

# Installation and Maintenance Technology for Undersea Cable Systems

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Since 1963, AT&T has installed more than 230,000 kilometers of undersea cable systems. The extensive experience gained from the placement of such systems, as well as from their upkeep and repair, has allowed AT&T to develop and refine installation and maintenance techniques to their present, high state of efficiency and reliability. This paper discusses the tools and techniques typically used for installing undersea cable systems, as well as the ships employed for transporting and placing the cable. The paper concludes with a discussion of some plans for future installations that are being driven by markets and technology.

## Introduction

Several technologies are employed in the installation, jointing, coupling, and maintenance of undersea cable systems. Specific tools and techniques depend on the type of installation, either repeated or non-repeated.

Specially designed ships provide highly maneuverable ocean platforms for cable placement, as well as for maintenance and repair of existing systems. The AT&T fleet of cable-placing ships is comprised of modern vessels, which represent the state of the art in cable-ship construction. The design and operation of these ships are discussed in detail.

Environmental factors that can affect cable-placing techniques and system longevity are outlined. Such operations as powered-system branch repair, which allows maintenance work to be completed on one leg of a system while the other branch remains in service, are also discussed.

The conclusion section leads the reader through some recent changes in technology and markets that necessitate the development of new and improved methods of cable placement, maintenance, and system design.

## Repeated-System Installation

The installation process begins about one year before initiating the actual

load-and-lay marine (or wet) program. The first phase—a desk-top study of the installation site—is conducted, together with engineering the system. The study's purpose is to "explore" the ocean floor. Results of the exploration dictate the optimal product for specific bottom conditions.

Any one of several cable types (single armored, double armored, special application, or light weight), combined with a single installation method (buried, protected within pipes, etc.), is typically recommended for suitable cable protection.

The desk-top study also provides a basis for accurately estimating a cable's length. Having such information beforehand, system engineers can achieve proper cable coverage of the ocean bottom by minimizing slack and eliminating cable suspensions. Table I presents an outline of the complete installation and maintenance process.

Once the wet system has been manufactured and its cable and repeaters assembled and tested<sup>1</sup>, loading of the cable ship begins. Systems are normally assembled at the factory and loaded as two or three segments corresponding to a ship's cable tanks. Temporary joints are made between the segments to facilitate testing of the entire system before loading. When testing has certified conformance with specifications, ship loading

**Table 1. Major elements of the installation and maintenance process**

Route and cable engineering	System loading	Laying of shore ends	Deep-water installation	Maintenance
<ul style="list-style-type: none"> <li>• Landing</li> <li>• Cable route</li> <li>• Cable types</li> </ul>	<ul style="list-style-type: none"> <li>• Double or triple load lines</li> <li>• Scheduled testing</li> <li>• Load/lay program</li> </ul>	<ul style="list-style-type: none"> <li>• Armored installations</li> <li>• Laying with tension</li> <li>• Burial</li> <li>• Retro-burial</li> <li>• Continuous testing</li> </ul>	<ul style="list-style-type: none"> <li>• Lightweight installation</li> <li>• Laying with slack</li> <li>• Final bight lowering</li> <li>• Continuous testing</li> </ul>	<ul style="list-style-type: none"> <li>• As-laid records</li> <li>• Spares quantity and location</li> </ul>

**Panel 1. Abbreviations, Acronyms, and Terms**

- ACMA — Atlantic Cable Maintenance Agreement
- CCR — cable control room
- CDIS — cable data instrumentation system
- coupling — the process of connecting a cable to a repeater
- CS — full-size cable ships
- DCE — drum cable engine
- DE-20 — Dock Express 20, a large dock and container vessel
- DOHB — draw-off/hold-back, a linear cable-handling machine
- GPS — Global Positioning System
- ISO — International Organization for Standardization
- jointing—the process of connecting two cables together
- LCE — linear cable engine
- LHT — long-haul transoceanic
- MCS — mini cable ships
- PLC — programmable logic controller
- RF — regional festoon
- ROV — remotely operated vehicle
- SCARAB — submersible craft assisting repair and burial
- SH — short haul
- SSI — the Submarine Systems, Inc. business unit of AT&T
- SV — support vessels
- UJ/UC — universal jointing and coupling
- 10-type technology — first-generation lightwave jointing technology
- 11-type technology — second-generation lightwave jointing technology

begins. For safety, power to the system is turned off during the loading process. Once a day, loading is stopped and the system is powered and tested to verify its performance.

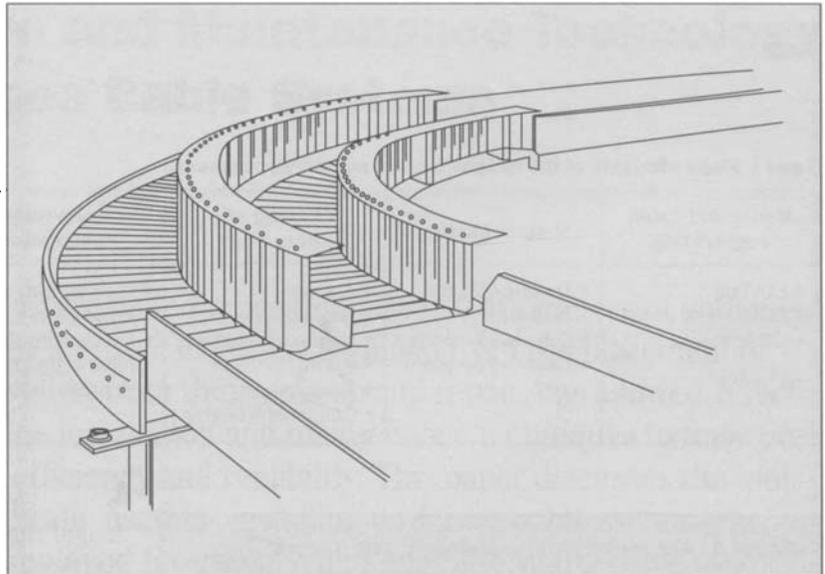
In the past, the loading operation often took longer than the cable placement itself. Today, the process has been streamlined and equipment optimized to reduce loading time dramatically. Equipment to load two or three cable segments simultaneously—that is, double or triple load lines—was designed in 1988 and has been used since then. This equipment reduces the load interval by a factor of two or more. In addition, high-speed, self-contained cable transporting machines (haulers) are now available that facilitate loading speeds of up to six knots, cutting the interval—again—by a factor of two. Figure 1 shows a horizontal, dual-loading facility used for feeding cable into two tanks aboard the cable ship *Global Link*.

During the loading operation, cable is coiled in the cable tanks, and the repeaters are bighted out to special storage racks where the surrounding temperature can be controlled. For the crew's safety, repeater housings are grounded to the ship's hull to prevent the build-up and sudden discharge of static electricity. The cable bights leading to and from the repeaters are arranged neatly in preparation for repeater deployment. Permanent cable joints are made aboard ship to connect the bights leading from one tank to another.

The first cable sections to be installed are the shore ends that, in most instances, are buried. The end of the cable facing toward the shore is floated to the beach from the ship or a barge. It is then secured at the beach and spliced in the beach manhole to the previously installed land cable. Installation of the land cable entails both pulling it through pre-installed ducting and subsequently testing it two ways. The first test, for insulation integrity, confirms that no cable damage occurred during the installation process. The second test, for integrity, ensures that transmission characteristics and loss budgets were not altered by possible cable mishandling.

Installation of the deep-water segment of the system begins after the shore-end work is finished. Before cable is paid out from the tanks, the complete system is tested again, starting from the terminal and progressing through the entire length stored aboard the ship. Cable

**Figure 1. This illustration shows a horizontal, dual loading facility (dual load-line arrangement) used for feeding cable into two tanks aboard the cable ship *Global Link*.**



placing then commences and testing continues, except for brief intervals when system power is reduced. This ensures the crew's safety during certain crucial operations, such as "overboarding" a repeater. At the conclusion of a placement operation, the cable end is attached to a buoy for later retrieval. Shore-end operations at the other end of the system are carried out as they were at the beginning of the cable-placing process.

Next, the buoy is retrieved and the deep-sea and shore ends joined. Before overboarding the final joint, however, the now complete system is tested—terminal to terminal—to verify proper operation. The final joint is then lowered to the ocean bottom to complete the installation.

Whenever a system contains a branching unit<sup>2</sup>, one of the branch cables is initially installed from the shore end to the planned location of the branching unit. Here, the seaward end is sealed, fastened to a rope, and affixed to a buoy. The second segment, already attached to the branching unit, is then installed from the shore end to the buoy. The first branch is then recovered and joined to the branching unit. Using the trunk cable, the branching unit is lowered carefully to the bottom. Then the trunk is installed onto its shore end, where the final joint is made.

Low bottom tension is maintained during the installation of armored cable to prevent the formation of loops and kinks. Correct bottom tension is assured by continuous monitoring of both on-board cable tension and water depth under the ship. The speed of both the ship and cable pay-out are varied, in response to changes in sea-bottom slope, to enhance cable conformance with the ocean floor.

Conversely, when either unarmored deep-water or special-application<sup>2</sup> cable is installed, bottom slack is typically maintained. This is accomplished by constantly controlling the cable's pay-out speed so that it is maintained slightly higher than the ship's speed. Computers

are used to sustain the desired slack automatically and continuously, both by reading the ship's speed and by controlling the cable's pay-out speed. In most instances, the ship's speed is determined either by using the port/starboard taut-wire method (measuring the speed of a thin wire, under constant tension, paid out from the ship), or by using extremely accurate navigation systems, usually based on the Global Positioning System (GPS). Sometimes, however, yet another technique is used. This method, known as *differential GPS*, estimates and compensates for any GPS errors.

Accurate records are maintained during the cable-installation process. These records allow for precise cable locating in the event a repair is needed. The actual route and the location of each repeater are recorded and compared with the pre-surveyed, planned cable route. Slack is adjusted, in real time, during cable placement, based on the output of echo-sounding equipment that displays the bottom contour. Computer systems used aboard ships have largely automated the record-keeping function.

AT&T has one of the world's most complete sets of undersea tools for burying, recovering, and inspecting cables. Sea Plow V, VI, and VII, as well as the Sea-Bed Tractor, provide the capability for cable and repeater burial in a wide range of bottom conditions. Three remotely operated vehicles (ROVs), known as submersible craft assisting repair and burial (SCARABs), allow retro-burial, inspection, and recovery operations to be carried out from several different types of ships. Inspection operations made possible by these tools provide detailed information about ocean-bottom and cable conditions. Burial of cables using these tools provides the best protection, by far, against such external damage as bottom fishing. The tools are discussed in greater detail later in this paper.

**Table II. Systems versus platforms functional matrix**

Systems	Platforms		
	Full-Size Cable Ships (CS)	Mini Cable Ships (MCS)	Support Vessels (SV)
Long-Haul Transoceanic (LHT)	<u>Required</u> Used for more than 90 percent of system length	<u>Non-economical</u>	<u>Possible</u> Used for non-direct landings
Regional Festoon (RF)	<u>Preferred</u> Used for total system: • Cable capacity • Space for buried tools	<u>Second alternative</u> Used for festoon segments	<u>Possible</u> Used for: • Non-direct landings • Festoon segments
Short Haul (SH)	<u>Non-economical</u>	<u>Second alternative</u>	<u>Preferred</u> Used for: • Direct landings • System installation

**Non-Repeatered System Installation**

In support of the global information network, AT&T is leading the development of local and regional networks, which are the gateways to the global information highway.<sup>3</sup> Most of today's planned, secondary networks include undersea cable routes that optimize communications. Undersea cables are faster to install than any terrestrial alternative. The challenges, though, are to provide cost-effective installation packages, as well as regional maintenance centers capable of completing repairs whenever needed. Maintenance ships, designed specifically for repair operations, are somewhat smaller than their transoceanic cable laying counterparts. They are equipped, however, with all the tools, cable-handling machinery, testing equipment, and monitoring systems needed to repair undersea communication systems quickly and effectively.

Although the placement method for non-repeatered systems varies from that of repeatered installations, the underlying theory and technology—as well as the machinery and tools—are all fundamentally the same. The difference is that emphasis is placed on distinct elements of the installation process. For example, shore-end installation is similar for both types of systems. There are many more shore ends in non-repeatered festoons, however, and the limited landing terrain most likely would be much harsher. The installation platforms, equipment, tools, and procedures, therefore, are altered appropriately.

AT&T Submarine Systems, Inc. (SSI) specializes in the installation and maintenance of three general types of undersea systems:

- *Long-haul transoceanic* (LHT), such as TAT-11 and TPC-5;
- *Regional festoon* (RF), such as PATAGONIA-I; and
- *Short haul* (SH), such as TAINO-CARIB, CIOS, TEFKROS, and CADMOS.

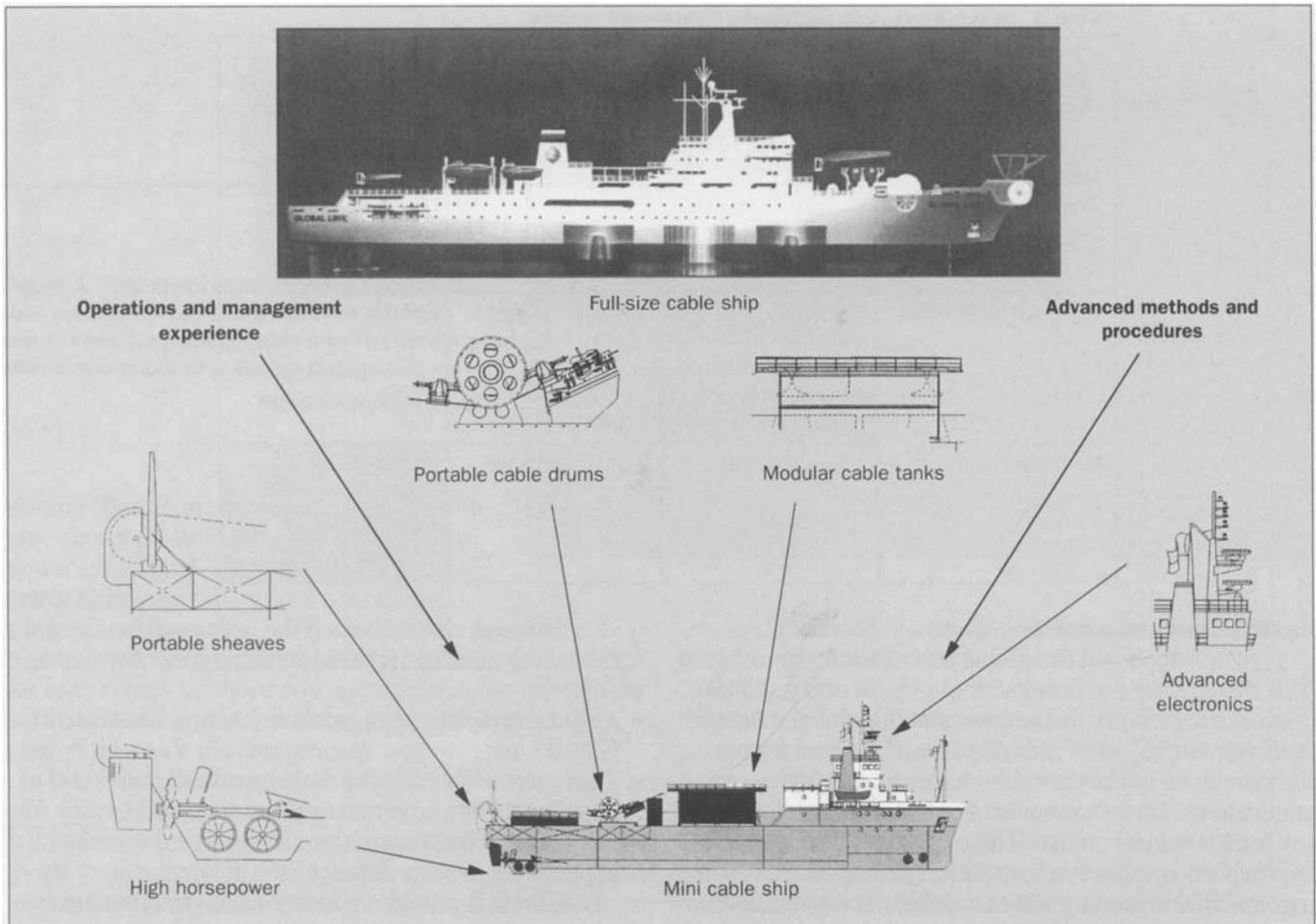
SSI has also optimized the ocean platforms used for installing each of the three general types of systems, as follows:

- *Full-size cable ships* (CS), such as CS Long Lines and CS Global Link;
- *Mini cable ships* (MCS), such as a transformed vessel of opportunity of a larger class (75 m long); and
- *Support vessels* (SV), such as a transformed vessel of opportunity of a smaller class (50 m long).

Table II provides a functional matrix that ties the two fundamental variables, systems and platforms, together.

In essence, a complete technology transfer is occurring. The expertise, procedures, tools, and equipment used in LHT systems and CSs are being shared with SH systems and SVs. All this technology is needed to install and maintain a reliable, global, undersea cable network. The AT&T installation service, based on this technology-transfer principle, is designed to be comprehensive—one in which the skills needed for the placement of non-repeatered systems are cultivated and enhanced through repeatered installations.

Integral to the establishment of a global network, AT&T is developing modular cable-handling equipment. It can be deployed quickly on board support vessels that are being transformed into mini cable ships. This equipment is designed to be transported by means of normal carriers (trucks and container ships) and housed in International Organization for Standardization (ISO) containers, allowing rapid mobilization for system installations worldwide. The support ships used in this program are industry-standard vessels, available throughout the world, and capable of performing well under adverse conditions. Figure 2 provides some examples of how this technology transfer is taking place.



**Figure 2. Integral to the establishment of a global network, AT&T is developing modular cable-handling equipment. It can be deployed quickly on board support vessels that are being transformed into mini cable ships. The illustration shows how this technology transfer is taking place.**

Development of several innovative tools and procedures has been initiated to support the rapid deployment and mobilization program. This includes cable shipment and quick joints<sup>4</sup> that cater to rapid assembly at the installation site.

#### **Maintenance of the Undersea Plant**

System repairs are expensive, due to the investment in cable ships, the many technicians required, and heavy equipment needed. More important, however, are lost revenues or the cost of temporary circuit restoration. Minimizing system outages, therefore, is the overriding concern in undersea-maintenance planning and repair.

Today, the world is witnessing rapid growth in undersea lightwave systems. Since 1986, AT&T alone has supplied more than 105,000 kilometers of cable, and a roughly equivalent amount is scheduled to be installed during the next two years. The need to maintain undersea lightwave systems in top condition, for the designed life span of more than 25 years, underscores the importance of the burgeoning maintenance-and-repair business.

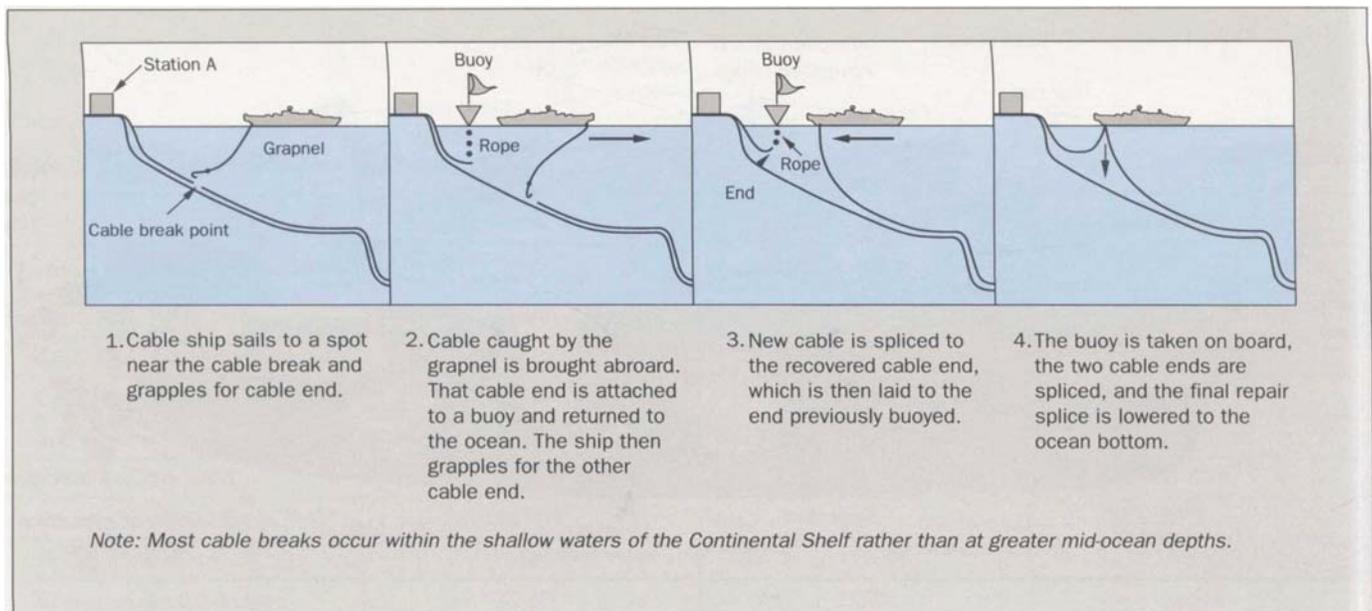
In the tradition of the undersea telecommunications industry, the wet plant is designed and manufactured

according to the highest reliability standards. The great majority of system trouble reports are caused not by inherent product defects, but by physical damage, either environmental or mechanical. A good preventive maintenance strategy begins with sound construction planning and an effective cable-protection program. In addition, *routing*, *cable selection*, and *burial method* are three of the most important engineering factors affecting cable longevity and reliability.

In order to establish an effective cable-protection program, it is necessary to maintain:

- A fully equipped cable ship, available and close to the installation site;
- Skilled technicians, on standby, prepared to carry out the necessary work; and
- Ready-to-load equipment and spare parts.

Typically, repairs done by ship are both random and infrequent, and it is common industry practice for sev-



**Figure 3.** It is common industry practice for several system owners to share maintenance resources. The Atlantic Cable Maintenance Agreement (ACMA) allows each of the trans-Atlantic cable-system owners to contribute a specific monetary amount to pay for the ready availability of repair ships and technicians. This illustration depicts a typical, wet-plant repair process normally covered under the ACMA.

eral system owners to share maintenance resources. The Atlantic Cable Maintenance Agreement (ACMA) is the first such arrangement. Each owner of the trans-Atlantic cable systems contributes a specific monetary amount to pay for the ready availability of repair ships and technicians. This arrangement allows rapid, cost-effective response to trouble reports. In most cases, repair ships can be mobilized and dispatched within 24 hours. Figure 3 depicts a typical, wet-plant repair process.

For branched or networked systems, a new approach to managing the repair operation, known as *powered-system branch repair*, has recently been developed. This process, discussed later, can be conducted on one cable segment while the rest of the system remains powered and operational.

In addition to its own systems, AT&T provides maintenance services to other undersea cable administrations around the world. Sometimes, these services are even part of a joint maintenance program. AT&T maintenance services typically include:

- Fully equipped repair ships;
- Qualified technicians;
- Technical and engineering support;
- Remotely operated vehicles;
- Testing equipment;
- Jointing tools; and
- Training services.

### Second-Generation Cable Ships

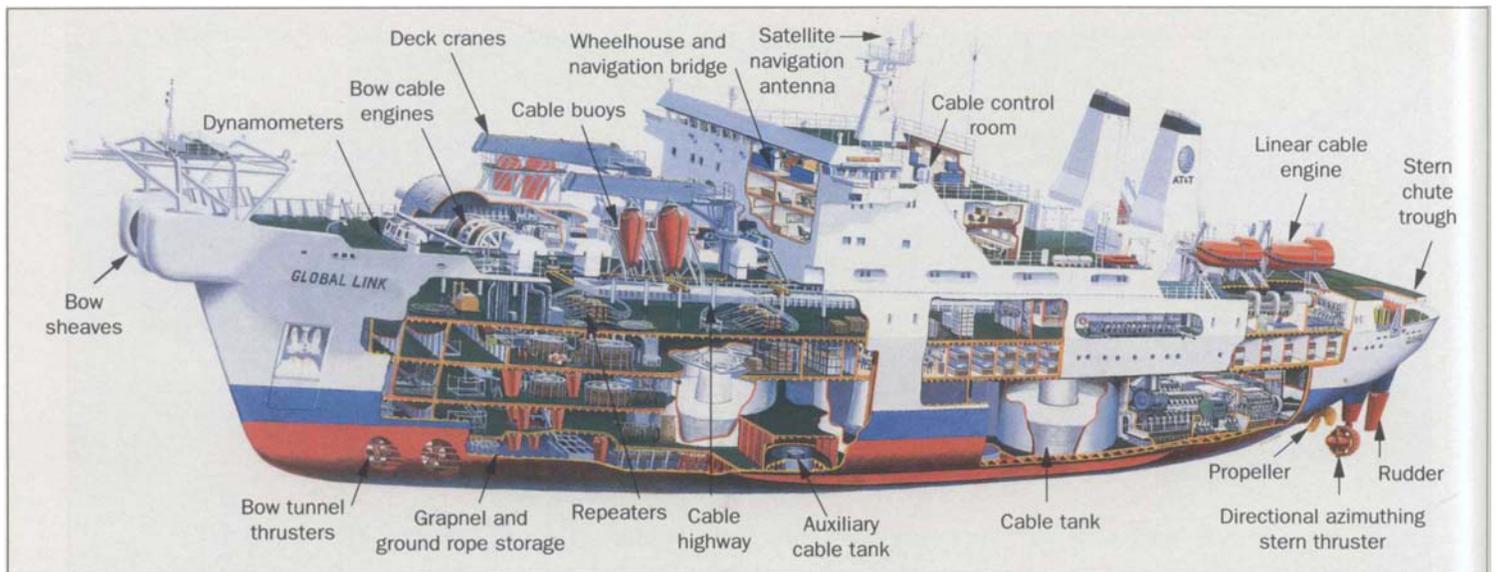
AT&T cable ships represent the state of the art in modern design. They feature a capacity of more than 6,000 metric tons of fiber-optic cable. Their precision navigation equipment and maneuverability allow placing a one-centimeter-diameter cable on the ocean floor within only a few meters of its intended position.

Principal shipboard operations are the storage and pay-out of cable systems. Figure 4 provides a cross-sectional view of the cable ship *Global Link*, whose operations are representative of all AT&T vessels. Its major equipment is discussed in the rest of this section.

A *cable highway* runs virtually the entire length of the ship. Situated above the cable storage tanks, in a location where repeaters and cable are handled under low tension, is the cable-jointing and repeater-assembly area.

Cable can be handled over either the bow or the stern. Pay-out and recovery are managed through the use of three cable engines. The main machinery, located at the stern, consists of a *linear cable engine* (LCE), capable of placing cable and repeaters at speeds of up to eight knots. The cable jacket is securely gripped within the LCE between its tracks or, in some cases, its tires. The LCE can accommodate both small-diameter cable and 43-centimeter-diameter repeaters without loss of control or precision.

Both slow-speed cable-placing and repair-and-recovery operations are handled over the bow. Shipboard apparatus consists of two *drum cable engines* (DCEs), each having a *draw-off/hold-back* (DOHB) linear machine. Cable is wrapped three to five turns around each of the drums to allow safe handling during high-cable-tension operations. Each DCE is equipped with fleeting rings and knives, which are used to move the cable continuously across the surface of the drums. This movement prevents cable turns from crossing each other. *Bow sheaves*



**Figure 4.** This cross-sectional drawing provides an internal view of the cable ship *Global Link*, whose operations are representative of all AT&T vessels. Its major equipment is highlighted.

safely guide the cable and repeaters over the bow.

A state-of-the-art *dynamometer* is associated with each of the DCEs and LCE. It is capable of measuring cable tension ranging between 500 and 100,000 pounds. Table III provides a comparison of the main characteristics of the cable ships *Global Link*, *Global Sentinel*, and *Global Mariner*.

The center of onboard operations is the *cable control room* (CCR), where cable placement is monitored and controlled 24 hours a day. The ocean bottom is re-surveyed, in real time, during the placement operation. Slack is continuously adjusted to position the cable on the bottom without suspensions. A *bottom-profiling sonar system* allows engineers to verify pre-surveyed areas of the ocean bottom and adjust slack as required.

During a repair, onboard equipment is used for splicing cable and replacing repeaters. Engineers power-up a cable system and continuously monitor its performance in the *transmission test room*. Special instruments verify proper operation of individual components.

The ship's propulsion system is designed both for long-distance, high-speed operation, during transit periods, and slow-speed, high-precision maneuvering—to within a few meters—during cable placing and repairing operations. The main propulsion system is comprised of three diesel-electric units. Two 4,700-horsepower electric motors, geared to one, centrally mounted drive shaft, deliver 9,000 shaft horsepower to a four-meter-diameter main propeller. The ship's cruising speed is about 15 knots.

*Directional azimuthing stern thrusters* assist the main propulsion system, delivering variable thrust at virtually any angle to compensate for both currents and wind during cable placing or retrieval. *Bow thrusters*, used in conjunction with the stern thrusters, can maintain the ship's position, even in 40-knot winds and rough seas. In most instances, such tasks are carried out with

the help of a computerized control system known as the *dynamic positioning system*.

Each of the AT&T ships is equipped with a *satellite navigation system* having a differential-positioning capability. This system can pinpoint a ship's position, within three to five meters, anywhere in the world. It facilitates accurate cable placement along the intended route.

#### Automation in Deep-Sea Cable Placement

The fundamental principles of placing undersea cable have not changed since the late 1950s.<sup>5</sup> The new AT&T cable ships, however, incorporate the latest, state-of-the-art equipment and tools. As a result, the installation and repair of such systems have become much easier, in spite of different systems and owner requirements. Each of the ships carries a cable data instrumentation system (CDIS), capable of displaying and recording installation parameters around the clock.

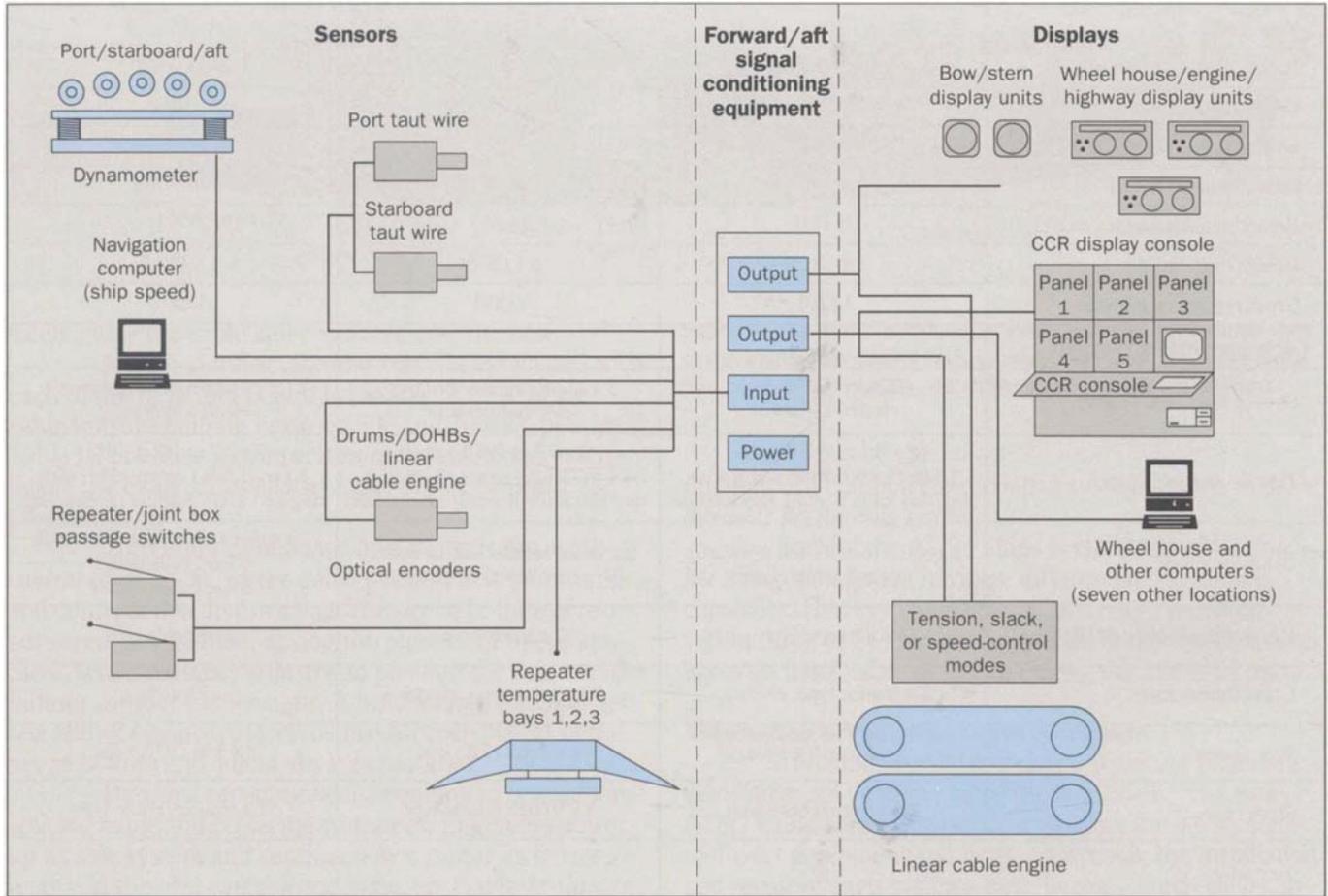
In addition, this modern, modular equipment maintains automatic control of cable-placing operations. It also provides redundancy backup, which is built into each and every hardware and software element.

The CDIS interfaces with sensors, located on much of the equipment aboard ship, and measures specific cable parameters. Tension is determined using three dynamometers. Pay-out speed and count (the number of kilometers of cable, line, chain, and so forth, paid out or recovered during cable operations) are measured using optical encoders on separate cable engines.

Ship speed is gauged by using either the *navigation or taut-wire* method. In the navigation method, a signal

**Table III. Characteristics of current AT&T cable ships**

	<i>CS Global Link</i>	<i>CS Global Sentinel</i>	<i>CS Global Mariner</i>
<b>General specifications</b>			
Year built	1990	1991	1992
Range, nautical miles (days)	10,000 (60)	10,000 (60)	10,000 (60)
Crew complement	138	138	94
Service speed (knots)	15	15	13.8
Overall length, m (ft.)	146 (478)	146 (478)	146 (478)
Breadth, molded beam, m (ft.)	22 (71)	22 (71)	22 (71)
Design draft, m (ft.)	8.1 (26.5)	8.1 (26.5)	7.8 (25.7)
Gross registered tonnage	13,201	13,201	12,518
<b>Cable-handling equipment</b>			
Stern linear cable engine	1 x tractor type, electro-hydraulic	1 x 21-pair rubber-tire type, electro-hydraulic	1 x 21-pair rubber-tire type, electro-hydraulic
Bow drum cable engine	2 x 3.7 m (12 ft.) dia., 1.1 m (3.5 ft.) drum width with ring and knife fleeting mechanism	2 x 3.7 m (12 ft.) dia., 1.1 m (3.5 ft.) drum width with ring and knife fleeting mechanism	2 x 3.7 m (12 ft.) dia., 1.1 m (3.5 ft.) drum width with ring and knife fleeting mechanism
Dynamometers	2 x roller saddleback (forward) 1 x roller type (aft)	2 x roller saddleback (forward) 1 x roller type (aft)	2 x roller saddleback (forward), 6 load cells under linear cable engine
Draw-off/hold-back (DOHB)	2 x tractor type	2 x tractor type	2 x tractor type
Cable transporter	2 x tractor type, electric	2 x tractor type, electric	Electric
Bow sheaves	2 x 3 m (10 ft.) dia.	2 x 3 m (10 ft.) dia.	2 x 3 m (10 ft.) dia.
Stern chute	1 x trough/chute type	1 x trough/chute type	1 x trough/chute type
Taut wire	2	2	2
Deck cranes	2 x 10-ton, 20 m (65 ft.) outreach (forward)	2 x 10-ton, 20 m (65 ft.) outreach (forward)	2 x 10-ton, 20 m (65 ft.) outreach (forward)
<b>Capacities</b>			
Cable tanks, main	3 x 1,086 m <sup>3</sup> (38,400 ft. <sup>3</sup> ) each	3 x 1,086 m <sup>3</sup> (38,400 ft. <sup>3</sup> ) each	2 x 2,175 m <sup>3</sup> (34,800 ft. <sup>3</sup> ) each
Cable tanks, auxiliary	4 x 41 m <sup>3</sup> (1,450 ft. <sup>3</sup> ) each	4 x 41 m <sup>3</sup> (1,450 ft. <sup>3</sup> ) each	3 total 446 m <sup>3</sup> (15,780 ft. <sup>3</sup> )
Cable dead weight, metric tons (long tons)	6,098 (6,000)	6,098 (6,000)	4,620 (4,547)
<b>Power and test (TTR) equipment</b>			
Power-feed equipment	1 x AT&T J86927	1 x AT&T J86927	1 x Power Nova R100N
dc cable test set	1 x Tinsley type 5901C	1 x Tinsley type 5901C	1 x Tinsley type 5901C
Analog cable test equipment	1 x complete suite for all repair operations	1 x complete suite for all repair operations	1 x complete suite for all repair operations
Fiber-optic cable test equipment	1 x complete suite for all laying/repair operations	1 x complete suite for all laying/repair operations	1 x complete suite for all laying/repair operations



that represents the ship's speed is computed, in real time, by comparing consecutive positions of the vessel. In the taut-wire method, the speed of a ship can be directly measured by means of a thin wire. Anchored to the ocean floor and paid out from a spool on deck, the wire leaves the ship at precisely the same speed as the vessel travels over the ocean bottom. Optical incremental shaft encoders, mounted on the wire pay-out machines, interpret this measurement in terms of knots.

To ensure proper speed control of an LCE during pay-out of repeaters or splice boxes, photo-sensors provide an automatic indication of the passage of such equipment through the line. Figure 5 is a schematic representation of these sensors, together with other important elements of the CDIS.

The heart of the CDIS is comprised of two sets of

**Figure 5. To ensure proper speed control of a linear cable engine (LCE) during cable pay-out over the Mid-Atlantic Ridge, sensors provide automatic indications for speed-up and slowdown of the engine. This illustration is a schematic representation of these sensors, together with other important elements of the cable-data instrumentation system (CDIS).**

programmable logic controllers (PLCs). PLCs are data gathering, process-monitoring, and control devices that receive input signals from sensors aboard the ship. The PLCs process sensor signals, save some data in their memory, and send output signals to various display devices. The two sets of PLCs provide redundancy, and they fulfill two distinct system functions. Redundancy is achieved by obtaining sensor input to both PLC sets and

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by providing output to two different forms of displays.

The first display form is a hard-wired set, mounted on ten consoles and panels throughout the ship. The second display form is composed of eight PC terminals that echo the same information as that provided by the hard-wired subsystem. These PC terminals have the capability to show cable-parameter changes over time (trends). They are also able to edit, save, and print such information at certain intervals.

Each one of the PLCs is pre-programmed with a set of application software to provide signals to the meters, indicators, and computers. The software that handles incoming sensor signals and outgoing display and control signals has been proven over many years, and it is sufficiently flexible to be modified for specific system applications. The main parameters measured by the system are:

- Cable tension;
- Cable speed, distance, and distance to go;
- Ship speed (navigation and port/starboard taut-wire methods);
- Computer-based subsystem software; and
- Cable slack.

Slack computations are made in real time and are added to a running average. The average is computed and displayed for *both* ship-speed measurement methods: navigational and port/starboard taut-wire. A switch on the CCR console selects the slack to be used to control the LCE's speed.

**Linear Cable Engine Control.** The CDIS system has a major control function: to remotely control the pay-out speed of the LCE. Such control is accomplished through the PLCs by means of a standard and reliable control scheme. This control function has three different operational modes:

- *Manual speed*, which automatically drives the LCE in the pay-out direction by setting the desired speed;
- *Automatic slack*, which drives the LCE by setting the desired cable slack and allowing the engine to accelerate or decelerate to maintain such slack; and
- *Automatic tension*, which drives the LCE by setting the desired cable tension and allowing the engine to accelerate or decelerate to maintain such tension.

#### **Modular Cable Equipment**

In the past three years, AT&T added three state-of-the-art cable ships to its fleet. Such ships represent the lat-

est know-how, expertise, technology, and equipment in cable installation and recovery. These ships are designed primarily for placing long-haul systems, and they have sufficient cable-carrying capacity for transoceanic installations.

As previously pointed out, AT&T has optimized its ocean platforms to provide custom and cost-effective solutions for any of the three types of systems: long-haul transoceanic, regional festoon, and short-haul.<sup>6</sup> A crucial part of this strategy is the use of alternative deployment platforms to minimize transit and operational costs for each individual installation.

The essential element of this strategy is the ability to mobilize a suite of portable, modular equipment ready to be deployed on any support vessel for any installation. A typical example is the complete transformation of a large dock and container vessel (Dock Express 20 or DE-20) into a cable-laying ship. AT&T needed a vessel capable of carrying long lengths of armored cable, and one that could bury cable for an extended time. The DE-20 was chartered on a long-term basis, and it was outfitted with all the cable-ship elements, from deployment sheaves to a repeater storage facility.

In addition to this semi-permanently installed machinery, AT&T built portable, modular equipment designed for a variety of smaller vessels. It is used for a range of such cable-placing activities as shore landings, shore-end burial, short-haul placements, and branching-unit deployments. Equipment includes cable engines, dynamometers, deployment sheaves, cable data instrumentation systems, testing apparatus, repeater stowage facilities, and cable tanks.

This ready-to-go, self-contained equipment is built around a rapid-deployment philosophy. It can be handled and shipped by normal carriers, combined with relatively short system cable, and mobilized aboard a support vessel at an installation site. This eliminates transit costs, as well as the off-charter operating cost of a regular cable ship. Such equipment is fitted into ISO containers and can be mobilized within a few days.

#### **Containerized Cable Transport**

With the advent of non-repeated systems, equipment bulk is minimized as cables of both smaller diameter and lighter weight are used. This, in turn, facilitates the transport of such systems in smaller containers and on freighters or barges. Thus, the containerized

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cable-transport process eliminates the high cost of operating a cable ship from its home port to the cable manufacturer's site, and then to the installation site and back.

Although ISO containers are still used for transporting cable, their suitability is limited to lightweight cable, very-short-haul systems, and the delivery of system spares. Handling cables in and out of ISO containers requires both substantial logistical planning and a considerable time investment. This makes ISO containers suitable only for cables having small outside diameters and bending radii, and those using the new AT&T Quick Joint technology. In all other cases, the optimal ways of transporting cable—other than on cable ships—is either by freighter, barge, or in cable pans (portable cable tanks in depots and storage facilities).

#### **Modular Terminal Stations**

The process of providing terminal stations for regional-festoon systems constitutes a greater percentage of the undersea provisioning process than ever before. Installation of such stations, if not optimized, could prolong the regional-festoon installation interval, making it comparable to a terrestrial system. Over the last ten years, AT&T has created and enhanced modular designs for such stations and established a common platform for producing them quickly and reliably, regardless of their final destinations. Custom work becomes streamlined and focused on technology and future expansion, rather than on physical environmental limitations.

Some of the factors that contribute to the decision of whether or not to install modular, prefabricated stations are:

- Availability of permits and easements;
- Delivery interval; and
- Possibility for system growth and expansion.

Containerized, modular stations offer the following general advantages:

- Each station is built within an ISO shipping container.
- Each container constitutes the complete shipment, and there is only one object to track.
- Site preparation and containerized station construction can occur in parallel instead of linearly.
- Due to assembly-line manufacturing, the total cost of these stations is lower.
- Component installation and testing, as well as overall assembly, are completed in a controlled factory envi-

ronment. Assembly problems, therefore, are resolved faster and with greater ease.

- The overall time to build a cable station is dramatically compressed due to the centralized, assembly-line construction process.
- Shipping costs are minimized due to the integration of station equipment into one, single, containerized station.

Stations are easily upgraded by mounting another container adjacent to an existing one. Access ducts allow interconnections between container buildings, thus facilitating the addition of switching, multiplexing, transmission, or power equipment. A spare container station for each festoon system can be maintained in the event of catastrophic failure of one of the sites.

#### **Underwater Tools**

AT&T employs a variety of specialized, remotely operated vehicles (ROVs), also known as *sea plows*, to protect its underwater plant and maintain its network. These ROVs operate from the beach and out through the surf, in water depths of up to 2,500 meters. Such ROVs as the Pacific SCARAB One and SCARAB IV, Sea Plow V, VI, and VII, and the Sea-Bed Tractor all have incorporated current, state-of-the-art technology into their design. SCARAB systems are fifth-generation, free-roaming ROVs used for undersea-system construction, survey, and maintenance.

Built in 1982, Sea Plow V complements Sea Plow IV, which was built in 1976 for installation of the TAT-6 system. The major design objective of Sea Plow IV and V was to improve the ability to bury undersea cables, repeaters, and splice boxes. New designs for the plowshare and control mechanics were developed to achieve that goal. Secondary design objectives were to increase operational depth to 1,000 meters, improve methods of transferring the tow wire from the pulling position to the launch-recovery system, and to improve electronic command control. After meeting these design objectives, Sea Plow IV and V became the workhorses of the industry throughout the 1980s, and they were used for installing undersea, buried systems worldwide. While the older Sea Plow IV was retired from service in 1992, Sea Plow V will continue to be used for the foreseeable future.

As the demand for fiber-optic cable burial grew, AT&T increased its inventory of tools by adding Sea Plow VI and VII. These two machines represent the latest evolution in plowing technology. They can retro-bury

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cable, previously installed under low tension, by depositing it under a mound of sand that has been raised, and then replacing the sand on top of it. In addition, these newest plows incorporate a self-loading capability, allowing the cable to be installed or removed from the plow without severing it.

AT&T commissioned its latest, purpose-built ROV, called the Sea-Bed Tractor, in May of 1992. This vehicle is a tracked, multipurpose ROV designed for trenching, as well as for inspecting and repairing undersea cables. Independently controlled, hydraulically-powered tracks facilitate precise maneuvering over a wide variety of sea-bottom terrain.

In 1978, AT&T undertook the design and construction of SCARAB I and II to meet its commitment to cable-system owners for re-burying cable in high-risk areas. Since then, improved equipment has been introduced. Both SCARAB IV and Pacific SCARAB One are fifth-generation ROVs designed specifically for underwater cable maintenance and repair operations. They can maneuver very effectively, even in waters having strong currents, facilitating the burial or excavation of undersea cables.

### **Jointing and Coupling Technologies**

The greatest challenges that lightwave undersea transmission systems present to installation and maintenance technology are *jointing* (connecting two cables together) and *coupling* (connecting a cable to a repeater). In analog undersea transmission systems, jointing and coupling are relatively simple and fast operations.<sup>7</sup> That is, analog systems can be assembled aboard a cable ship during the loading operation. Shipboard jointing and coupling of lightwave systems, however, is still a cherished dream.

Lightwave-system jointing is considered a meticulous factory operation, even under the best conditions.<sup>4</sup> When attempted at sea during installation or repair, isolation—as well as the harsh marine environment—decidedly affect success. This environment offers the greatest of the two challenges because of problems with storing equipment, protecting it (and spare parts) from corrosion, and performing precise operations under rigorous conditions. Ideally, at-sea jointing can be completed by two skilled technicians in six hours. Actual field experience ranges from eight to 16 hours. For armored cable, even more time is needed to terminate and overlay all the cable elements.

So-called *10-type technology* was developed for the jointing and coupling of the first-generation, SL280 lightwave system. 10-type technology, which was the first lightwave jointing process, evolved from 1-type technology, the first analog jointing technique. In the 10-type process, jointing and coupling are designed more or less independently, resulting in two sets of tools and fixtures—one for each operation. The coupling tools and fixtures, however, are engineered for factory use and not intended for field maintenance. Thus, spare repeaters are fitted with short cable sections at the factory, so that only jointing need be performed during repair operations.

Subsequently, more highly advanced *11-type technology* was developed. Among other cost-reduction innovations, it unified the jointing and coupling of the SL2000 third-generation undersea equipment. 11-type technology is used in the manufacture of SL2000 systems, as well as the maintenance of systems already deployed.

### **Universal Jointing and Coupling**

The idea of universal jointing and coupling (UJ/UC) was first proposed in 1986, two years before the first internationally supplied system, TAT-8, was cut over for service. The notion was not acted on until 1989, however, when the owners of TAT-9 suggested that UJ/UC might be an effective way to integrate all the system components, which were supplied by three different manufacturers. In response, the suppliers—AT&T, British Telecom Marine, and Alcatel—formed an international consortium to develop and offer UJ/UC. Later, KDD of Japan also joined the consortium, making the UJ/UC concept truly worldwide in its scope.

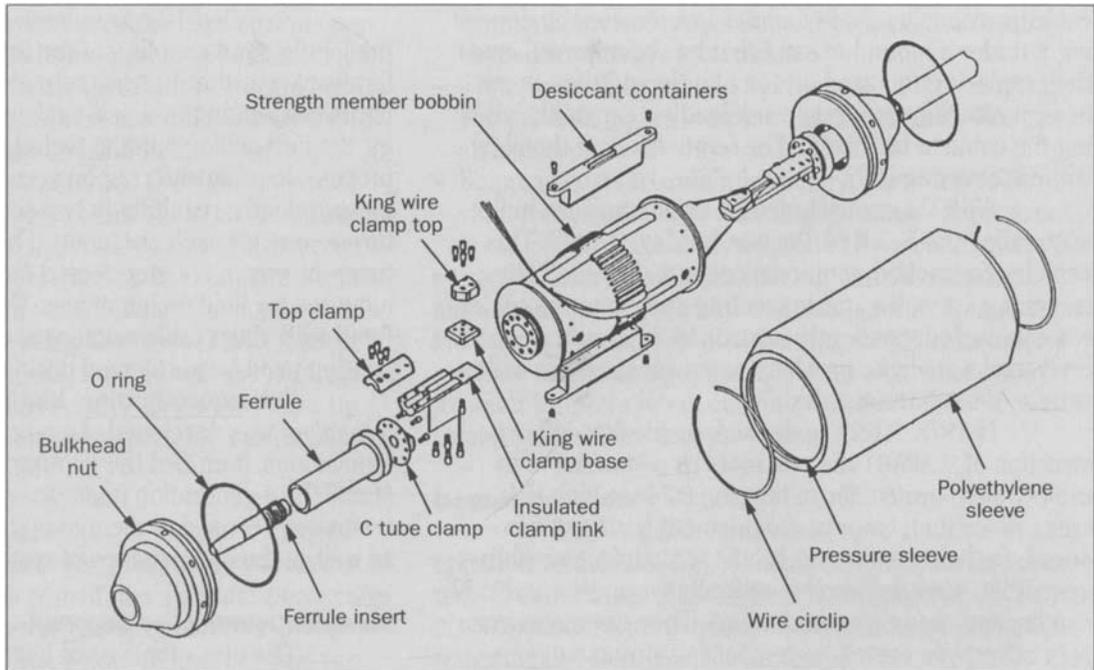
In simple terms, UJ/UC offers a set of tools that can be used to connect cables and repeaters, irrespective of their suppliers. This tool kit greatly simplifies the assembly and maintenance of undersea cable systems.

UJ/UC technology pooled the efforts of the consortium. AT&T provided the expertise both for the shipboard automated molding system and an elastomer-removal process. In addition, AT&T Bell Laboratories' responsibility was to develop the universal-coupling technology used to join cable to repeater.

For undersea-plant maintenance, UJ/UC offers the following benefits:

- Standardization of jointing equipment and skills (one set fits all);

**Figure 6. During the manufacture of TAT-11, universal jointing and coupling (UJ/UC) technology was used in a factory owned by STC, an undersea cable supplier, to integrate AT&T repeaters into STC cable. This drawing illustrates a universal joint of the same type used for the TAT-11 installation.**



- Allowance for the sharing and interchange of spare cables; and
- Allowance for the sharing of resources world wide.

In the manufacture of TAT-11, UJ/UC technology was used in a factory owned by STC, an undersea cable supplier, to integrate SSI repeaters into STC cable. Figure 6 illustrates a universal joint of the same type used for the TAT-11 installation.

#### **The Baltimore Training Center**

AT&T SSI established the Baltimore Training Center in 1988 to teach undersea-system installation and maintenance procedures and to train and qualify AT&T jointers. Since then, the center has gained international renown. Technicians from Spain, Taiwan, Japan, England, and Canada have come to the center to improve their jointing and maintenance skills. The training center now teaches the latest techniques in both 11-type technology and UJ/UC.

#### **Powered-System Branch Repair**

With the advent of transoceanic, lightwave transmission technology came the concept of undersea net-

works. First, there was the branching repeater, followed by the branching multiplexer. Then came the ring network and many other variations. All these arrangements created the need for powered-system branch repair, whereby one network segment could be taken out of service and repaired while the other continued carrying traffic. In addition, this procedure allowed revenues to be generated by at least half the system.

Since the completion of development work in 1993, powered-system branch repair has demonstrated its effectiveness. It has been used on several occasions to maintain the TPC-4 system in the North Pacific.

#### **Conclusion**

Undersea-system installation and maintenance techniques that have been developed during more than 30 years of at-sea experience now provide robust, cost-effective cable-placing capabilities. Changes in technology and markets, however, are driving the development of still more improved methods.

In the past, almost all undersea cable systems were relatively long (thousands of kilometers). They required repeaters, as well as large ships, to carry the

cable and to provide adequate handling and storage facilities for repeaters. Recently, regional system markets, using non-repeated undersea systems, have developed. These much shorter systems can be installed using small vessels not originally designed as cable ships. In addition, portable cable-handling equipment is being developed that can be mounted for specific cable-placing applications on many of these ships.

Smaller systems typically are not powered, and they are usually located in relatively shallow water. Thus, new cable-jointing techniques are being developed that take advantage of the savings in material and assembly time resulting from the absence of high system pressures (due to deep-water installation) and voltages. These new designs have two other distinct advantages: they require fewer specialized tools and less operator training.

While considerable automation has been designed into the cable-handling and control systems of new ships, further development is still possible. In particular, considerable overall cost savings, and increased accuracy, could be achieved by using real-time bottom surveys during installation. Preliminary route surveys could be eliminated—or at least confined—to areas known to have severe bottom conditions, or those containing significant obstacles.

There are certain bottom conditions—rock outcroppings, for example—where normal burial is essentially impossible. Heavy, armored cable is typically installed in such areas. If armored cable must be manufactured in a factory, extensive planning is required to place the cable in exactly the right position. If the armoring could be applied aboard ship, however, it could be installed selectively—in real time—only where needed, for heavy-duty sheath protection.

Whether any of the aforementioned improvements will prove to be economically viable, and come to pass, is yet to be determined. The changing nature of the products and markets, however, along with the continually increasing demand for higher speed and higher-quality operations, will continue to encourage innovation and fresh thinking.

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