent 440A coaxial plug, or equivalent, as follows:
I40: Care should be taken with the receive line clock and line data signal phase relationship to insure proper data re-clocking (usually realized by having the rising clock edge in the middle of the data pulse). This can be achieved by adjusting the coaxial cable length if the new Ethernet Clear-Channel De-multiplexer does not include an internal means of adjusting clock phase. Also note that the requirement reads that the line clock signal must be accepted; not that it has to be used. It is possible to use the transmit line clock signal for the demultiplexer since the receive line clock is at the same exact frequency as the transmit line clock due to the line being in a looped back configuration; however, low frequency line jitter and or wander may make this approach not viable.

R50: The new Ethernet Clear-Channel Multiplexer Shelf transmit/receive line side signals shall be routed via the station overhead racks to/from the TTE Regenerator Shelf Interconnect Panel area using RG-59B/U 75-Ohms coaxial cable, or better, terminated with Lucent 440A coaxial plugs, or equivalent. The transmit cables shall be affixed to the style strip between the TTE A and B Bays with ends properly labeled as being line TRANSMIT LINE-1 and TRANSMIT LINE-2; and, the receive cables shall be affixed to the style strip between the TTE B and C Bays with ends properly labeled as being line RECEIVE LINE-1 and RECEIVE LINE-2.

I50: While it would be desirable to have the cabling completely hidden, it is not physically possible to do so and retain the capability to easily switch between TTE configurations.

R60: The cables/plugs defined in R170 shall be used to connect the Ethernet Clear-Channel Multiplexer Shelf line side signals to the TTE Regenerator Shelf as follows:

<table>
<thead>
<tr>
<th>Cable end</th>
<th>Regenerator Interconnect Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMIT LINE-1, $\geq 800$ mV p-p</td>
<td>TRNSPOS SW1 IN (adjacent to the MXR 1 OUT jack)</td>
</tr>
<tr>
<td>TRANSMIT LINE-2, $\geq 800$ mV p-p</td>
<td>TRNSPOS SW2 IN (adjacent to the MXR 2 OUT jack)</td>
</tr>
<tr>
<td>RECEIVE LINE-1</td>
<td>TRNSPOS SW1 OUT, $\geq 800$ mV p-p (adjacent to the DMXR 1 IN jack)</td>
</tr>
<tr>
<td>RECEIVE LINE-2</td>
<td>TRNSPOS SW2 OUT, $\geq 800$ mV p-p (adjacent to the DMXR 2 IN jack)</td>
</tr>
</tbody>
</table>

I60: Inserting the indicated coaxial plugs to the indicated jacks automatically disconnects the standard TTE line signals. Removing the coaxial connections will automatically re-apply the standard TTE line signals, as long as, the jumper cables indicated in R170 are not present.
**R170:** The line side of the TTE multiplexer line signals shall be looped back to the TTE demultiplexers via the Regenerator Patch Panel using RG-59B/U 75-Ohms coaxial cable jumpers terminated with Lucent 440A coaxial plugs as follows:

```
On the Regenerator Patch Panel
MXR 1 OUT to DMXR 1 IN
MXR 2 OUT to DMXR 2 IN
```

**I170:** Removing the coaxial connections will automatically enable re-application of the standard TTE line signals when the connections indicated in R160 are removed.

**R180:** The Ethernet Clear-Channel Multiplexer FAIL alarm shall be routed to the SL280 TTE (to be determined).

### 5 Reliability

All the requirements in this document having to do with the SL280 TTE relate to coaxial, power and fiber connections. The existing PFE, SCOUT and PFE reliability considerations where engineered by the initial supplier, cannot be change and are more than adequate.

**R210:** The combined failure rate of all connections shall not result in more than one failure for the expected 15-year lifetime of the equipment with 95% confidence.

**I210:** Following industry procedures associated with cable (coaxial, fiber, etc) installation and mating should be sufficient. The new Ethernet Clear-Channel Multiplexer reliability requirements are specified in the Terminal 100BASE-FX Ethernet Clear-Channel Muldex document.

### 6 Documentation

**R310:** Documentation in the form of appropriate schematic, equipment and/or handbook drawings and certification/qualification procedures shall be provided to support engineering, manufacturing, procurement, installation, operation and maintenance functions. Duplication shall be kept to a minimum between the documents and by referring to existing AT&T TTE documentation where applicable.
Appendix 5

ALTERNATIVE NODE ARCHITECTURES UTILIZING AT&T SL280 SYSTEMS

M. D. Tremblay

Two alternate approaches are presented: architectures that support communications to two end terminal stations (ala standard telecommunication practices) and architectures that support communication to one terminal station only. It is envisioned that most re-used cables will operate single-ended with both in-line and end Observatories. Some long systems may physically have both cable ends terminated on shore for powering purposes; however, transmission connectivity would be configured as having end-nodes as seen from the shore ends. In either case, it is possible to test prototype observatory communications at cable stations prior to deployment by utilizing the TTE connectivity and wet-plant repeater loopback capabilities.

In the following examples, it is assumed (for comparisons only) that the same communication hardware is used for both in-line and end Observatories even though end node hardware could be reduced in the dual-ended transmission case.

Dual-ended transmission:

Note: Bidirectional transmission capability is not recommended due to requiring double the observatory communication hardware (a costly commodity). However it is presented here in the interest of completeness.

Figure C1: Dual-ended Node Architecture reflects Observatory communications passing through SL280 Regenerators (R & T) and multiplexers (D & M) located in the Junction box for each direction of transmission. When the applied line signal is in the standard SL280 format, the de-multiplexer (D) will not be able to find frame and, thus, the signal path is via the relays in their de-energized states as shown (relays are depicted in Figure C1 for its simplicity of operation; however, the function could be realized by other means). This allows one to use the standard line fault location techniques via SCOUT. When the applied line signal is the new line data format, the de-multiplexer passes the signal back to the line via the multiplexer (M) and the transmitter (T) (relays in their energized position) with the 100 Mbit/ data portion also being passed to the observatory processor. Observatory responses are sent back in the opposite direction via the Junction Box multiplexer (M) and transmitter (T) by overwriting the appropriate data portion of the new line format. Each node on a fiber pair would operate in the same manner with only the observatory being addressed providing a response. This arrangement supports bi-directional communications in systems having two landing points with only in-line nodes and unidirectional transmission in systems having one landing point with in-line and/or end nodes. End node would have to be looped backed via an optical attenuator as indicated to provide a formatted line signal in the opposite direction.
While the SL280 line maintenance subsystems has been designed to work with line signal loop back situations like seen in systems with end nodes, special care would have to be taken with respect to the new line data format signal. Specifically, the Observatory processor software would have to ignore a duplicate of each message sent from shore. That is, a delayed copy of each outgoing message having gone through the end node back to node-n (a check for the reception of a duplicate message within 100 milliseconds should be sufficient to overcome this).

The end “Branch or Splice Box” as shown in Figure C1 is for comparison only. Actual line cable connections would be more cost effectively made directly to the Junction Box. Unused fiber pairs could be looped back at the Junction Box or they could be electrically looped back at the last repeater. Node to fiber pair assignment flexibility would suggest that both working fiber pairs terminate at the junction box. And, lastly, it is understood that a sea ground connection to the end Junction Box would be required.

Note that with the exception of when one switches from the standard SL280 line format to the new line data format, the end receive terminal(s) are always in frame resulting in the maximum data transfer rate.

This architecture also increases the amount of hardware and software required for the Observatory processor.
FIGURE C1: DUAL-ENDED NODE ARCHITECTURE

R: REGENERATOR  D: DEMULTIPLEXER  I: NORM CLOSED ELEC RELAY (or equivalent)
T: TRANSMIT LASER  M: MULTIPLEXER  X: NORM OPEN ELEC RELAY (or equivalent)

FIBER PAIRS LOOPED BACK VIA ATTNS
"BRANCH OR SPLICE BOX?"

attenuator
**Single-ended transmission:**

**Figure C2: Single-ended Node Architecture** reflects node communications passing through SL280 Regenerators (R & T) and multiplexers (D & M) in one direction of transmission only. The advantages of this approach are: the Junction Box is equipped with the fewest regenerators and multiplexers, overall system availability is improved over that in **Figure C1**; and, duplicate message concerns in the Observatories do not exist. Observatory communications is essentially 100 Mb/s full duplex per node with the possibility of data collisions only when there are more than two nodes per fiber pair (four in an end-end power feed arrangement).

Unlike **Figure C1** which suggest that the end node communications architecture could be different than the in-line nodes, the Junction Boxes in **Figure C2** are identical making **Figure C2** the preferred approach both from a cost and reliability points of view. This recommendation is also in line with expected overall system deployment configurations since the majority of systems would terminate at only one shore location. And, even though very long systems would have to be powered from two shore stations, they can still be operated as either dual single-ended systems or a single-ended system from the transmission point of view. It is also interesting to note that the Junction Box communications hardware could be placed either in the forward or the return path direction. And, as in **Figure C1**, it is understood that a sea ground connection to the end Junction Box would be required.
FIGURE C2: SINGLE-ENDED NODE ARCHITECTURE
Replacing node electrical switches with optical components:

On the surface, it appears that there might be an advantage in using line pair optical taps (bridging) for node connections in the interest of being node fault tolerant as can be done in WDM (Wavelength Division Multiplex) systems. However, unlike WDM systems whereby each node can have its own wavelength channel, nodes on the same fiber pair share time in a TDM (Time Domain Multiplexed) system. Node to shore communications would have to include breaking the return optical path. Optical couplers, optical switches and switch controls would increase overall node communication hardware cost and lower node reliability even though it is possible to increase overall system availability. Return path switching would also introduce synchronization and data interruptions drastically reducing the return path effective transmission rate (much less than 100 Mb/s per fiber pair). There is also the issue of where to place the optical components: the Branch, Junction Box or split between them (optical switches in the branch would require additional electrical Junction Box to Branch connections). Overall, trying to fit a WDM solution to a TDM system is not a viable approach; it was discussed here in the interest of covering possible alternative approaches.

Junction Box communication hardware:

The Junction Box communication hardware reliability is maximized by first utilizing the highly reliable SL280 regenerator for the T and R functions which also provide access to all line clock and data signals required for the multiplexing function. Secondly, the synchronous nature of the 100Base-FX interface protocol reduces the amount of bit-stuffing control electronics; that is, all the overhead bits, including bit-stuffing, can be passed straight through.

Junction Box regenerator laser redundancy:

Junction Box regenerator transmitter laser switching is provided via the standard SL280 SCOUT System. The only modification required is the establishment of unique repeater/regenerator addresses for the regenerator physically located in the Junction Box (addresses are set via simple jumpers on the regenerator unit).

Junction Box 100Base-FX data channel assignment:

Data channel assignment can be achieved in a number ways: 1) hardwired in the Junction Box prior to deployment, 2) selectable from the shore end by sending a command to the appropriate Junction box using overhead bits as used for transmitter laser switching, 3) by routing both channels to the Observatory with selection done by the Observatory or, 4) by a connection option between the Junction Box and the Observatory. A slight modification of option 3 coupled with option 4 is proposed later in this document.
Junction Box fiber selection:

Is possible to remotely to select which fiber pair a particular Junction Box uses for communications by including remotely controllable optical switches. However, the reliability of optical switches and the additional control functions required makes this option unattractive. An alternative approach is discussed later in this document.

Node communication faults:

There are two general types of node communication faults: single node and all nodes.

A single node communication fault would most likely be an Observatory fault with the Junction Box and umbilical cabling to the Observatory being less likely possibilities.

An all node communication fault would most likely be a Junction Box multiplexer (D/M) or a regenerator (R/T) fault with the Connector, Branch, umbilical cable and fiber cables being less likely; a span failure elsewhere in the system or a system power fault. Manually switching to the standard SL280 line signal would quickly verify that a multiplexer is at fault if the standard TTE demultiplexer goes in-frame. Determining the faulty node for a multiplexer fault is accomplished by manually making a repeater span switch for all spans that contain a node until the faulty node is identified (procedure would include going back and forth between line signal types to verify multiplexer operation). Determining the location of all other faults (including Junction Box power supply) is accomplished by using standard SL280 fault location procedures. A repeater span switch over a span containing an in-line node or a loopback switch for an end-node that results in through transmission would indicate that the failure is in that node (the next action to then take would be to do a Junction Box laser switch). Note that both types of node failures can result in isolating the failed node from the system thus keeping other nodes operational while waiting for repair activities.

Timing Jitter and Increase Span Loss Effects on Bit Error Performance:

At first glance, it would appear that timing jitter would increase due to looping the line signal at the end-node location which, in turn would increase the bit error rate. One should note, however, that the actual round-trip path length would not be significantly longer than the original commercial path length due to the nature of expected typical observatory deployments (most commercial systems will be segmented to form two or more smaller systems terminating at one shore only). This is also true for an end-end power feed arrangement whereby transmission loopbacks would be established in the middle of the system forming two functionally independent deployments. In-line and end nodes would introduce timing jitter equivalent to one regenerator for the appropriate fiber pair. The small additional jitter may be considered insignificant considering the approximate square-root-of-N jitter addition, where N equals the number of regenerators.

The greater concern is the increased span loss at in-line node locations (end-nodes do not increase the span loss by virtue of placing the node at the approximate mid-span loss.
location). Increased span losses in the 5-6 dB range are expected due to additional cable lengths required in deploying a branching unit, additional splices and optical connector losses associated with mating to the Junction Box. This additional loss uses up all of the regenerator span repair margin and much of the system penalty and component aging margin originally built into the systems. Even with this much additional span loss, the expected bit error rate is expected to be better and $10^{-10}$ (another way of interpreting this error rate is that less than one out of ten million 100 Mbit/ message blocks would require retransmission). We should note, however, that a further repair of an in-line node span would essentially erase the remaining margin and may require the inserting an additional repeater. An alternate node architecture that results in less span loss is discussed later in this document.