Paths Beneath the Seas: Transatlantic Telephone Cable Systems

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Abstract

The year 2006 marks the fiftieth anniversary of the first transatlantic telephone cable, TAT-1, which inaugurated the modern era of global communications. Over the last fifty years since TAT-1 went into service, the capacity of telephone cables has grown explosively from the initial thirty-six voice-band channels to modern broadband optical fiber systems, which can carry 100 million voice circuits. As well as a beginning, TAT-1 was a continuation; submarine telegraph cables had been in operation for 90 years. The paper reviews the history of submarine cable starting with the telegraph era, continuing through the TAT-1 and the coaxial systems that succeeded it and culminating in the modern optical systems. The prominent role played by Canada in all of these developments is highlighted.

Sommaire

L'année 2006 souligne le 50e anniversaire du premier câble téléphonique transatlantique, TAT-1, qui a inauguré l'ère moderne des télécommunications globales. Depuis les 50 ans que TAT-1 a été mis en service, la capacité des câbles téléphoniques a crû de façon explosive depuis les 36 canaux initiaux à fréquence vocale jusqu'aux systèmes modernes de fibres optiques à large bande, lesquels peuvent transporter 100 million de circuits vocaux. De même qu'un commencement, TAT-1 a été une continuation : les câbles télégraphiques sous-marins étaient en opération depuis 90 ans. Cet article parcourt l'histoire du câble sous-marin depuis l'ère télégraphique, en passant par TAT-1 et les systèmes coaxiaux qui l'ont succédé et culminant vers les systèmes optiques modernes. Le rôle substantiel joué par le Canada dans tous ces développements est souligné.

1.0 Inception of True Global Telecommunications

It is nearly 50 years since the September 26, 1956 edition of the New York Times had the front page headline:

First Call Made by Phone to Europe
Line's Capacity is 3 Times as Great as Radiophone's

On the same day, similar stories appeared in newspapers throughout Canada. The subject was TAT-1, the first transatlantic telephone system, which had been inaugurated on the previous day. Simultaneously, a symposium on the Atlantic Cable was in progress at the Chateau Laurier in Ottawa. TAT-1 began the modern era of global communications. Before TAT-1, voice was carried on unreliable and expensive radio channels. Text messaging was carried on submarine telegraph cables (the technology of the previous 90 years) which was reliable, but slow and expensive.

2. Back to the Beginning

As well as being a beginning, TAT-1 is the continuation of a story that began on November 8, 1850 with a letter by the Catholic bishop of Newfoundland, J.T.M. Mullock in the St. John's Courier . His Grace outlined a scheme whereby messages dropped from ships passing the eastern coast could be relayed by telegraph across Newfoundland and the Cabot Strait to mainland North America, effecting a saving of days. Fredrick Glisborne, an English telegraph engineer took up the challenge and began the construction of the telegraph line across the rugged interior of Newfoundland. Unfortunately, he ran out of money a short way out from St. John's. Before shuffling off the historical scene, Glisborne's made one lasting contribution: enlisting the involvement of a retired paper manufacturer, Cyrus Field. Field immediately went beyond the relay scheme by advocating transatlantic telegraph transmission. His first concerns were with, what he called, the twin problems of "geography and lightning". On the latter, the challenge of long distance electrical transmission, he consulted Samuel Morse, receiving assurances of feasibility. On the geography, he was encouraged by Lt M. F. Maury, Head of the National Observatory in Washington. In 1853, the US Brig Dolphin had surveyed the ocean floor on the likely path across the Atlantic and found a 'telegraph ridge', whose depth and the surface were suitable for cable laying.

The 1857 and 1858 Expeditions

The first task was installing the cable across the Newfoundland (See Figure 1.) The route consisted of four hundred miles of wilderness with mountains, rivers and gorges – formidable obstacles. In 1856 a cable connecting Cape Ray to Cape Breton in Nova Scotia was laid.

The project then turned, in the summer of 1857, to the bridging of the Atlantic. The American naval ship Niagara started from Queenstown (now called Cobh) followed by the British ship Agamemnon, both fully loaded with cable. The plan was for Niagara to start laying from Valencia Harbour. Agamemnon would then finish the lay to Trinity Bay in Newfoundland after a mid-ocean splice. William Thompson, later Lord Kelvin was the electrician on board, monitoring electrical continuity with his mirror galvanometer. Unfortunately, after 200 miles the cable broke and was lost in 2000 fathoms.

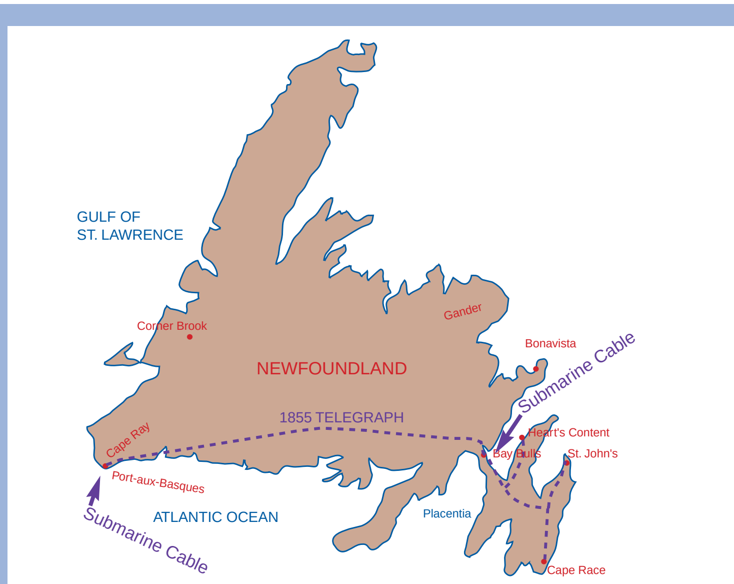

Figure 1: The Route of the 1855 Telegraph Across Newfoundland

The same cable was used in the 1858 attempt; it was, in retrospect, an error. The same two ships met in mid-ocean with Niagara laying. to the west and Agamemnon to the east. Based on the lessons learned in 1857, the cable laying machinery had been improved. There were still cable breaks; nevertheless, the lay finally succeeded.

The new telegraph connection to England was greeted with a widespread outpouring of joy in the New World. This spirit is exemplified in Figure 2 which shows a woodcut depicting huge bursts of fireworks over New York's City Hall[1]. The cable never worked very well and failed after a month of shaky operation.

[1] This as well as other wonderful illustrations are reproduced in [2].

The 1865 and 1866 Expeditions

Alarmed by a succession of costly failures in cable laying operations, the British government convened a blue ribbon committee to examine the whole question and to make recommendation. There had been a few examples of success providing grounds for hope. The committee made a number of recommendations one of which was a heavier and bulkier cable; accordingly, the demands on the cable laying ship were correspondingly greater. By a stroke of good fortune, just the right vessel was available-the Great Eastern, which was five or six times the size of anything else afloat when completed in 1857.

Armed with experience and new equipment, the 1865 lay went well until there was a break 600 miles from Newfoundland. The position was carefully noted for future retrieval. Flaws were identified and rectified, and the expedition in 1866 succeeded. The cable was brought ashore at Heart's Content a deep, still inlet on Trinity Bay. There was a message from Vancouver to London on July 31, 1866. There was a double triumph as the Great Eastern grappled for and found the end of the 1865 cable. Thus, there were two fully operational cables! There has been continuous operation ever since.

Figure 2: Fireworks in N.Y. City, celebrating the Atlantic telegraph cable
Illustration reproduced with permission of Emphemera Society of America

Thereafter, submarine cable telegraph service developed continually. A noteworthy point was reached on November 1, 1902 when the "All-Red Route" was inaugurated. This was a globe encircling telegraph path linking only parts of the British Empire. On the west coast the route was across Vancouver island and entered the ocean at Bamfield connecting to Fanning Island over the longest link in the system, 4000 nautical miles.

A significant improvement in cable performance was obtained by applying the principle of inductive loading derived by Oliver Heaviside. In 1924, permalloy, a Bell Labs invention, was wrapped around telegraph cable increasing the bandwidth to 100 Hz, which represented increase in capacity to 400 of words per minute. Further improvement was provided by using paragutta as the insulating material; this is a derivative of guttapercha, the material used from the earliest days of submarine cable. (In later systems, this insulating material would be superseded by the British development, polyethylene.) The siphon detector, invented by Lord Kelvin, continued as the means of deciphering electrical signals by skilled operators.

3. TAT-1

Laying the Groundwork

Long wave radio service was established in 1927 and short wave in 1928[2]. While radio circuits provided a voice service, they are subject to the vagaries of sunspot and seasonal and daily variations ; consequently, submarine cable still had a role to play. The first undersea telephone was a link in a circuit between London and Paris in 1891. In 1921, deep-water telephone cables were laid between Key West and Havana.

[2] Oliver Heaviside contributed to this aspect of transoceanic transmission as well; he suggested the existence of an atmospheric channel for radio waves, the Heaviside layer.

In 1919, a study of transoceanic submarine telephone cable was initiated by American Telephone and Telegraph Company(AT&T). The advances in materials, mentioned above, enhanced the feasibility of the project. In 1928 this work culminated in a proposal for a repeaterless cable bearing a single voice channel across the Atlantic. Two considerations killed the project: radio circuits were continuously improving and the cost estimate was $15,000,000, a substantial sum in the midst of the Great Depression.

By the early 1930's electronic technology had advanced to the point where a submarine cable system with repeaters became feasible for the transatlantic link. The design of repeaters presented two challenges: electrical and mechanical. The electrical challenge was reliability; repeaters were expected to lie on the ocean bottom for twenty years. The cost associated with the repair due to component failure was prohibitive. All of the electrical components were subject to rigid reliability requirements; however, most fragile were the vacuum tubes, which were the only means of amplification. Development of these super reliable tubes was initiated in 1932. They were life tested for a period of eighteen years. When installed they were significantly below the current state of the art, a mutual conductance of 1000 vs. 6000 micro mhos. They were manufactured under conditions that presaged those of modern semiconductor fabrication.

The repeater design features also contributed to reliability. In order to increase tube life, the signal levels into each stage of the amplifier were a level lower than that causing grid current to flow. In parallel to the three stages of the amplifier was a gas tube which would fire and bypass the stages in the event of a tube failure. In each repeater, was a crystal tuned to a frequency unique to the repeater, thus allowing a malfunctioning repeater to be identified.

The mechanical challenge was the laying of cable in the open sea to depths of up to two and a half statute miles. Standard coaxial cable had spiralled external armouring, which was in danger of kinking if the ship stopped to drop a repeater. The solution to the mechanical problem was a flexible repeater, which, with some modification, could be laid with equipment designed for telegraph systems. (Projected traffic did not justify the construction of a ship designed to lay rigid repeater cable in a continuous fashion.) The repeater used in TAT-1, shown in Figure 3, was designed to flex enough to be wound over the cable drum. The cable itself was coax. The stray capacitance and inductance engendered by the close proximity of components within the repeater restricted bandwidth with the result that amplification could only be in one direction and two cables would be necessary, resulting in a physical four-wire system. The flexible repeater technology in deep water was tested by the 1950 Havana-Key West cable, which used an earlier version of the TAT-1 repeater.

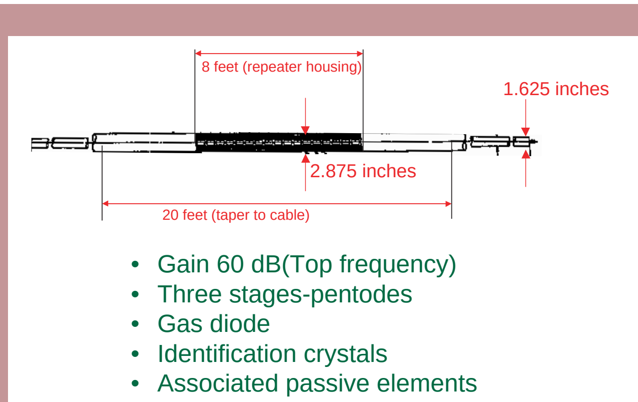

Figure 3: Flexible Repeater

The British Post Office (BPO) pioneered an alternative approach to submarine telephone cable, deploying rigid repeaters with a far larger diam-

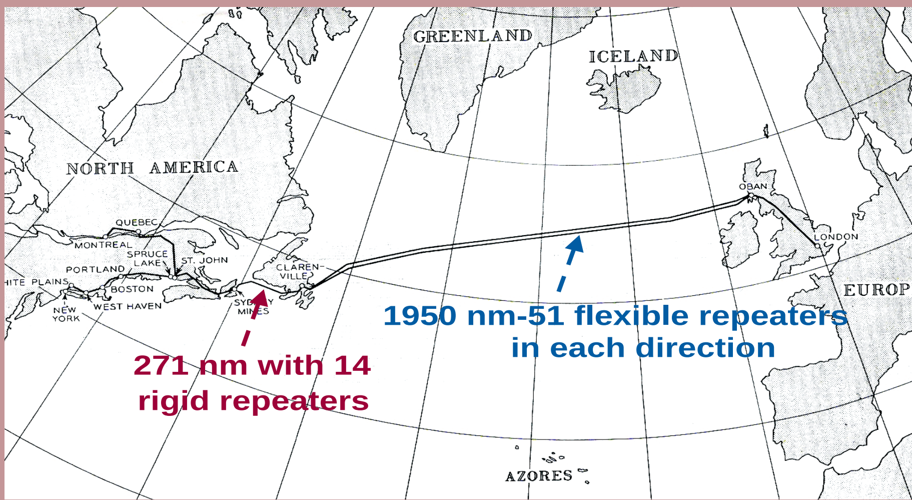

Figure 4: TAT-1 system

eter. This configuration together with more modern vacuum tubes allowed wider bandwidth. With wider bandwidth, the same repeater, with suitable filtering, could be used for both directions of transmission. Undersea telephone systems, using repeaters were not without precedent. In 1943,the British Post Office(BPO) installed a single repeater link between Anglesey and the Isle of Man. The same shallow-water repeater system connected UK and continental Europe in 1946. These steps were the culmination of work that had been going on since 1938.

Laying the Cable

TAT-1 was a joint enterprise between AT&T and its Canadian subsidiary, the Eastern Telephone and Telegraph Company, the BPO and the Canadian Overseas Telecommunications Corporation[3]. Its basic geography is shown in Figure 4. The flexible repeater cable was laid between Oban, Scotland and Clarenville, Newfoundland over the summers of 1955 and 1956 on a route well to the north of existing telegraph cables. Each link was coaxial cable approximately 1950 nautical miles long with 51 repeaters spaced at 37.5 nautical mile intervals. The maximum feasible number of repeaters was determined by the maximum terminal voltage which could be applied to power the systems without affecting the reliability of the high voltage components. The bandwidth of the system was, in turn dictated by the number of repeaters. In addition to the repeaters there were 8 undersea equalizers in the East-West link and 6 in the West-East link. The equalizers served to correct accumulated misalignment in the frequency band. Although the gross difference in cable loss across the transmission band of 144 kHz was 2100 dB, the correction of the equalizers and the repeater circuits led to a difference of less than 1 dB across the band.

As the New York Times headline states, TAT-1 immediately tripled the circuit capacity across the Atlantic. The band of the Atlantic link was between 20 and 164 kHz, allowing 36 voice channels (4 kHz), which were split with six between London and Montreal and twenty nine between London and New York. A single channel was dedicated to narrow band uses such as telegraph and order wire for maintenance.

The system also included an overland portion across the Burin Peninsula to Terrenceville, Newfoundland and an underwater link under the Cabot Strait to Sydney Mines, Nova Scotia. The Cabot Strait link was a single cable 271 nautical miles long with 14 repeaters spaced at 20 nautical miles intervals. The repeater were the rigid type pioneered by the British. This link carried 60 voice channels, 24 of which carried traffic between Newfoundland and Nova Scotia.

Improvements in Terminal Equipment

Transatlantic bandwidth was so costly that it made sense to increase to develop terminal equipment which would use it more efficiently. The BPO designed a channel bank which increased the number of voice channels in the standard 48 kHz band from 12 to 16 by fitting the voice signal into 3 kHz rather that the standard 4 kHz. A two-stage filtering process reduced the guard band between channels without a significant decrease in quality.

[3] Later to become Teleglobe Canada

A second advance in terminal equipment was Time Assigned Speech Interpolation (TASI). This system was design to take advantage of the fact that, with listening and inter-syllabic pauses, the average speaker uses the voice channel only a quarter of the time, on average. With a voice-activated switch, available bandwidth could be allocated to an active speaker on demand. Using this technique, TASI allowed a doubling of the number of voice circuits, with an imperceptible impairment.

4. Coaxial Systems Following TAT-1

Systems with a flexible repeaters and unidirectional transmission are designated as SB. These systems were subsequently deployed between Clarenville and Penmarch, France (1959) Port Angeles, Washington and Ketchican, Alaska and Port Angeles and Hanauma, Hawaii. Indeed, all of the systems that followed TAT-1, coaxial and optical, were deployed in all of the worlds oceans; however, space limitations require us to concentrate our discussion on cables that crossed the North Atlantic as typical of long-haul submarine cable technology.

After TAT-1, transatlantic traffic grew at a rate of over 20 % year after year. To keep pace with this growth, systems after TAT-1 employed technology that was ever closer to the state of the art in land systems. In 1961 the BPO and the Canadian Overseas Telecommunications Corporation installed CANTAT 1, a system incorporating a lightweight, armourless cable between Hampden, Newfoundland and Oban, Scotland. The cable had strength member in the center rather than the periphery; consequently, in contrast to armoured cable, there was far less danger of kinking if the ship stopped during the lay. The new cable allowed the deployment, in the open sea, of a rigid repeater, with its inherently larger bandwidth . With the larger bandwidth and increased space for circuitry, the repeater, could, by suitable bypass circuitry, carry traffic in both directions on a single cable. The number of available channels increased from 48 to 160. After this last installation, all subsequent transatlantic systems were the single cable, rigid repeater type.

In 1963, TAT-3, a system incorporating SD technology, similar to that of CANTAT-1, was laid between Tuckerton, New Jersey and Widemouth Bay, England by the newly launched cable ship Long Lines. Repeaters were at 20 nautical miles intervals. As in the case of TAT-1, the number of repeaters was limited by the allowable maximum voltage. The bandwidth allowed 138 voice channels in each direction on the single cable. A vacuum tube developed for the SD system improved performance. Reliability was safeguarded by a parallel strings of tubes in the repeater, with one in reserve. A second SD system, TAT-4, was installed between Tuckerton, New Jersey and St Hilaire de Riez, France in 1965.

In addition to increases in the number of voice channels, increases in repeater gain-bandwidth product allowed longer systems.TAT-3 was the first transatlantic system that did not terminate in Canada. Part of the motivation for this change was increased reliability. From the beginning cables have been vulnerable to damage by fishing trawlers. There have been several such breaks on the Grand Banks, whose size increases the hazard. In order to reduce trawler damage, the way that cable lay on the ocean floor was studied in detail by means of submersible , remote controlled vehicles. This study led to the development of techniques for burying cable on the ocean floor.

In 1970, semiconductor technology, in the form of germanium transistors was introduced to submarine cable design with the SF system. The technology was used in TAT-5 which stretched between Tuckerton, New Jersey and St Hilaire de Riez, France. The Canadian cable ship, John Cabot buried the cable in the shallow water off the coasts while Long Lines laid the deeper portions. The lower power requirements of transistors allowed repeater spacing to be decreased to 10 nautical miles resulting in a sizable increase in the number of voice channels, from 138 to 845.

The next advance was the silicon technology, deployed by CANTAT-2 in 1974. This system provided 1840 voice channels between Beaver Harbour, Nova Scotia and Widemouth Bay, England. CANTAT-2 was a second joint effort of the BPO and the Canadian Overseas Telecommunications Corporation.

What was to be the last coaxial system to be deployed across the North Atlantic, the SG system, was a joint development by AT&T, the BPO and the French Ministry for Posts and Telecommunications (FPTT). Two cables, each providing 4200 voice circuits, were laid: in 1976, TAT-6, between Green Hill, Rhode Island and St Hilaire de Riez, France and in 1983, TAT-7 between Tuckerton, New Jersey and Lands End, England. Repeater spacing was 5.1 nautical miles. In keeping with the pace of the introduction of technology, amplification in the repeaters was provided by silicon transistors. At a relatively late stage in the system development, it was discovered that the attenuation of cable lying on the ocean floor could change with time. In response, a shore-controlled equalized was developed.

5. Optical Systems

The continual exponential growth rate of well over 20% per year motivated the development of ever higher capacity systems, leading naturally to optical fibre with its vast capacity. Coincidentally, the time of introduction of optical fibre was the beginning of a whole new era in the organization of the telecommunications industry. In the coaxial cable era, systems were developed by public service oriented organizations, like British Telecom, AT&T, France Telecom, and KDD. In the optical era, the business was thrown open to competition. It is symptomatic that the submarine cable operations at AT&T moved, lock stock and personnel to Tyco Inc. In this new competitive era, the number of systems have proliferated; we focus here on typical systems with a Canadian connection.

The use of optical fibre in submarine cable introduced two new requirements in existing optical technology. The first was the familiar requirement for reliability. The vast increase in traffic over fibre limited the role of satellites as backup. The requirement was system lifetimes of twenty-five years with an average of three failures of components. Secondly, the laying and anticipated repair operations placed new demanded on the strength and flexibility of optical fibre.

The first transoceanic optical system, TAT-8[4], went into service in 1988. Transmission was at 1.3 μm over single-mode fibre. The technology mandated digital transmission; signals were generated by injection lasers and detected by newly developed high sensitivity photodiodes. The repeaters were regenerators, which converted from optical to electrical and back again. The system delivered 280 Mbps providing 4000 voice circuits over a pair of fibres.

The system connected Tuckerton, New Jersey, Widemouth Bay, England and Penmarch, France. The inherently smaller size of fibre, compared to coax, allowed two fibre pairs to be housed in the same cable assembly. Repeaters were spaced at 67 km. The repeaters had spare lasers that could be switched into service by shore-based commands. Shore command could also be used to monitor performance. The system also provided a branching unit (BU) at its eastern end, which connected legs from France and England to a single transatlantic cable. The BU enabled switching of branches and fibre pairs in the event of failure in one of the branches.

The innovations of TAT-8 were radical in the conservative milieu of submarine cable; however, TAT-8 amply demonstrated the viability of digital undersea lightwave technology. By 1993 more than 125,000 kilometres of TAT-8 systems were in service worldwide, which almost matched the total length of analog submarine coaxial installations, but installed in 5 rather than 30 years. As time went on, optical cable, with its vastly greater capacity, replaced satellites as the major carrier of intercontinental traffic.

TAT-9, representing a second generation of regenerated undersea lightwave systems, was developed by AT&T and Standard Telephone and Cable (STC) and installed in the summer of 1991. It is a regenerative system with repeater spacing as long as 100 km and three fibre pairs per cable, operating at 560 Mbps. One of the pairs was held in reserve on segments of the system. There are five land terminals: Pennant Point, Nova Scotia, Manahawkin, New Jersey, Conil, Spain, St. Hillaire, France, and Goonhilly, England. Three Undersea Branching Multiplexers (UBM), developed in Canada by MPB Communications, provided circuitry allowing for 140 and 45 Mbps exchanges among fibre pairs. In addition to traffic regeneration and multiplexing, in the UBMs there was DC circuitry to allow for different system powering arrangements, primarily for fault location and restoration after a power fault. The subsequent transatlantic systems, TAT-10 and TAT-11, were a similar design with regenerative repeaters and UBMs.

4 The generic designation for this system was SL; however, usage changed with optical systems. There was never SM, SN, … Term like SL-280, indicating the bit rate and SL-2000, the millennium became current.

In 1994, the last transatlantic regenerative repeater system, CANTAT 3 went into service. It was developed by Standard Telephone and Cable. The landing points are Nova Scotia, Vestmannaeyjar, Iceland, Tjornuvik, Faroes, Redcar, England, Blaabjerg, Denmark and Sylt, Germany. This was another system employing branching at the eastern end of the cable. The total length of the system was 7500 km with 89 repeaters. The line rate was 2.5 Gbps.

Submarine cable system employing regenerative repeaters have two fundamental limitations:

- The data rate is inherently limited by the intermediate electrical stage in the repeater.
- The data rate of a system is fixed, once the repeater is in the water. Improving performance by upgrades to terminal equipment, such as the 3 kHz channel banks and TASI in TAT-1, is not possible.

The next generation of optical fibre systems employed erbium doped optical amplifiers in the undersea repeaters. These amplifiers amplify signals in the optical band centered at 1.55 μ; there is no optical/electrical conversion. Within the optical band covered by the amplifier, one or more information bearing wavelengths can be placed. This dense wavelength division multiplexing (DWDM) allows data streams to be added as technology advances.

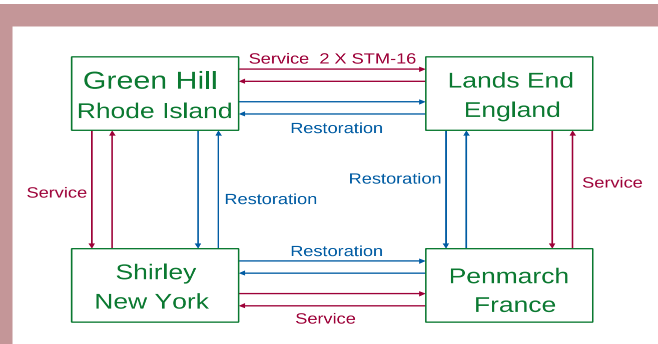

Figure 5: TAT-12/13

The first transatlantic system to employ optical amplifiers was TAT-12/13, which went into service in 1995. The system was a joint development by AT&T-Submarine Systems Inc (SSI), British Telecom, France Telecom and Toshiba. As indicated in Figure 5, the TAT-12/13 has a bidirectional ring topology connecting points in the USA, England and France. The links between Rhode Island and the UK and between France and New York are 5913 km and 6321 km, respectively. Both contain repeaters spaced at 45 km intervals. The segment between the UK and France is 370 km in length and contains four repeaters spaced 74 km apart. Finally, between New York and Rhode Island, high powered optical amplifiers in the terminals power the signal over a repeaterless link.

The cables between the terminals contained two fibre pairs, one in service and a spare. The bidirectional data rate on each of the pairs is 5 Gbps. During normal operation the spare carries lower priority traffic that can be interrupted without penalty. In the event of a cable break, service can be restored in full, immediately by rerouting traffic in the opposite direction around the ring over the spare pair. Subsequently, data was transmitted of two additional wavelengths (colours); thereby tripling capacity.

The latest generation system is represented by TAT-14, which was developed and installed in 2001 by KDD and SCS, a subsidiary of Pirelli. The system is in the form of a bidirectional ring topology. Going counter-clockwise around the ring the its terminals are: Manasquan, New Jersey, Blaabjerg, Denmark, Norden, Germany, Katwijk, Holland, St Valery en Caux, France, Bude-Haven, England and Tuckerton, New Jersey. The capacity of TAT-14 is 640 Gbps, carried on four fibre pairs, two pairs in regular service and two in reserve for restoration of service. Each pair carries sixteen wavelengths bearing a 10 Gbps digital traffic stream.

The latest generation system is the Tyco Global Network (TGN) which was laid in both the Atlantic and Pacific Ocean in 2000-2003. The submarine cable has eight fiber pairs each using DWDM. The total capacity of the system is 7.68Tbps. It can carry more than 100 Million voice circuits. Consider the growth from 36 circuits in fifty years!

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Jeremiah F. Hayes received the BEE from Manhattan College, the MS in mathematics from New York University and the PhD in Electrical Engineering from the University of California, Berkeley. Dr. Hayes has taught at Purdue University and McGill University, and on 01/01/01 he retired as Distinguished Professor Emeritus from Concordia University in Montreal. As well as academic positions, he was also a member of technical staff at Bell Telephone Laboratories. He is a Life Fellow of the Institute of Electrical and Electronic Engineers. In 1998, he was the fourth recipient of the Canadian Award for Telecommunications research.