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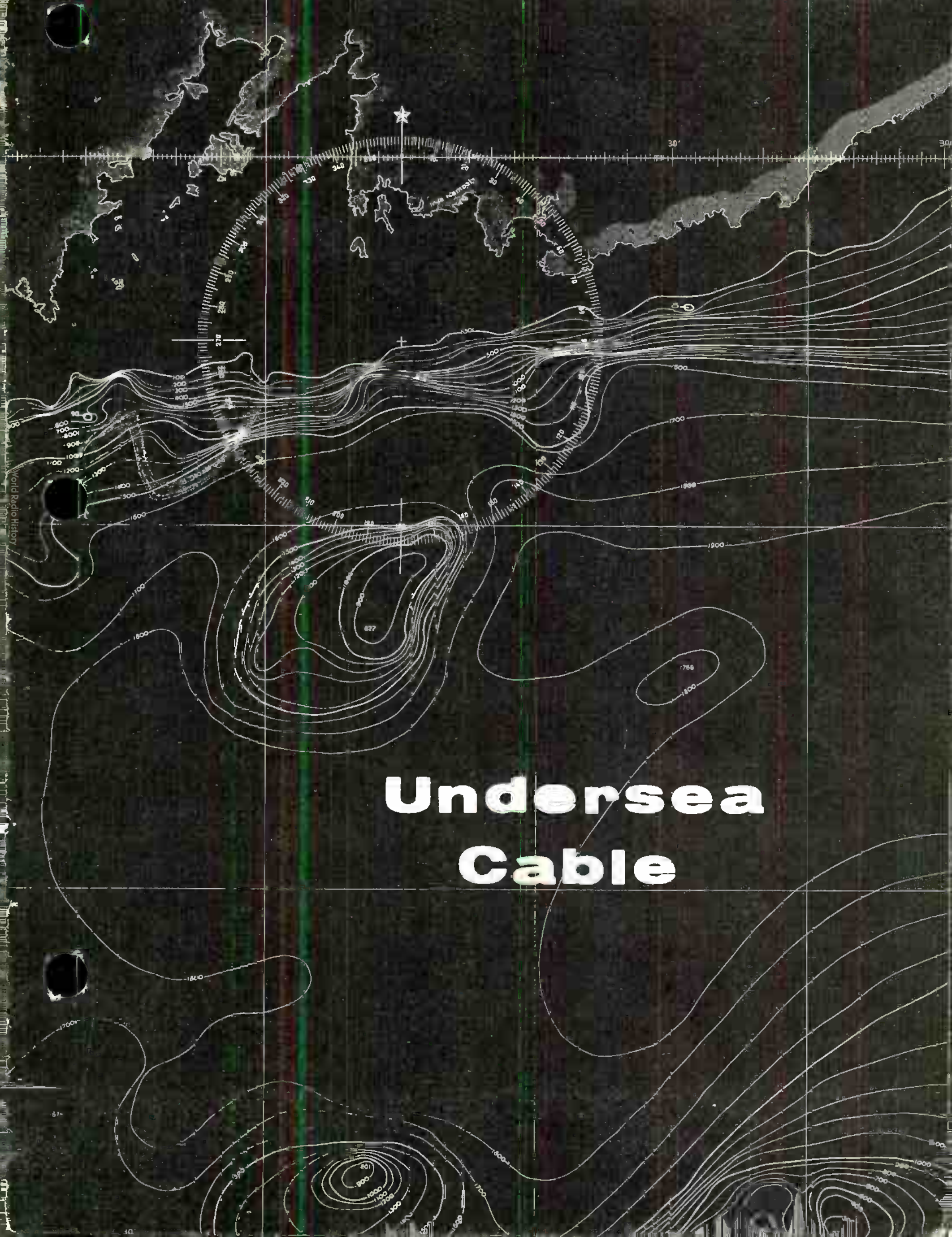
DEMODULATOR



Undersea Cable

Undersea telephone cable presents problems which have no parallel on dry land.

A dry land telephone cable system is relatively uncomplicated. It requires cable, of course, and uses repeaters energized by power sources available along the cable route. Whether above or below the ground, the system can be easily maintained because it is accessible.

When it comes to an undersea cable system, power and maintenance are not quite so simple. Power is not available four miles or even a few hundred feet below the ocean surface. Repair and maintenance services are hard to perform in a marine environment.

Yet power, maintenance, and the ocean environment are problems which designers of undersea cable have had to cope with and master.

Power for the water-isolated repeaters must come from land based sources. It must travel through the cable to distant repeaters. But the amount of power available is limited by the size of the cable which is itself limited by manufacturing and cable laying techniques.

Because power is fed from the shore end of the cable, it is a precious commodity. It must be carefully conserved. Each repeater – each power user—must be constructed to draw a minimum of power while producing maximum results.

In every phase of the design and construction of an undersea system reliability plays an important part. Again the isolation of an undersea system presents a unique challenge. For all practical purposes repeater maintenance is out of the question. Recovering a submerged cable takes hours and sometimes days.

As a result designers make every effort to use components which have low failure rates. Twenty years or more without a system failure is normal. To meet such a goal designers require components which have well documented use histories. This cautious approach has meant highly reliable undersea cable systems.

In addition the undersea cable itself must be strong enough to withstand pressures up to 12,000 pounds per square inch. The cable must also be light and pliable enough to withstand the high tensions of being lowered from an unsteady cable ship in the open sea.

The challenges of power, environment and reliability were met over a number of years. They are challenges peculiar to telephone cables—a johnny-come-lately to the world of undersea cable.

History

The first transatlantic cable, laid in 1858, was a telegraph link between the Old and New Worlds. It lasted approximately 20 days, carried 732 messages and allegedly saved the British government 50,000 pounds. It also took six-

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Eugene A. Garcia

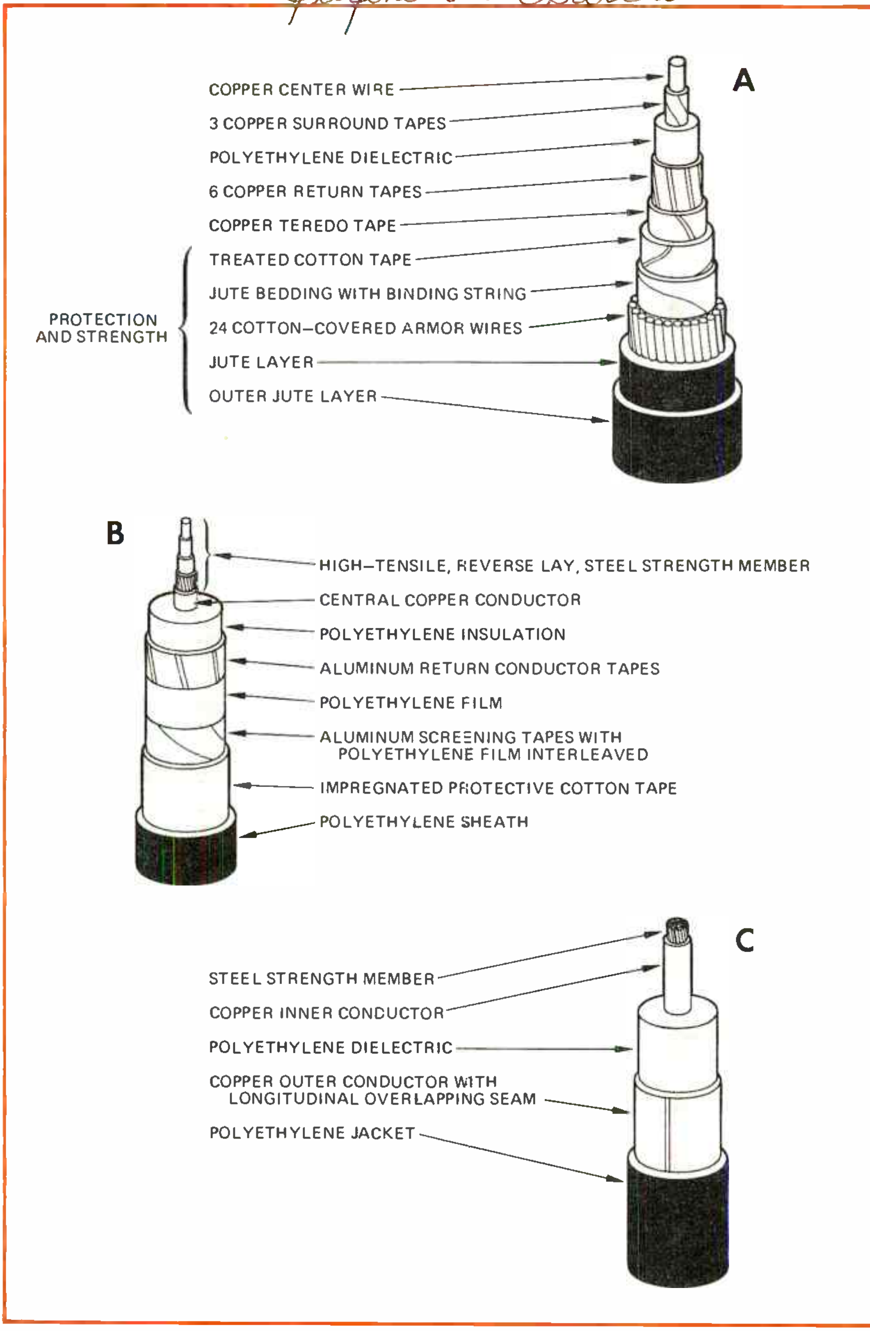

Figure 1. Armored cable shown in A was used in the SB system. B and C show armorless cable developed by the British Post Office (B) and American Telephone and Telegraph (C). All three cables measure 1-1/4 inches in diameter.

teen and a half hours to pass a 99 word message from Queen Victoria to President Buchanan—a long time for any woman, let alone a queen, to wait.

The next cable went down in 1866. This one lasted. In fact it lasted so well that the next major change to transatlantic communications did not come until 1927. In that year radio telephone bridged the Atlantic.

It was not until 1956 that the first transatlantic telephone cable connected Scotland with Newfoundland. Actually Alexander Graham Bell had tried without success to complete a transatlantic telephone call over existing telegraph circuits in 1879. At that time not enough was understood about bandwidth and attenuation to appreciate the reasons for Bell's failure.

Today the reasons are well known. Commercial telephone transmission requires much greater bandwidth than does telegraph. The greater bandwidth, in turn, requires higher frequencies which means more attenuation.

Only short undersea telephone systems were possible using telegraph cable technology. In the 1920's short systems to Havana and the Catalina Islands were laid from the United States mainland. Similar short systems connected the British Isles with the continent.

Breakthrough

But these systems could not have evolved into the three and four thousand mile undersea systems which exist today without the introduction of the submerged repeater. The British Post Office developed the first submerged repeater and put it into service in 1943. The American Telephone and Telegraph Company laid the first deep water repeater in 1950 between Key West and Havana.

The full story of undersea cable is not limited to the repeater—as significant as it is—or to modern communications technology. An undersea telephone cable system must also conform to recommendations and requirements of oceanographers and seamen.

A system, for instance, must be laid along a path as free as possible from deep trenches and jagged undersea mountains. It must be laid smoothly, steadily and at a reasonable speed. It must be resistant to the corrosive effects of water and boring of marine animals. Taken as a whole the system must be strong enough to support four

	SB*	SD	SF
Capacity (3 kHz Channels)	48	128	720
Top Frequency On Cable	164 kHz	1.1 MHz	5.9 MHz
Cable	Two 0.620" Armored	One 1.00" Armorless	One 1.50" Armorless
Repeater Type	Flexible Vacuum Tube	Rigid Vacuum Tube	Rigid Transistor
Components Per Repeater	67	205	161
Repeater Spacing	44.5 Miles	23 Miles	11.5 Miles
Maximum System Length	2530 Miles	4025 Miles	4600 Miles

*Data for SB system based on operation after installation of new modulation scheme.

Figure 2. A comparison of three undersea cable systems developed by the American Telephone and Telegraph Company, showing growth of undersea cable capabilities.

or five miles of its own weight in water.

The system which has evolved consists of coaxial cable, repeaters and equalizers. At the shore end are special terminals for multiplexing signals and supplying power, and fault location equipment. It is a fully complementary system, each part having been built specifically for undersea use.

The Cable

The first deep water telephone cable was similar to its telegraph counterpart. The only appreciable difference was a concentric return conductor added to form a coaxial structure.

The cable had a copper center wire surrounded by three thin copper tapes as its electrical member. A solid dielectric separated the center wire from a helix of six copper tapes. The solid dielectric—made of polyethylene—was necessary because of the high water pressure on the ocean bottom. Around these electrical members were several layers of protective and strengthening materials.

Telegraph cable did not use copper tapes but usually had strands of copper wire. Both cables were armored by wire rope and were further protected by tar, linseed oil and pitch.

The important difference between the telephone and telegraph systems was, of course, the repeater. Telegraph systems had operated for years without them, but telephone systems could not get along without periodic boosts from repeaters.

Even within the telephone community the undersea repeater made an important difference. In fact the use of different repeaters turned the first transatlantic system into two systems.

The first transatlantic telephone cable system — in spite of being two systems — was a triumph of international cooperation. It was the result of coordination between governments and private businesses in at least three countries.

The final venture included the active participation of the American Telephone and Telegraph Company, the British Post Office and the Canadian Overseas Telecommunications Corporation. The Americans and British were responsible for planning and laying the system.

Stiff or Soft

The project was divided into a deep water section—the American sphere—and a shallow water section which the British controlled. In both sections deep water repeaters were used, but in the interest of reliability and to avoid laying problems at sea, all concerned agreed that an American developed repeater should be used in the deep water section.

The American repeater had two advantages. It had a longer history of successful deep water operation, and it was a flexible repeater. To an extent the repeater behaved like a section of armored cable twisting with the tensions experienced during laying.

The British repeater was a rigid instrument which could not conform to a cable's twisting. At mid-ocean depths, where several miles of cable stretch under tension between ship and ocean bottom, the rigid repeater resisted the tensions placed on an armored cable. Such resistance causes damaging kinks and loops in the cable.

Both the British and Americans agreed that the risk of kinking was too great to try the British repeater in deep water laying operations. In addition the participants felt that a flexible repeater system could be handled and stowed aboard ship more easily and economically than could a rigid repeater system.

Irony

Ironically, the rigid repeater had a higher capacity than the flexible repeater. Its size did not impose the severe component limitations placed on the flexible repeater. As a result the rigid repeater system was able to accommodate 60 two-way voice channels on a single cable.

Even more ironic: the Americans were forced to lay two cables in the more difficult deep ocean section of the route because of the limited capacity of their repeater. The deep water system was a physical four-wire system using two cables of thirty-six 4-kHz voice channels each. Each cable carried voice transmissions in one direction through a string of 51 repeaters approximately 44.5 miles apart.

The cable itself was manufactured in lengths of about 200 miles, called blocks. During the laying of each block transmission measurements were made and analyzed aboard the cable ship. From the analysis the cable was equalized to correct for deviations in the cable arising from manufacture, temperature, depth and pressure.

Different types of cable were used in the system but the differences were physical rather than electrical. In shallow water up to 1300 feet, cables designated either type A or B were used. Both types had more protective and strength members than did the deep water, type D cable.

The heavier outer jacket in cable types A and B was necessary because of the frequent natural and man made disturbances which occur in shallow water. The type D cable did not need as much protective material because the deep ocean bottom is more serene.

Growth and Expansion

Since the first transatlantic system others have followed. There are now six coaxial cables spanning the Atlantic. Two cross the Pacific. Currently under construction is a system which will link Cape Town, South Africa and Lisbon, Portugal.

With this growth have come changes. The system used in the deep water section of the first transatlantic cable—dubbed the SB cable system—has been altered and has itself given way to radically different cable systems.

Originally the SB system had thirty-six 4-kHz voice channels. To optimize the use of these channels TASI (Time Assignment Speech Interpolation) was applied.

TASI made it possible to switch unused speech channels to a talker within milliseconds and switch away again to another user when the first talker stopped to listen. In effect TASI doubled the number of speech channels available.

In 1959 a new modulation scheme, called double modulation, was introduced to the SB system which reduced the 4-kHz voice channel to a 3-kHz channel. With double modulation it was possible to obtain 48 voice channels in the same frequency range that had carried 36 voice channels.

To cram the additional 12 voice channels into the system the band edges of adjacent channels had to be put 100 or 200 Hz apart, depending on the channel. This was much closer than the 800 Hz used for the 4-kHz channels. To support the closer channels much sharper cut-off filters were required. This made it possible to use 95 percent of the gross frequency band available.

Development of TASI and the slicing of frequencies are achievements which have no parallel in land cable systems. The developments do fit in with continuous efforts by undersea system designers to knock down formidable obstacles—inaccessibility, lack

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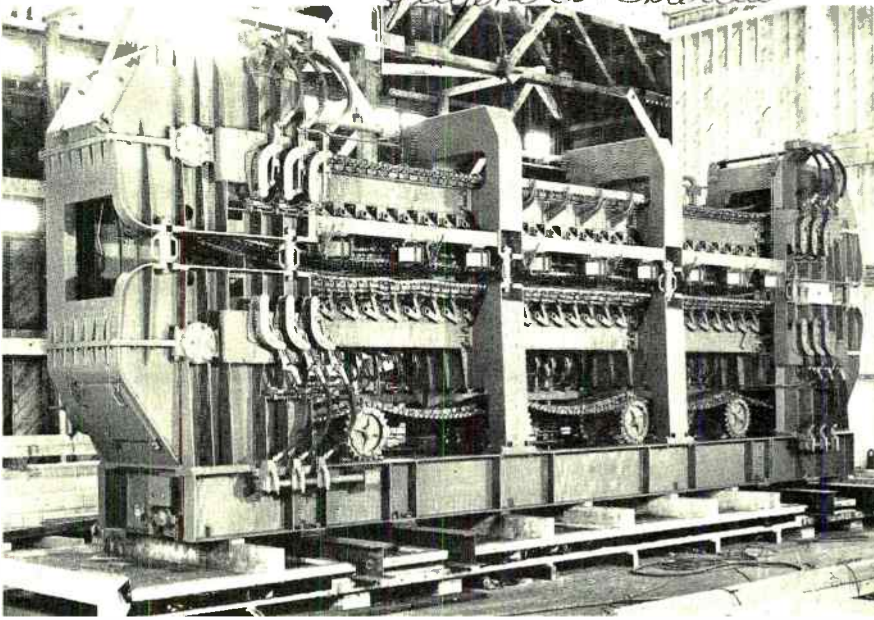


COURTESY A T &T

Figure 3. Cable engine used aboard C.S. Long Lines. *The engine is designed to run at payout speeds compatible with ship speeds of 8 knots.*

of power sources, the ocean environment, system capacity.

Armorless Cable

Another obstacle fell in 1961 when the English and Canadians teamed up to lay a second transatlantic telephone system. They used rigid repeaters in their entire system and added something new—armorless cable.

The armorless cable system brought its own circle of improvements starting with the cable core diameter. It increased from a 0.62 inch diameter to a full inch.

The overall diameter of the new cable was the same as the old, but the larger core gave the new cable 2/3 the attenuation of the old. Its expanded core made it possible to increase the line voltage from 2000 volts to 4000 volts which made it possible to put more repeaters on the system.

Finally, armorless cable made laying the rigid repeater easier. With the increased core size, the strength member could be put inside the central conductor. Placing the strength member there minimized torque tension coupling, thereby preventing the twisting and stretching characteristic of armored cable.

Reducing the tension had further advantages. With armorless cable it was possible to get a more consistent and predictable sea bottom performance. The risk of kinking caused by mechanical discontinuities at the rigid repeater decreased.

The cable itself used reverse lay strands—strands wrapped together in one direction enclosed by other strands wrapped in the opposite direction—for their center strength member. The reverse lay overcame internal torque.

The strength member was enclosed in a copper conductor surrounded by polyethylene. Around the polyethylene was a spiral of aluminum tape and around it a cover of overlapping turns of aluminum foil.

Armorless American Style

In 1963 a United States to England system went into operation also using armorless cable. It was American Telephone and Telegraph's SD cable system which used cable developed in the United States. It had a single lay strength member surrounded by a copper inner conductor. A polyethylene dielectric separated the inner and outer conductors.

Both the American and the English armorless cable were sealed in a thick polyethylene jacket. The resulting armorless cable was not as strong as armored cable, but because the newer cable was lighter, it retained the same strength-to-weight ratio.

The SD system employs rigid repeaters. These repeaters, like the flexible repeaters, contain a feedback amplifier which gives the system a wider frequency response with less distortion.

A common unit amplifies both directions of transmission by the use of directional filters. With the increased room in the rigid repeaters parallel amplifiers can be included which give added protection against failure.

Rigid Repeater

The SD system repeater is considerably more complex than the flexible repeater. It contains 205 components—about 3 times the number used in the earlier SB repeater. The new system carries 138 3-kHz channels in each direction. (It originally carried 128 voice channels.) The channels are derived by conventional frequency division multiplex.

Pilots in each group modulator are used for monitoring, equalization adjustments and automatic switching. Both the low band (108-504 kHz) and the high band (660-1052 kHz) have order wire channels. One of these channels is split so that it can be used for voice and teleprinter exchange.

The completed system has 182 repeaters, spaced every 23 miles. An equalizer follows every tenth repeater.

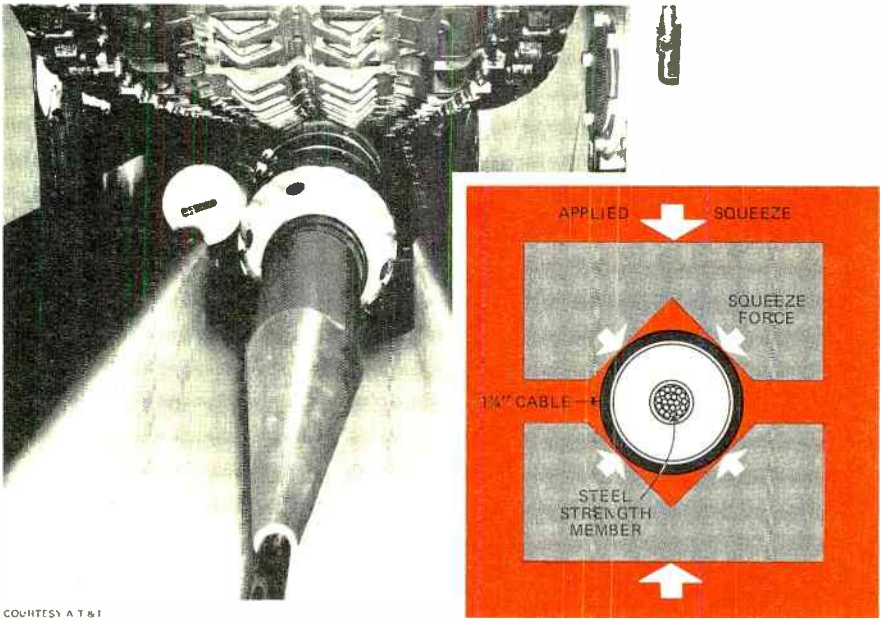
The repeater is made up of five sections with amplifiers and directional filters in the center three sections. Power separation filters which separate the power and information signals are at each end of the repeater.

Both the power separation filters and the directional filters create spurious feedback around the amplifier. This makes it necessary to use two transformer-regulated, symmetrical paths to cancel the unwanted signals.

The majority of the electrical components used in the SD repeater are similar to those in the earlier SB repeater. To fill new needs several new types of components were introduced but only after extensive testing. In all cases, each component and the whole repeater had to meet the reliability requirement of the earlier system—20 years of continuous operation.

The 500 pound repeater and housing are subjected to some 1700 tests. One test can find holes so tiny it would take 26 years to get a thimble of gas through them. The repeater is 50 inches long and 13 inches in diameter.

At the input and output, gas tubes protect the repeater against high voltage surges. The entire system – cable, repeaters and equalizers – requires 11,000 volts fed from 5500 volt power supplies at each end of the 4000 mile cable. The system draws 389 milliamperes of current.



COURTESY AT&T

Figure 4. End view of cable engine as repeater enters engine. Insert shows how tracks grip a piece of cable. When repeater goes through, the flexible tracks separate to give the necessary clearance.

Special Ship

With the rigid repeaters and armorless cable came another development in undersea cable technology—a new cable laying ship, *C.S. Long Lines*, specially built for the American Telephone and Telegraph Company. The ship incorporated several innovations in cable handling.

Historically, cable laying has revolved around the circular drum. To use the drum, cable had to be bent around the drum's diameter. Sometimes this meant winding the cable around the drum several times.

While this was less a problem for armorless cable than for armored cable, it was a considerable problem for the rigid repeater. Complicating this was the requirement to lay cable and repeaters continuously at high speeds.

To avoid bending the repeaters a special cable engine with flexible, tractor-like tracks was developed and installed aboard *Long Lines*. The cable, repeaters or equalizers were fed between two of the tracks and pulled along by V-shaped blocks which gripped them at four points.

The engine was only one development. In place of a sheave with a diameter greater than 7 feet—required for rigid repeaters — a chute was molded into the stern of the ship's hull. The chute made it possible to pay out the cable and repeaters with a minimum of bending stresses.

At the bow of *Long Lines* a cable repair and recovery system was installed. The installation was a little more conventional, using large, wide drums which permit the passage of a rigid repeater at slow speeds.

On the Bottom

The first undersea cables were laid along existing shipping routes without much concern for the condition of the ocean bottom. Today a sizable amount of preliminary survey work is done to determine the best cable route. Ideally, such a route should avoid deep ocean trenches and steep grades, stay clear of centers of earthquake activity and the rough mountain ranges on the ocean bottom.

During the installation of one of the Pacific cable systems, oceanographers had to chart vast mountain ranges, deep trenches, thousands of volcanic seamounts and scores of live volcanoes in order to find an acceptable route for the cable.

While planning a section near Guam, it took six passes over the Magellan Seamount to find a safe passage. At the Marianas Trench (almost 6 miles deep) oceanographers searched for and found a natural bridge for the cable four miles down.

Remarkably it has been the forces of nature and man that have caused the most cable damage. Earthquakes and landslides are believed to have cut and washed away lengthy sections of cable. Other breaks have been caused by ship's anchors or trawlers dragging their nets.

In one study of recovered telegraph cable, it was found that 36 cables had suffered from trawler damage, 12 from corrosion, and 5 from

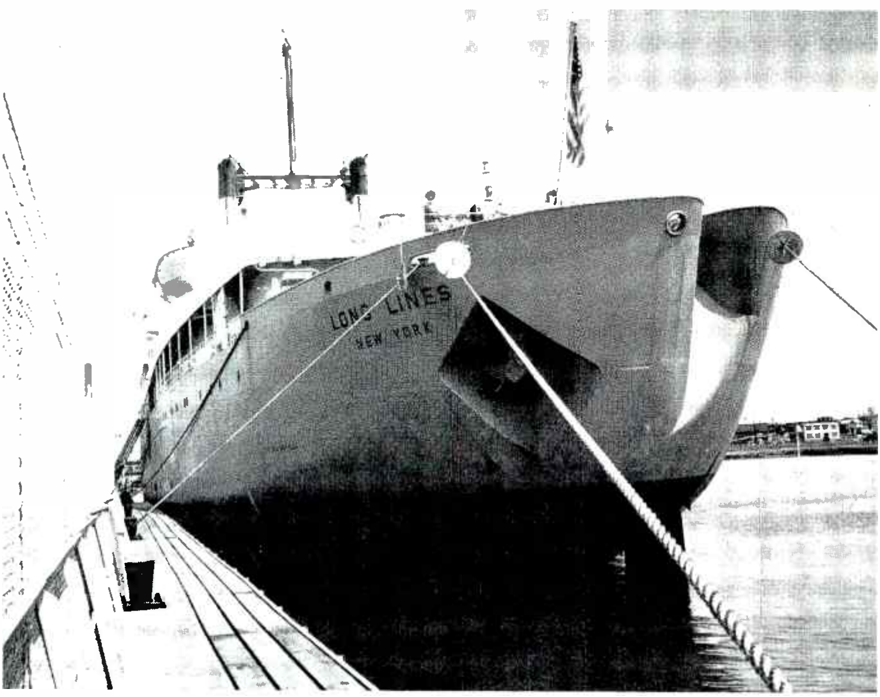


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Figure 5. Stern of C.S. Long Lines *showing special chute to accommodate rigid repeaters. Most cable laying innovations incorporated in the ship's design were pioneered by the American Telephone and Telegraph Company.*

chafing. Four more had either deteriorated, been crushed or had telegraph repeater failures and three had armor pinches or tension breaks from a ship's anchor.

Most cable damage happens in shallow areas where the cable is not protected by several hundred feet of deep water. With this in mind, the American Telephone and Telegraph Company has begun to bury shallow water sections of cables.

Coming Up

The next generation of undersea cable will differ somewhat from the SD system. The new SF system will use diffused germanium transistors and a cable diameter of 1.75 inches.

Electrically the SF system is a direct successor of the SD. The cable construction remains the same. The repeater will be rigid but will contain only 161 components--44 less than the SD but 94 more than the SB system.

It does have definite advantages. Its 720 voice channels is one of them. Another is that a 4000 mile system will need only 3500 volts fed from each shore terminal and will draw 136 milliamperes of current.

The system will operate at higher frequencies than its predecessors–564 kHz to 5884 kHz–which will mean putting the repeaters closer together. In the new system there will be repeaters every 10 miles. Equalizers will still come every 200 miles.

Why Bother?

With the advent of satellites it might seem impertinent to talk about expanding undersea telephone capacity. Even in their infancy satellites can provide bandwidths which are just barely possible with the most advanced undersea systems.

But to look at the satellite as an immediate replacement for undersea cable systems is to overlook the virtues of each.

Satellites usually carry several repeaters in parallel, thereby avoiding complete system failures caused by the loss of a single repeater. In addition the terminal points in a satellite system can be changed, making it possible to re-route traffic when necessary. Being able to switch from one terminal to another gives the satellite system a flexibility which undersea cable systems do not have.

But undersea systems do not require the large, expensive terminals satellite systems do. In fact their fixed terminal points make undersea systems ideal for daily, well established international telephone service. Finally the ocean floor does not limit the number of undersea cables as much as does the area available for synchronous satellite orbits.

In the final analysis the two systems are complementary. With the growth of international communications both cable and satellites will have to share that growth.

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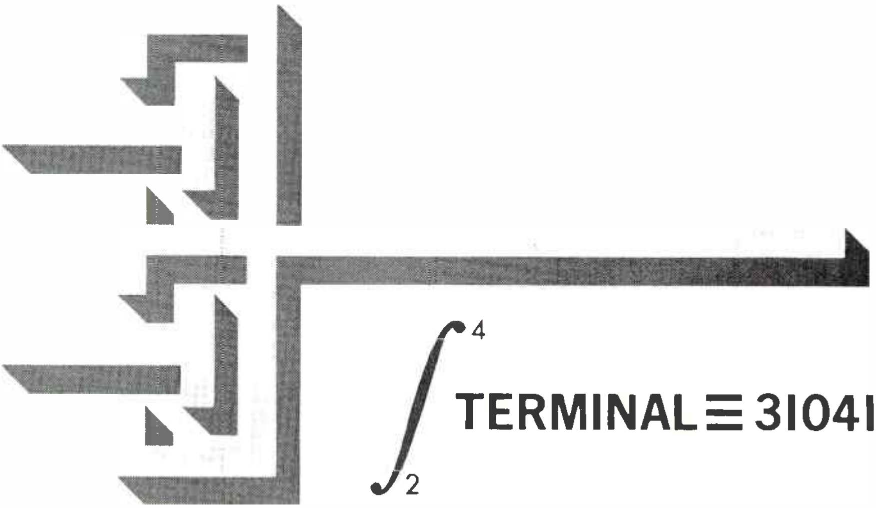

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