Route Selection and Cable Laying for the Transatlantic Cable System

By J. S. JACK*, CAPT. W. H. LEECH† and H. A. LEWIS‡

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The repeatered submarine cables which form the backbone of the transatlantic telephone cable project were installed during the good weather periods of 1955 and 1956. This paper considers the factors entering into the selection of the routes, describes the planning and execution of the laying task and presents a few observations on the human side of the venture. It also covers briefly the routing of some 55 nautical miles of repeatered submarine type cable which were trenched in across the neck of the Burin Peninsula in Newfoundland to connect the Terrenceville submarine terminus with the cable station at Clarenville.

GENERAL

In the days of Cyrus Field, Lord Kelvin and those other foresighted and courageous entrepreneurs of the early transoceanic submarine cable era, the risks involved in selecting a route and laying such a cable must have appeared formidable beyond description. And indeed they were, for not until the third attempt was a cable successfully laid.

Today the hazards may be somewhat more predictable, our knowledge of the ocean bottom more refined and our tools improved, but only to a degree. The task still remains extremely exacting in its demands for sound engineering judgment, careful preparation, high grade seamanship, and good luck — weatherwise. For the basic methods now in use are still remarkably like those employed on *Great Eastern* and other early cable ships and the meteorological, geographical and topographical problems have changed not at all.

In the current transatlantic project — the first transoceanic telephone cable system — there are two submarine links. Between Clarenville in Newfoundland, and Oban in Scotland there lie some 1,850 nautical miles§ of North Atlantic water, most of it deep and all of it subject to

* American Telephone and Telegraph Company. † British Post Office. ‡ Bell Telephone Laboratories.

§ A nautical mile, as used herein, is 6,087 feet, 15.3 per cent longer than a statute mile.

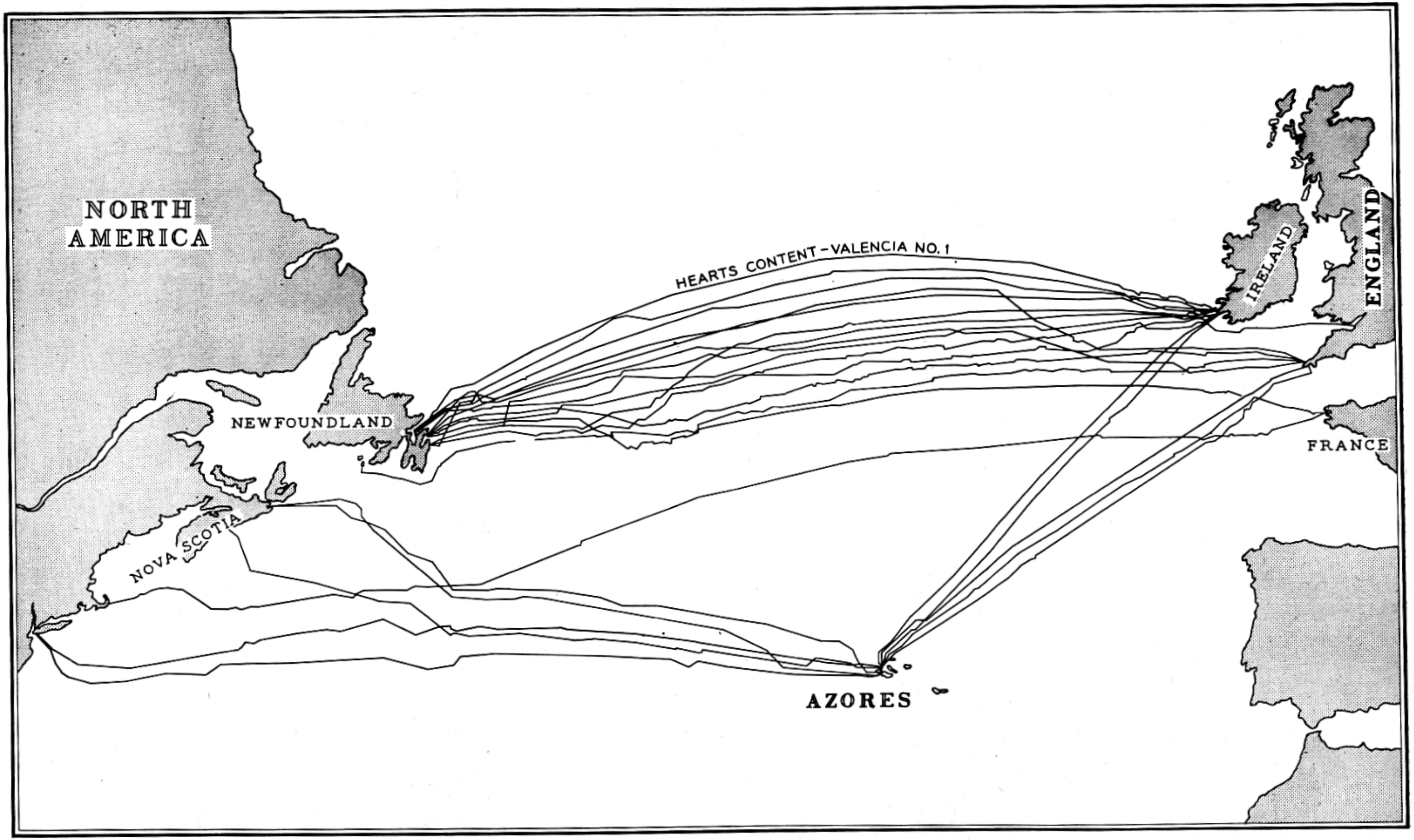

Fig. 1 — Telegraph cables in the North Atlantic.

weather of unpredictable and frequently unpleasant nature. The bridging of this required the laying of two one-way cables over carefully selected routes, using an available cable ship. And the presence in these cables of 102 flexible repeaters posed problems quite unique for such long and deep cables, as also did the need for trimming the system equalization during laying so that transmission over the completed system would fall within the prescribed limits.

From Terrenceville, Newfoundland, to Sydney Mines, Nova Scotia, a single cable, 270 nautical mile path was required through Fortune Bay and across Cabot Strait. While this water is considerably shallower, here again a relatively conventional cable laying problem was complicated by the presence of repeaters which in this section were rigid units, 14 in number.* Trimming of system equalization was also required.

These cables were laid during the spring and summer months of 1955 and 1956. And the preparation for the laying required many months of effort in fields which were for the most part quite foreign to the usual scope of land wire telephone activity. Some appreciation of the problems encountered in this phase of the venture may be gained from the following sections.

NORTH ATLANTIC LINK

Route Selection

The first successful transatlantic telegraph cable was laid across the North Atlantic in 1866. Since that date 15 direct cables have been laid and 5 cables by way of the Azores. The approximate routes of these cables are shown in Fig. 1. It is at once evident that the shortest and possibly the best routes were already occupied so that selection of routes for the two transatlantic telephone cables could be expected to present some difficulty.

Some of the more important considerations which guided the selection were (a) route length, (b) clearance for repairs, (c) trawler and anchor damage possibilities, (d) terminal locations suitable for repeater stations, with staffing in mind as well as facilities for onward routing, due consideration being given to the strategic aspects of the locations.

Route Length

Obviously, the shorter the length of a submarine route, the better. In the present instance, any system length much in excess of about 2,000

* Two additional repeaters are located in the 55 nautical-mile section which is trenched in across Newfoundland from Clarenville to Terrenceville.

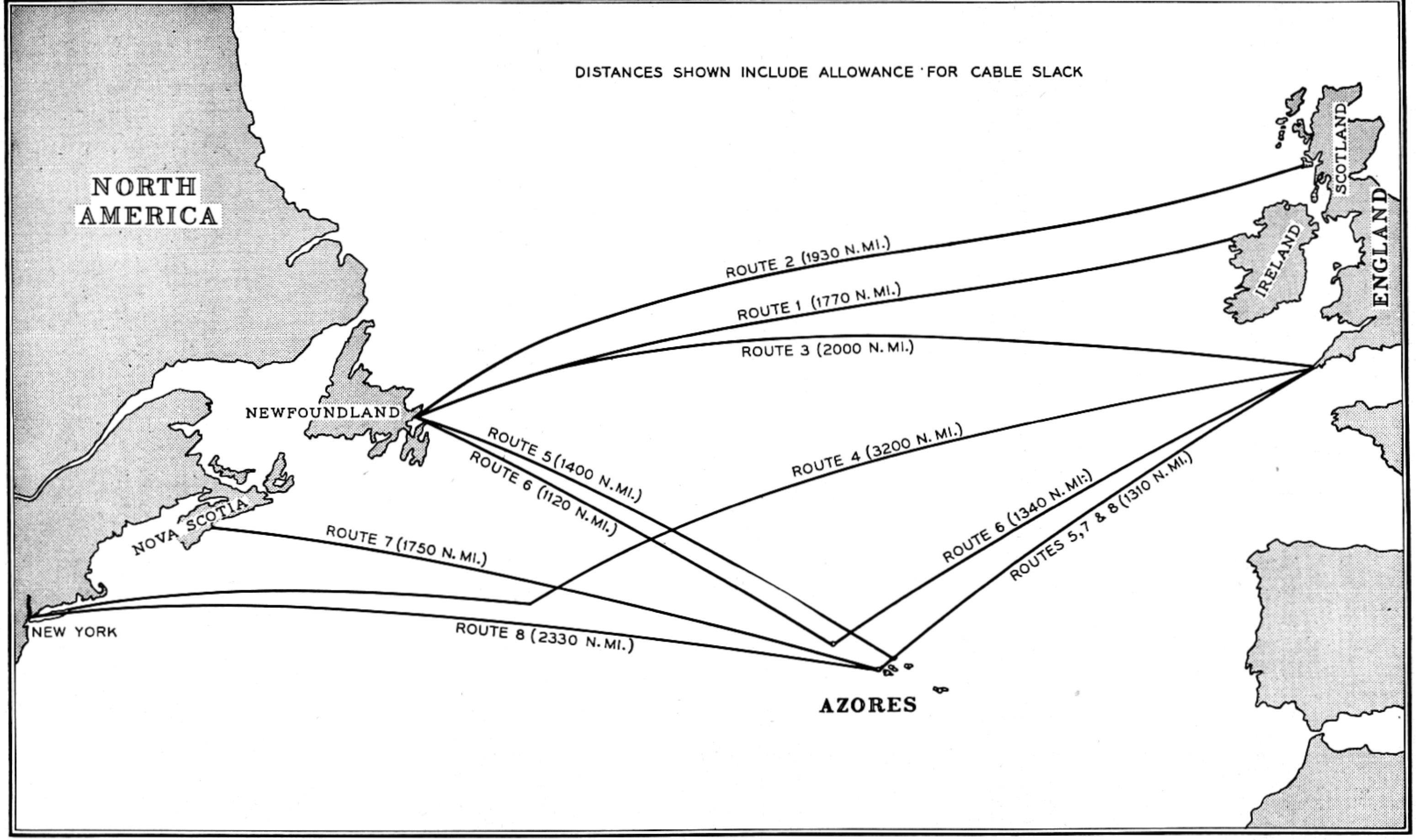

FIG. 2 — Tentative telephone cable routes.

nautical miles would have resulted in a reduction in the number of voice channels which could be derived from the facility.

On Fig. 2 are shown a number of the routes to which consideration was given in the early planning stages. The distances shown are actual cable lengths and include an allowance for the slack necessary to assure conformance of the cable to the profile of the ocean bottom.

Route 1, from Eire to Newfoundland, at 1,770 miles, is the shortest route and in point of fact was provisionally suggested in 1930 for a new cable. But the difficulty of onward transmission of traffic to London made this route unattractive.

Route 2, from Newfoundland to Scotland, compared favorably in length with Route 1, but its adoption was dependent upon location of a suitable landing site in Scotland.

Route 3, from Newfoundland to Cornwall, England, approximated 2,000 miles laid length and would have been very attractive had not so many existing cables terminated in southern Ireland or the southwest corner of Cornwall, which would lead to a great amount of congestion and consequent hazards to the telephone cables.

Route 4, from New York to Cornwall, was too long to be considered as its length amounted to some 3,200 miles.

Routes 5, 6, 7 and 8 were indirect via the Azores. They were attractive, as only relatively short lengths were involved and suitable sites for intermediate cable stations could have been found on one of the several islands in the Azores. But difficulties attendant upon landing rights, and staffing problems in foreign territory could be foreseen.

Clearance for Repairs

Repair of a faulty cable or repeater necessitates grappling, and in deep water this is likely to be a difficult operation. To avoid imperiling other cables while grappling for the telephone cables and, conversely, to provide assurance against accidental damage to the telephone cables from the grappling operations of others, it was considered essential that the route selected provide adequate clearance from existing cables. Suitable clearance is considered to be 15 to 20 miles in the ocean, with less permissible in the shallower waters of the continental shelves.

Trawler and Anchor Damage Possibilities

It is probable that fishing trawlers cause more interruption of submarine cables than any other outside agency. Cables laid across good fishing grounds are always liable to damage from fouling by the otter boards of the trawlers. Final splices, either initial or as a result of repair operations, are especially vulnerable to damage because of the difficulty in avoiding slack bights at such points. It was desired, therefore, to avoid fishing grounds if at all possible.

If cables are laid in or near harbors frequented by merchant shipping, damage must be expected from vessels anchoring off shore in depths of less than 30 fathoms and proposed routes should, therefore, avoid such areas.

Cable Terminal Siting

Location of the cable terminal stations must be considered from the standpoints of suitability of shore line for bringing the cables out of the water and also from the standpoint of amenities for the staff. This latter factor is most important in keeping a permanent well-trained staff. For example, owing to staff difficulties, it was necessary to move a terminal station of one company from the west side of Conception Bay in Newfoundland to a site within easy reach of St. Johns.

A further factor in proper siting of the cable terminals is consideration for onward routing of the circuits carried by the cables.

And finally in view of the importance, generally, of submarine cable facilities, it is considered desirable to avoid cable terminal locations in or near a potential military target area and, if at all possible, consideration should be given to underground or protective construction for the terminal stations.

Preliminary Selection

The routes for the telephone cables were considered in the light of the foregoing and after preliminary discussion it was agreed that the two new cables should lie north of all existing cables, should avoid ships' anchorages and should lie on the best bottom which could be picked, clear of all known trawling areas.

In 1930, A.T. & T. Co., in conjunction with the British Post Office, gave serious consideration to the laying of a single coaxial telephone cable between Newfoundland and Frenchport, Ireland (Route 1, Fig. 2). A tentative route was plotted and the cable ship *Dominia* steamed over this taking a series of soundings. These soundings indicated that good bottom was to be found about 20 miles north of the Hearts Content — Valencia cable of 1873. This cable was the most northerly of the telegraph cables spanning the Atlantic. Study of its life history indicated that faults clear of the continental shelf were few and far between throughout its long life.

The latest British Admiralty charts and bathymetric charts of the U. S. Hydrographic Office for the North Atlantic Ocean were scrutinized and from these and a study of all other relevant data, two routes were plotted which appeared to fulfill the necessary requirements so far as possible. However, it was agreed that if possible the selected routes should be surveyed so that minor adjustments could be made if desirable.

Landing Sites

East End — It was now necessary to find suitable landing sites having regard for the decision that the telephone cables should be routed north of all other existing cables.

On the British side it was necessary to look north of Ireland.

The North Channel, the northern entrance to the Irish Sea, divides northern Ireland from Scotland and had this channel been suitable, the telephone cables might have been run through it to a terminal station on the southwest coast of Scotland in the vicinity of Cairn Ryan. However, the tidal streams through the channel are strong, at least 4 to 5 knots at spring tides; the bottom is rocky and uneven, with overfalls, and any cable laid through it would have a very short life indeed.

It was therefore necessary to search farther north. The west coast of Scotland presents a practically continuous series of deep indentations and bald, rocky cliffs and headlands. The chain of the Hebrides Islands stretches almost uninterruptedly parallel with and at short distances from the coast. It was obviously most desirable to land the cable on the Scottish mainland, and close to rail and road communication if at all possible.

From previous cable maintenance experience it was known that Firth of Lorne which separates the island of Mull from the mainland was a quiet channel, little used by shipping or frequented by trawlers and with tidal streams which were not strong. Earlier passages of Post Office cable ships through the Firth had yielded a series of echo sounding surveys which indicated that except for a distance of about 5 or 6 miles in the vicinity of the Isles of the Sea, the bottom was fairly regular. Several small bays on the mainland side of the Firth just south of Oban appeared from seaward to be very suitable landing sites and this was confirmed by a survey party, which selected a small bay locally named Port Lathaich for the cable landing and site of the station.

The fore shore was mainly firm sand with outcroppings of rock which could be avoided easily when landing the cables. The seaward approach

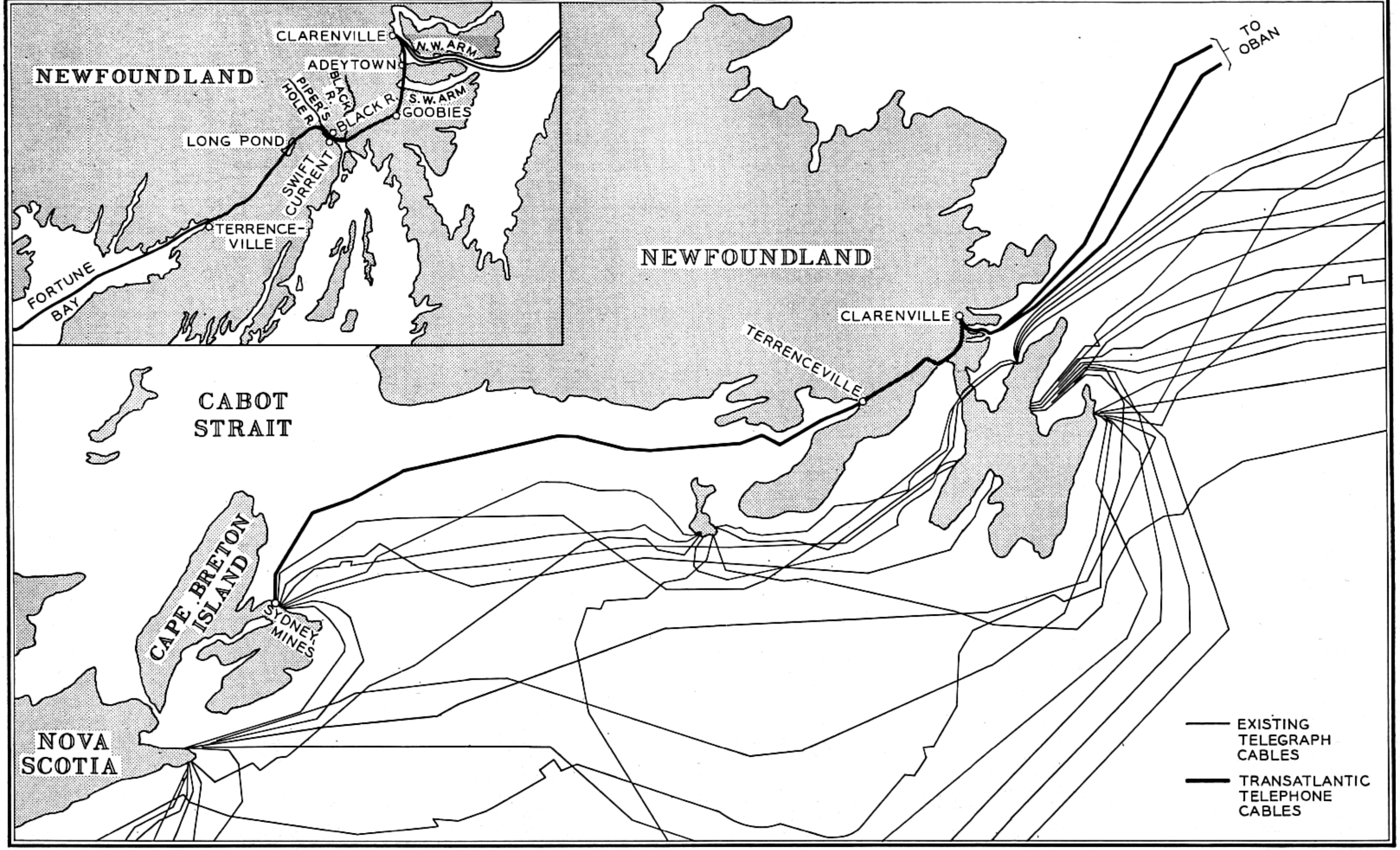

Fig. 3 — Cable landings on Newfoundland, and final route of overland section of the Clarenville-Sydney Mines cable.

was clear of danger and there was ample room to land two cables with a separation on the shore of some 30 yards.

Port Lathaich is only about 3 miles by road from Oban. Additional land cables would be necessary, however, to carry traffic to the main trunk network. From a strategic point of view, although Oban might only just be considered a target area, the cable landing was sufficiently remote to be relatively safe, especially if the cable terminal station was sited in the rocky hillside. To ascertain whether any serious chafing or corrosion would result if cables were laid over the uneven bottom in the Firth, some 8 miles of coaxial cable with E type armoring were laid over the area and recovered after 2 years. There was no evidence of any chafing or corrosion. It was therefore decided that the telephone cables should be routed through the Firth of Lorne to the cable terminal station site at Port Lathaich.

West End — The choice of a suitable cable landing in Newfoundland was more difficult to make, in view of the rugged and sparsely populated nature of the country. From Fig. 3 it will be seen that the existing telegraph cables spanning the Atlantic land either just north of St. Johns, in Conception Bay, or in Trinity Bay. North of Cape Bonavista the coast becomes more broken, and the sea approach is not good. Accordingly, there was no good alternative to routing both telephone cables into Trinity Bay, close to and northwest of the telegraph cable landing at Hearts Content on the southern shore of the bay. A survey party made an extensive examination of all likely places on the western side of the bay from Cape Bonavista in the north to Bull Arm at the southern end where, incidentally, the first successful telegraph cable was landed. Careful consideration of all of the places visited led to the agreement that Clarenville was the best site for a landing and for a cable terminal station.

Clarenville is at the head of the Northwest Arm of Random Sound. It is a junction on the main railway, and a good road to St. Johns will pass through the town in traversing its course from St. Johns to Port aux Basques. Clarenville has a growing population of some 1,600 inhabitants, with stores and repair facilities of various sorts. Good cable landing sites are available just out of town and the approach from the sea up the Northwest Arm presents no navigational difficulties. Such few small vessels as ply to Clarenville during the summer months are not likely to interfere with the cables.

Final Route Agreement

Having agreed Clarenville, Newfoundland, and Oban (Port Lathaich), Scotland, for shore terminations, it was possible to complete the routes

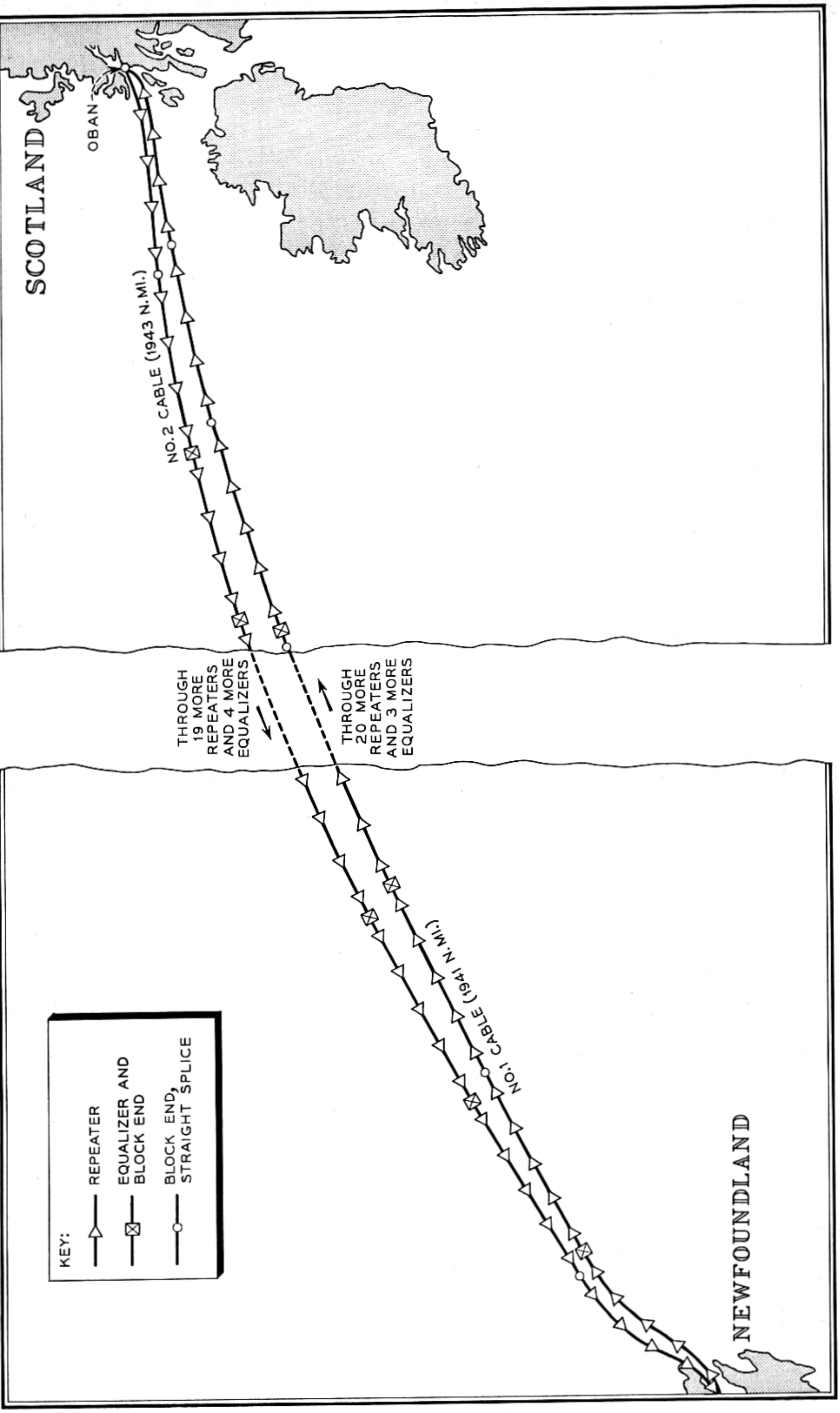

Fig. 4 — Transatlantic telephone cable routes.

for the two cables as shown in Figs. 3 and 4. The final routes are clear of existing cables and avoid crossing known trawling areas and anchorages. The cable stations are well sited with regard to staff amenities, accessibility and strategic requirements. Soundings taken during the laying of the two cables showed a very even bottom except in the Firth of Lorne and one or two places in Trinity Bay. The general profile of the route is shown on Fig. 5.

It is considered that these routes have been selected with care and meet all of the requirements of a well planned cable project. Time alone will tell how well the objectives have been met.

Cable Laying

Early Methods

In 1865 when the legendary *Great Eastern* was pressed into service to lay the first successful transoceanic telegraph cable she was fitted out with certain special cable handling gear. The need for such gear had been amply demonstrated by events which transpired during two earlier and unsuccessful attempts by *H.M.S. Agamemnon* and *U.S.S. Niagara*.

For her assignment, *Great Eastern* was fitted with three large tanks into which her cargo of cable could be coiled. She was also provided with a large drum about which the cable could be wrapped in the course of its passage from the tanks to the sea. This drum was connected to an adjustable braking mechanism which provided the drag necessary to assure that the cable pay-out rate was correct with relation to the speed of the vessel. In addition, a dynamometer was provided so that the stress in the cable would be known at all times. A large sheave fitted to the stern of the ship provided the point of departure of the cable in its journey to the sea bottom.

On Friday, July 13, 1866, *Great Eastern* steamed away from Valencia, Ireland, and 14 days later, on July 27, she arrived off Trinity Bay, Newfoundland, and completed the landing of the western shore end.

H.M.T.S. Monarch

Early in the planning for the transatlantic project it was realized that in no small measure the success of the venture would depend on availability of a vessel suitable for laying the cables. It was fortunate that one of the partners to the enterprise was also the owner and operator of the largest cable ship in all the world, and one well suited to the task at hand.

The twin-screw cable ship *Monarch*, Fig. 6, was built for H.M. Post Master General by Messrs. Swan, Hunter and Wigham Richardson, Ltd., at their Neptune Works, Walker-on-Tyne. She was completed in 1946. This ship is of the shelter deck type having principal dimensions as follows:

Length overall	482 feet 9 inches
Breadth moulded	55 feet 6 inches
Depth moulded to shelter deck	40 feet 0 inches
Gross tonnage	8,056

The ship has an overhanging bow which carries three cable sheaves, a cruiser stern with the after paying out cable sheave offset on the port quarter, a semi-balanced rudder having extra large surface, and a cellular double bottom extending from the collision to the aft peak bulkheads. Both main and shelter decks are steel and extend her complete length.

The cable is carried in four welded steel cable tanks fixed to the tank top plating. These are arranged along the ship's center line in a fore and aft direction forward of the main propelling machinery space. They are each 41 feet in diameter and have the following cubic capacities:

	Coiling Space	Gross Cubic Feet
No. 1 Tank	33,730	40,170
No. 2 Tank	31,820	38,460
No. 3 Tank	30,865	37,375
No. 4 Tank	30,230	36,300

The opening in the shelter deck above each tank is a circular hatch 8 feet in diameter.

A water tight cone of steel plates is built in the center of each tank to insure against fouling of the cable during payout. Further control

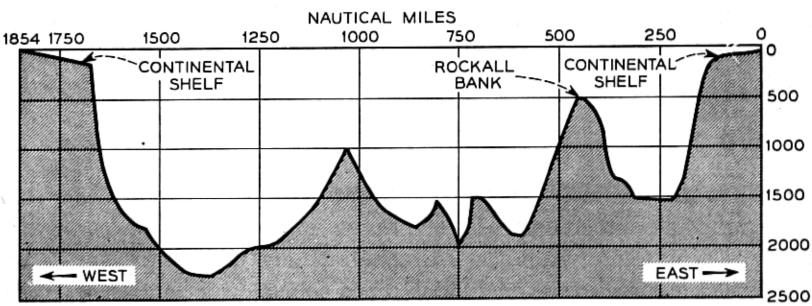

Fig. 5 — Profile of ocean depths between Clarenville and Oban.

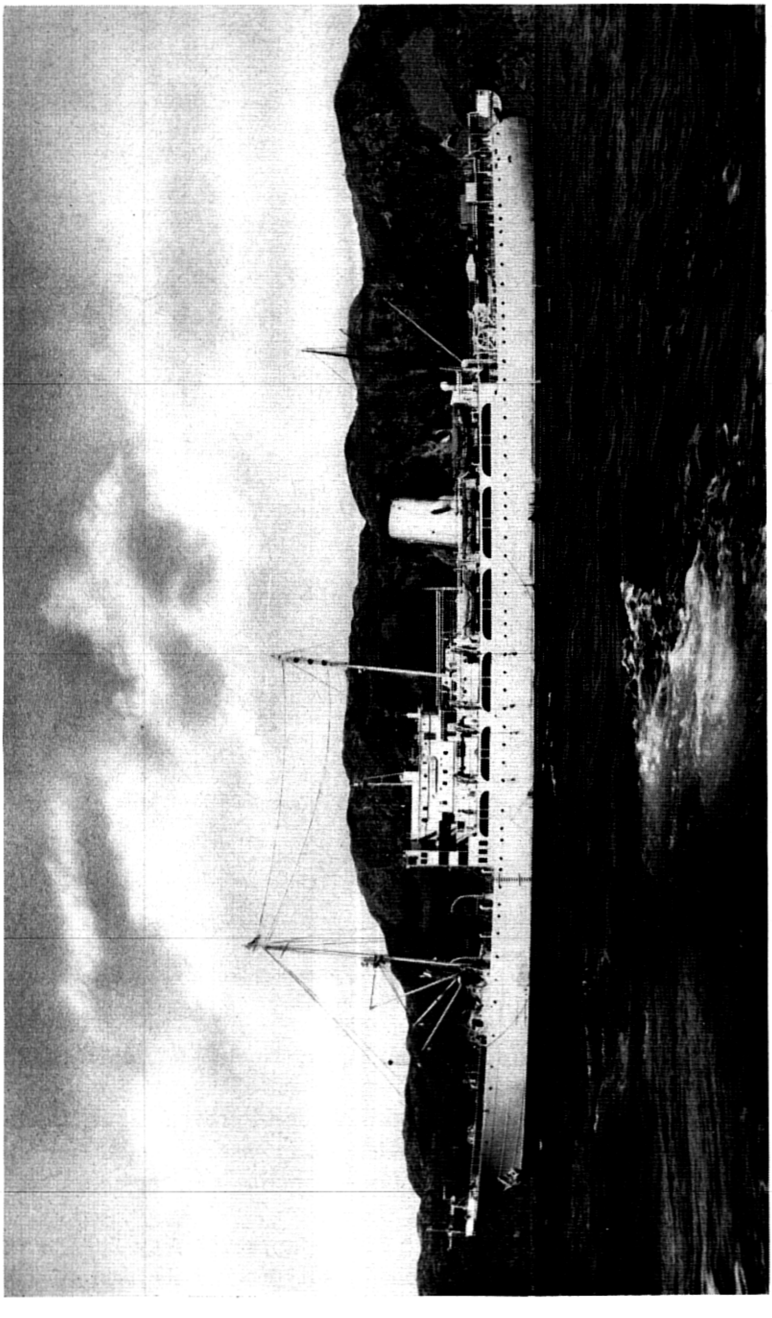

FIG. 6 — *H.M.T.S. Monarch.*

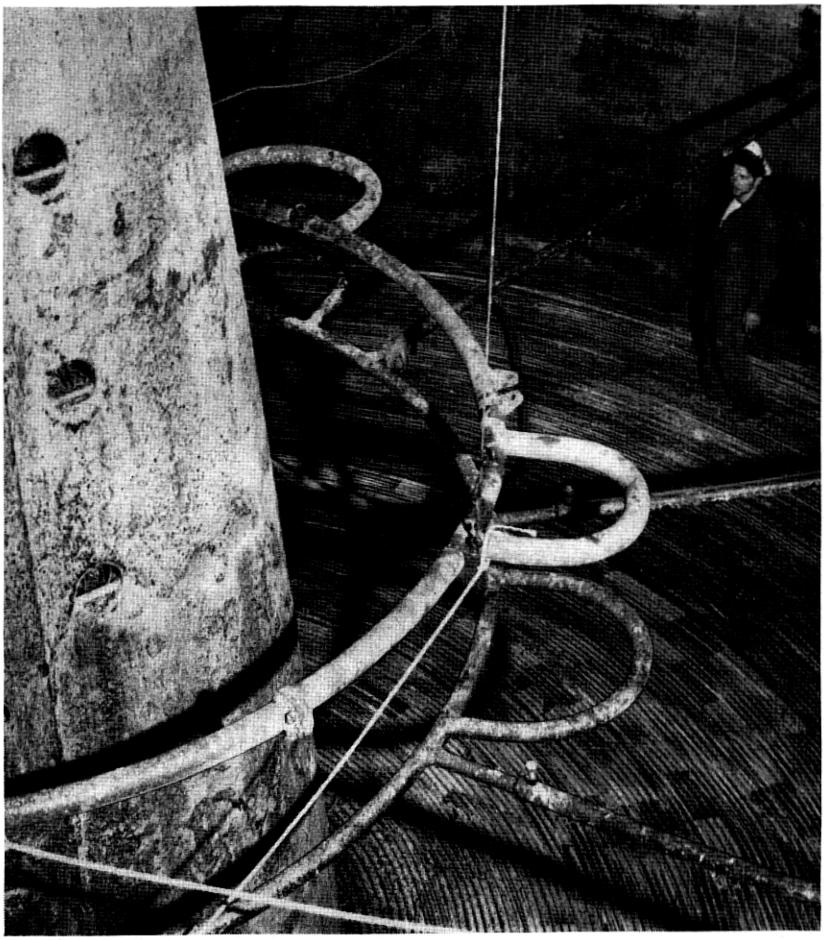

Fig. 7 — Interior of cable tank showing central core, crinoline and flake of cable.

of the cable is provided by a crinoline, Fig. 7, which is a circular spider of steel tubing normally suspended from 1 foot to 3 feet above the top layer of cable in the tank. The crinoline tends to prevent flying bights of cable and also provides a safety platform, in case of trouble, for the men who work in the cable tanks. Each crinoline may be raised and lowered by an electric motor drive.

The maximum cable carrying capacity is approximately 5,000 long tons, or almost 2,000 miles of the deep sea type of cable used on this project if no repeaters were involved.

Monarch is driven by two steam engines. The maximum propeller revolutions are estimated at 110 per minute, giving a ship's speed of about 14 knots.

Two cable engines are fitted forward, both capable of being used for picking up or paying out. These are driven by electric motors having a maximum rating of 160 hp, which will permit picking up at a rate of 0.9 nautical miles per hour with a stress of 20 tons, or at 3.5 knots with a stress of 5.3 tons. The drive system is constant current, so designed that a uniform torque may be held at the drum for any setting of the speed control. When paying out, these motors operate as generators to provide electrical braking, and auxiliary mechanical brakes are also provided.

A single cable engine is fitted aft and this is the main paying out gear. In addition to the electrical brake, the aft engine is provided with a multiple drum externally contracting band brake, manually adjustable and water cooled, and with a further auxiliary fan brake. The fan shaft is driven in such a manner that when cable is being paid out at approximately $8\frac{3}{4}$ knots the fan will revolve at 1,000 rpm and absorb 120 bhp. Adjustments in this are effected by varying the amount of opening in the fan shroud so that as little as 27 bhp may be absorbed.

Dynamometers, both fore and aft, provide for measurement of the cable tension.

Taut wire gear is furnished on the starboard quarter to provide an effective means for calculating the amount of slack paid out. With this gear, steel piano wire, anchored to the bottom, is paid out at constant tension and provides a rough measure of distance steamed over the ground.

A test room with trunks to each cable tank is provided on the shelter deck and fitted with instruments for measuring and locating faults.

Modifications for Flexible Repeaters

In the normal cable-paying-out process, the cable is drawn from the tank, carried along fairleads to the holdback gear (a mechanism for applying slight tension to the cable so that it will snub tightly around the drum), and then wrapped around the drum of the cable engine from two to four turns depending upon the weight of the cable and the depth of the water. At the drum, a fleeting knife is fitted which pushes over the turns already present to make way for the oncoming turn. From the drum the cable passes through the dynamometer and thence to the overboarding sheave.

The Bell System repeaters, manufactured by the Western Electric

Company, were designed with the objective of making them act as much like cable as possible.[1] Despite this, their presence introduced a loading and laying problem as their ability to bend without injury is limited to about $3\frac{1}{2}$ ft radius, and their structure is such that unnecessary bending may involve a hazard to their water tightness. As the majority of the sheaves and drums of the conventional laying gear are considerably smaller than 7 ft diameter, a number of modifications were required in *Monarch's* equipment to satisfy the repeaters.

For the most part, the new gear was designed by the Telegraph Construction and Maintenance Co., Ltd., to broad requirements supplied by the A.T.&T. Co. The modifications included providing the port bow sheave with a flat tread to bring its diameter to 6′10″, and replacing both forward dynamometers and the aft dynamometer by a new design employing a 7-foot wheel in a pivoted "A" frame bearing on Elliott pressure type load cells. Port and starboard forward drums were replaced with the maximum diameter drums possible without a major change in the complete gear. This diameter proved to be 6′10″ on the tread. The after paying out drum was replaced with one having a 7′0″ diameter. The forward port and aft cable drums were equipped with

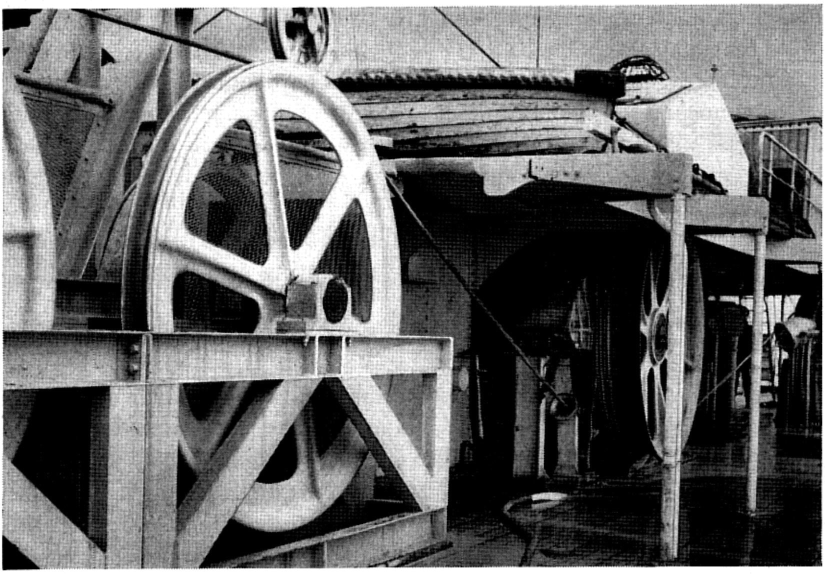

FIG. 8 — General view of modified after cable gear (one of 2 hold back sheaves, drum with fleeting knife and ironing board, and, at extreme right, dynamometer sheave).

Fig. 9 — Cable payout over the stern.

ironing boards. (An ironing board is a curved shoe placed adjacent to the cable drum and spring loaded so that it will force the repeater to conform to the curvature of the drum as it goes on.)

The forward port and starboard draw-off gear sheaves were replaced with larger ones 7′0″ in diameter which were made traversable. The aft hold-back gear, of the double sheave type, was also replaced with units having 7′0″ sheaves.

Fig. 8 shows a general view of the modified after cable gear, and the 7-ft stern sheave may be seen in Fig. 9. A line schematic of the gear will be found on Fig. 10.

Roller type fairleads shaped into arcs of minimum $3\frac{1}{2}'$ radius were fitted at each cable tank hatch, with smaller roller guides at convenient points to assure fair lead of the cable from the tanks to the cable machinery. Electric hoisting gear was provided for the crinoline in each tank as it was necessary to raise the crinoline whenever a repeater left the tank.

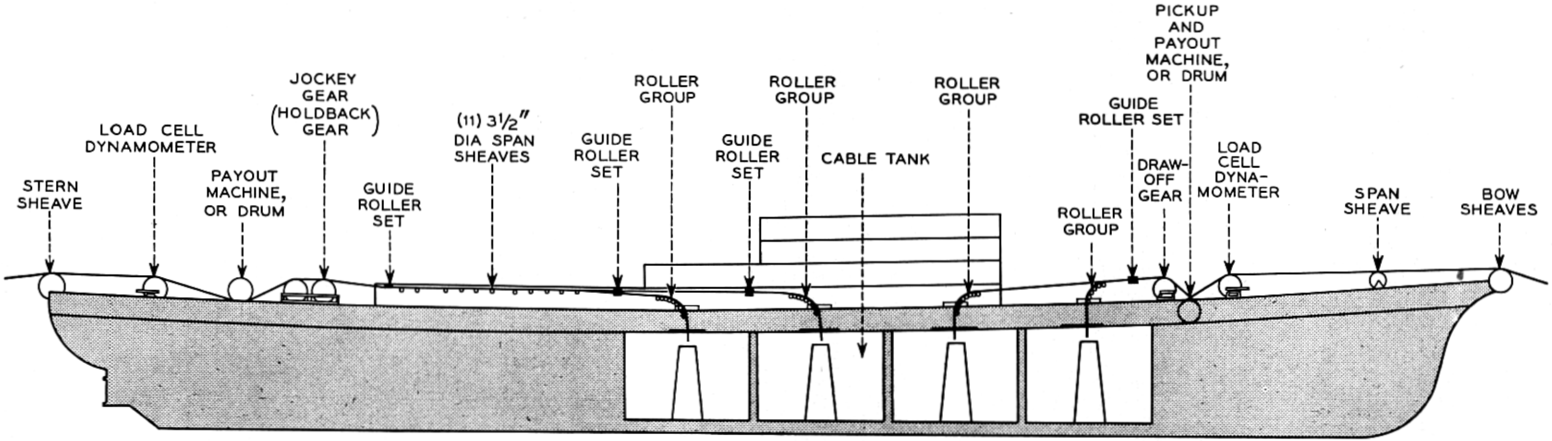

FIG. 10 — Line schematic of the cable gear on *Monarch*.

The test room was greatly enlarged and fitted with the special gear necessary for powering and measuring the system during laying.

Loading Considerations

When the ship is loaded, the cable is coiled carefully in the tanks, layer upon layer — each layer being called a "flake". The coiling is started from the outside of the tank and progresses clockwise toward the center so that the armor is untwisted one revolution for each complete turn in the tank. When paid out in the reverse order, this twist is restored.

Handling of the repeaters during loading presents a problem because of the need to restrict their bending. After some experimental work was carried out, splints were devised to provide the needed rigidity. These consisted of two angle irons each 12 ft long and equipped at the ends with cold rolled steel rods ranging in length from $1\frac{1}{2}$ ft to 6 ft. By this device it was possible to maintain rigidity over the main central portion of the repeater, including the junction of the core tube with the end nosing, and provide limited flexibility along the outer ends of the core tubes which are less sensitive to bending. The splints were removed once the repeater reached the tank.

Repeaters are always stowed at the outside of the flake where they need be subjected to only a minimum of bending. They are protected with wood dunnage, which must be removed before the repeater is paid out.

With these modifications all repeaters and equalizers were laid successfully from either forward or aft gear at a cable speed of around three knots.

Testing and Equalization

Purpose — Once a submarine cable system has been installed, it is accessible only at the ends for adjustment to improve performance, save at great difficulty and large cost. As some irregularities cannot be corrected from the ends, it behooves the designers to discover and account for such irregularities and to correct them before the cable is finally on the ocean bed.

The laying period offers the last opportunity for accomplishing this, and indeed all too frequently, also the first. This fact, coupled with the broadband design of the link and with the presence in the system of active elements (the repeaters), necessitated a very comprehensive program of tests and measurements during laying.

The program had three specific purposes; (1) to detect immediately any fault which might develop during laying; (2) to permit the design and execution of corrective system adjustments while en route so that transmission performance of the completed link would fall within specified objectives; and (3) to gather data on system characteristics at intermediate points for eventual use in fault location or in aging studies. The need for parts (1) and (3) of the program is more or less self evident, but part (2) merits some further discussion.

In an ideal submarine cable system in an average environment, the attenuation of the cable from one repeater to the next would be offset exactly across the frequency band by the gain of the following repeater. Such a result is never achieved in practice, as the temperature and pressure environments (which affect cable attenuation) cannot be known precisely in advance, and the cable structure itself cannot be manufactured for mile after mile without variation in transmission characteristic. Additionally, the mechanics of the laying process induce minor changes in the physical structure of the cable which reflect in attenuation changes.

If such deviations from desired characteristic produced only differences from the specified system gain objective, compensation could be readily applied at the ends of the submarine link. Unfortunately, this is only partly the case. Their more important effect is the resulting misalignment of operating levels of individual repeaters from design objective.

Misalignment magnitudes must be watched carefully, for at best misalignment narrows the system latitude for seasonal temperature changes and for aging, and at worst it can result in intolerable system noise. If a repeater is preceded by too much cable the signal to noise ratio at the repeater input will be less than desired because of thermal noise. In the opposite case of too little cable, the signal level will be too high and the resulting overloading in the repeater will also affect the signal-noise adversely. Once present on the signal, the noise cannot be removed, and so the cure for excessive misalignment must be applied before the misalignment has developed. Adjustments at intermediate points along the route must therefore be contemplated.

Testing Program — The program which was evolved to meet the three objectives outlined was meticulously reviewed and practiced before the start of laying, and various forms were prepared for entering data and plotting and evaluating results. This was essential to avoid wasting effort or missing valuable data. The wisdom of this was fully apparent to all involved after experience with the close time schedules and the mental tensions which developed during the actual laying.

Staffing for testing was provided by crews of 2 or 3 trained engineers located at the transmitting cable station and on shipboard. Those on the ship served $4\frac{1}{2}$ hour watches at 9 hour intervals, which permitted a reasonable amount of rest and avoided continuous "dog watch" duty by any one crew.

Close contact between shipboard and cable station crews was essential, and was achieved by means of cable and radio order circuits (or "speakers"). Communication from shore to ship when the cable was powered made use of the standard cable order wire circuit at the cable station to apply a signal in the frequency band 16–20 kc. The signal was demodulated and amplified aboard ship by a special stripped version of this same gear. The radio order circuits employed special land antennas and equipment, and for the most part the ship's standard single sideband telephone set, although other equipment at medium frequency was sometimes used for short distances. Radio telegraph with hand keying was available for back-up when conditions were too poor for the radiophone sets.

Plans called for powering the cable at all times except when splices were being made. This was necessary for the measurement program, of course, but also provided additional assurance of safe laying of repeaters, as the glassware and tungsten heaters of the vacuum tubes are more resistant to damage when hot. Power for the first half of each crossing was provided from the cable station. Beyond this point, the required voltage would have become excessive and so the shipboard supply was inserted into the series power loop and its voltage adjusted in proportion to the amount of second half cable actually in the loop.

Monitoring against the possibility of faults was accomplished by measurement of a pilot tone at 160 kc, transmitted over the cable at all times except when data were being taken or power was turned down. Audibly alarmed limits were set on the measurement to indicate any significant deviation in transmission. In actuality, all unanticipated received alarms were found to have resulted from frequency or voltage shifts in the primary shipboard supply for the measuring equipment.

During the design of the system,[2] consideration of the misalignment problem had indicated the desirability of splitting the cable for each crossing into a number of sections, called ocean blocks. These contained either 4 or 5 repeaters, and were 150 to 200 miles in length. In loading the ship, the two ends of each ocean block were left accessible for connection to the test room and for splicing operations.

Measurements made in the spring of 1955 off Gibraltar had indicated an unexpected change in attenuation called "laying effect",[3] which required some last minute adjustment of the repeater section lengths.

With incorporation of these changes, it was known that the factory lengths of cable between repeaters were adequate to keep misalignment within an ocean block within reasonable limits. The system could then be equalized between ocean blocks so that the signal level at the first repeater of a new block would be approximately correct, and the total system noise thus would fall within limits.

This equalization was accomplished in two ways. Excess cable of the order of $\frac{1}{2}$ to 3 miles in length was provided at the top end* of each ocean block. Based on measurements, this could be cut longer or shorter than the nominal spacing of repeaters, so that the repeater gains and cable losses would be matched at some frequency in the band. Residual deviations in other parts of the band could then be mopped up if necessary by inserting a simple equalizer, housed in a container similar to those used for the repeaters. Ten such equalization points were provided in each cable.

In practice, sending levels were adjusted at the cable station to give test tones at the grids of the output tubes of the repeaters which if the system equalization were perfect, would be flat across the frequency band, and at the proper level. These tones were measured on shipboard at the end of the ocean block being paid out. The results were plotted against mileage, with one sheet for each frequency being measured. Because of the "laying effect" and of temperature and pressure changes on the cable as it progressed to the bottom, these plots displayed a slope.

The value of loss (or gain) to be ascertained for each frequency was that which would exist when the entire ocean block was on the bottom. To obtain this, it was necessary to extrapolate the curves to the mileage point representing the end of the block in question. The extrapolation was required to avoid stopping the ship at the end of the block, and so had to anticipate the time needed for turning over and cutting the cable end at the proper point, and making one or two splices (depending on whether or not an equalizer was inserted at the point in question).

Having read the extrapolated values from the curves, these were compared with objectives for that block junction, and the deviations plotted. Transparent overlays, showing the net effect of each of several types of equalizer combined with varying amounts of cable around the nominal spacing, greatly facilitated the final decision as to cutting point and equalizer choice.

This implementation of the system undersea equalization represented a very large part of the effort required of the testing crews during laying.

Additional data gathered for fault location, aging studies and other

* First end out of the cable tank.

purposes included precise determination of repeater crystal frequencies on the bottom, gain frequency runs to show up any fine grained structure which might exist in the band, and values of line current and driving voltages.

Copper resistance and capacitance measurements proved to be of dubious value; in the first case because of the temperature/resistance characteristic of the vacuum tube heaters; in the case of capacitance, probably because of polarization effects in the castor oil capacitors used in the repeaters.

Shipboard Test Equipment — A new test room had been equipped for making the above measurements with transmitting and receiving transmission measuring sets[2] including the crystal test panels. These sets were provided in duplicate to forestall difficulty should one set develop trouble during the laying. The transmitting consoles were required only for use in calibrating the receiving sets, and for some measurements which were made on individual ocean blocks in the ship's tanks.

Additional gear in the test room included a cable current power supply,[4] and a "Lookator" which is a pulse echo type of fault locator useful from a point in the cable to the adjacent repeater on either side.

Laying Sequence

H.M.T.S. Monarch is the largest cable ship afloat, with capacity for about 2,000 miles of the Type D deep sea cable in her tanks. However, because of the inherent limitation on their bending radius, the presence of flexible repeaters in the cable puts a restriction on the height to which the coil can be permitted to rise in the tanks. For repeatered Type D cable, therefore, *Monarch's* capacity is cut back to about 1,600 nautical miles.

Types A and B cable, used in shallower waters, are considerably larger and heavier than Type D and consequently, less of these can be carried.

The ideal laying program would have involved one continuous passage across the North Atlantic from cable station to cable station. However, this would have required carrying over 1,900 miles of cable including about 300 miles of Type A and something less than 50 miles of Type B. Such an amount of cable would greatly exceed the ship's capacity.

Each cable was, therefore, laid in 3 sections. The No. 1 cable (southernmost), which transmits from west to east, was laid in the following sequence: Clarenville to just beyond the mouth of Trinity Bay, a distance of 200 miles; thence about 1,250 miles to Rockall Bank (a submerged plateau); and finally the remaining 500 miles from Rockall Bank to Oban. The No. 2 cable followed the opposite sequence, starting at Oban and proceeding in 3 sections of 500 miles, 1,250 miles, and 200 miles to the terminal at Clarenville. Shore ends, about $\frac{1}{2}$ mile long at Clarenville and 2 miles at Oban, were prepared and put in place in advance of the time when they would be needed. At each intermediate point, the cable was "buoyed off" with a mushroom anchor, connecting lines, and a surface buoy of size appropriate for the water depth.

The mileages indicated are actual cable lengths. They exceed the geographical distances between the points involved because of the slack allowance which experience has shown to be necessary to assure reasonable conformance of the cable with the contour of the ocean bed. Normally, about 5 per cent slack is considered desirable in deep water, with the allowance decreasing in steps to zero in shallow water.

All available information indicated that the most favorable weather conditions in the North Atlantic could be anticipated in the period May through August. Prior to May, ice could be expected along the western sections of the route and after August, hurricanes were likely, and later the winter storms.

The laying of the No. 1 cable was started June 28, 1955, and completed September 26. The actual laying period took in but 24 days in this interval, the remainder of the time being spent in transit and in reloading. The No. 2 cable was started June 4, 1956, and completed August 14. About 16 of laying days were involved.

The routine aboard ship during laying consisted in passing out cable at the rate of 6 to 7 knots for a repeater section length of a little over 37 nautical miles, then slowing down to about 3 knots as the repeater passed through the cable machinery and overboard, then back to speed again. During all of this period the testing crews, both on shipboard and at the transmitting cable station, were busy measuring, recording data and planning the equalization trimming. At a point shortly after the passage of the next-to-last repeater in an ocean block, special measures were required for the equalization program. From that point until the joints associated with the connection to the following ocean block had been completed, the speed was reduced to 5 knots. The need for this arose from the following considerations.

Stopping of the ship in deep water introduces serious possibility of formation of kinks in the cable, and is to be avoided at all costs. To permit continuous laying, it was necessary to determine the amount of cable needed for equalization, measure out this cable, and complete the splices before reaching the end of the block being laid.

The addition of an equalizer at the end of the block requires two joints and armor splices. Preparing the cable ends, brazing together the center conductor and associated tapes, injection molding the polyethylene around the center conductor, replacing and overlaying the armor wires and binding the splice consumes 6 to 7 hours for a single splice, and 8 to 9 hours for two splices when overlapping of operations is practical. An allowance of 3 hours is considered necessary for remolding in event of a defective joint (disclosed by X-ray inspection). The time allowance required to complete the splicing of ocean blocks is therefore 9 to 12 hours. About $1\frac{1}{2}$ hours are needed to carry out the extrapolation, make the equalization decision and turn over cable to the cutting point. During the interval between the cable cut and the completion of the joint, the ship's speed was maintained at 5 knots so as to minimize the distance over which extrapolation of equalization data had to be extended. Even so, the final extrapolation covered the last 60 to 75 miles of each ocean block.

During the jointing intervals, system power was turned down to avoid any hazard to the members of the jointing crew. It was restored as soon as the moldings had been X-rayed and the outer or return tapes had been brazed. These activities were so timed that in almost every case the system was powered as each repeater went overboard.

CLARENVILLE-SYDNEY MINES LINK

Route Selection

Clarenville having been selected as the site of the cable terminal station on the west end of the ocean crossing, it was necessary to consider how the system was to be extended to Nova Scotia for connection with the North American continental network.

A number of alternatives were possible as described below:

Alternative 1 contemplated radio relay across Newfoundland to Port aux Basques, and thence across the Cabot Strait. However, a survey revealed that maintenance access to suitable sites would be most difficult, particularly in winter, and primary power was not obtainable.

Alternative 2 involved a poor submarine route around the Avalon Peninsula to possibly Halifax, Nova Scotia. The length of the sea cable would be about 600 nautical miles. It would be necessary to cross many working telegraph cables, (Fig. 3). Trawler damage could be expected as the cable would need to traverse known trawling areas, and during the winter months any repairs would be costly and prolonged. Also it was not desired to lay another cable out of Trinity Bay as the route might be wanted for a second transoceanic cable at some time in the future.

Alternative 3 involved a submarine cable from Clarenville out through the North West Arm to Rantem at the head of Trinity Bay, a short land cable across the isthmus, and thence either a submarine cable direct to Sydney, Nova Scotia, or a land crossing of the Burin Peninsula at Garnish and thence by submarine cable to Sydney. This route involved three open sea sections with one or two land sections. There was rather limited space for a cable in Placentia Bay and the bottom was uneven and rocky. Existing cables laid around the Burin Peninsula have had interruptions which indicated an unsuitable bottom and fishing trawlers had been seen in the vicinity recently.

Alternative 4 also involved a cable overland, from Clarenville to Terrenceville at the head of Fortune Bay, there to join a direct submarine cable to Sydney Mines. Three short underwater sections would be involved in the Clarenville-Terrenceville link, but these could be in shallow water out of harm's way. The main submarine route from Terrenceville to Sydney Mines would be clear of other cables and would avoid trawling areas and anchorages, a not inconsiderable achievement in view of the congestion of submarine cables and the fishing activity around the southeast corner of Newfoundland. Further, a good landing site in Nova Scotia was available on property near Sydney Mines owned by Eastern Telephone and Telegraph Company.

After due consideration, Alternative 4 was chosen as being the most satisfactory from all aspects and the final route is shown on Figure 3.

This route is considered to be most likely to have a good life history. While it would have been possible to have one continuous land cable between Clarenville and Terrenceville, the three short underwater sections saved a considerable amount of trenching without adding undue hazard to the system.

Clarenville-Terrenceville Route

It having been decided to route the Post Office single cable system overland from Clarenville to Terrenceville a number of other matters required decision. The first was the type of cable to be employed for this section. Several alternatives were considered, bearing in mind factors such as the type of terrain, access, availability of primary power, possible future expansion of capacity and, of course, interference from static and radio frequency pick-up. The advantages of using standard solid dielectric coaxial ocean cable with submarine-type repeaters were judged to outweigh all other considerations and left only one problem, namely, shielding from interference.

Up to this time shore ends of submarine cables used by the Post Office were shielded for about a quarter of a mile from shore by a lead sheath insulated from the return tapes of the coaxial by a polyethylene barrier. Experience indicated that such shielding might not be adequate over a long distance on land. The question was resolved by the addition of iron shielding tapes and a plastic jacket to standard submarine cable. The structure is described elsewhere.[5]

Through the use of this robust, wire armored cable and two steel housed submarine repeaters, no limitations from the noise pickup angle were placed on the detailed route selection for the overland section. The first thought was to try to proceed directly across country from Clarenville to Pipers Hole River, saving at least 10 miles over a route which followed the road, and on which advantage might be taken of quite long water stretches into which the cable could be dropped. Black River Pond, for instance, is $4\frac{1}{2}$ miles long. This proposal was abandoned after surveys, because of the very rocky nature of the country and difficulty of access both for construction and any subsequent maintenance, and it was decided to follow the general course of the roads.

It was possible to avoid trenching in the rocky, precipitous cliff country from Clarenville to Adeytown by laying about 6 miles of cable in the water of Northwest Arm. Similar considerations dictated the choice of two miles of cable in the sea across Southwest Arm. Thence the route followed the road, at a distance ranging from 250 yards to more than a mile, as far as Placentia Bay, taking advantage of the larger ponds where possible to avoid trenching.

Reaching the 800 foot high ground beyond the Pipers Hole River from the north of Black River proved quite difficult. Here the road is carved out of the foot of the cliffs as far as Swift Current and the country behind is solid rock. Plans exist for a hydro-electric project involving dams in Pipers Hole River just north of the road crossing and it is naturally not desirable to bury a cable in such a locality. The river estuary itself passing by Swift Current presents only a narrow 6 foot deep navigable channel at low water but it was decided that this could be used for some 6 miles by employing a barge and a shallow draft tug for the laying.

A suitable route out of the basin up through wooded gorges to the top took about a week of very hard going to locate. Thereafter all was plain sailing taking advantage of ponds such as Long Pond (4 miles) and Sock Pond (3 miles) until the route arrived within 6 miles of Terrenceville.

Here it was reluctantly decided to bury the cable in a deep trench on the inner side of the road, as the other side falls sharply to the sea. The desire to avoid roads was due to their instability and the methods used for construction and repair. This road is dirt only, with no foundations, and in this particular section has been known to slide away into the river bed below.

The final length of cable laid was just short of 55 nautical miles.

Cabot Strait Laying

Coaxial submarine cables in which rigid repeaters are inserted cannot be laid with the existing cable laying machinery except by stopping the ship, removing the turns of cable from the drum and then passing the repeater by the drum and restoring the turns. Special equipment is also needed for launching the repeater over the bow sheaves.

Ship Modifications

The following equipment was installed on *Monarch* for the laying of cables carrying rigid repeaters.

A gantry over the bow baulks, consisting of a 22 foot steel beam projecting 6 feet beyond the sheaves, was installed for handling repeaters at the bow. This gantry was fitted with an electrically operated traveling hoist for lifting the repeaters over the bow sheaves and lowering them into the sea. A standby hand operated lifting block and traveller were provided to guard against failure of the power point.

A rubber-tired steerable steel dolly (or trolley) was developed from the chassis of a small car to transport the repeaters from the cable tank hatches to the bow sheaves. These repeaters weigh about 1200 pounds.

Storage racks were built up from steel sections provided with shaped, rubber lined wood blocks and were fitted at each cable tank hatch on the shelter deck. Each rack held 4 repeaters in double tiers. A hand operated lift was furnished for moving the repeaters from the storage racks to the dolly.

A special quick release grip was furnished for use when lifting the repeaters by the electric hoist on the bow gantry. Deflection plates were also fitted on the fore deck around dynamometers and hatches to avoid their fouling the dolly.

Launching Rigid Repeaters

The rigid repeaters were stowed in their racks in the order of their laying. The bights of the cable attached to the ends of the repeaters were brought up the sides of the cable tanks, secured along the arms of the crinoline and up the sides of the hatch coamings to the deck, clear of the running length of cable and from where the repeater could be drawn forward along the deck on the dolly.

When the time came for a repeater to be laid, speed was reduced and the ship finally stopped head to wind. A 6x3 compound rope from the starboard cable drum was secured to the cable just abaft the bow baulks. Sufficient cable was then paid out until the tension was taken up by this rope. The turns of the running cable were then removed from the port cable drum and the resulting slack cable worked overboard by paying out the starboard drum rope which was holding the tension. When the excess cable had been cleared from the deck, the repeater on its dolly was carefully hauled along the fore deck to the traveling hoist of the overhead gantry. Cable was then drawn from the tank so that the turns could be re-formed on deck and replaced on the port cable drum. The repeater was lifted from the trolley and traversed outboard as soon as it was high enough to clear the bow baulks. It was then lowered to the water's edge and when the tension had again been taken by the cable, the quick release grip was slipped and the starboard drum rope cut. Paying out was then resumed.

Laying Program

On February 1, 1956, *Monarch*, having returned to Ocean Works, Erith, after refitting, commenced loading the various sections of cable to be used for the Terrenceville-Sydney Mines route. The sections were all carefully tested and measured in the Works before loading. The cable ends were clearly marked and dogged together by a length of rope which was not removed until the repeater had been jointed into its connecting sections of cable.

Loading of the cable and splicing in of repeaters was finished by April 10 and the system tested and checked. *Monarch* sailed for Sydney Mines on April 18 and arrived there April 30. The cable station is situated about 1½ miles inland from the shore, with a small lake intervening. A length of Type B, insulated outer conductor, lead covered cable had previously been laid from the station across the lake to a narrow strip of land which separates it from the sea. The joint to the main cable was to be made on this strip. Two medium sized shore based motor boats were used to tow the end of the double armored section of cable from Monarch to the shore. During this journey the cable was supported by empty oil drums at close intervals. When the motor boats had reached shoal water the end of the cable was secured to a landing line and two tractors took over the hauling.

When enough cable was on shore to make the joint and the splice, the barrels were cut away and *Monarch* weighed anchor and paid out this section of double armored cable on the agreed route and buoyed off the end. She then steamed over the proposed track to Terrenceville, taking soundings and sea bottom temperatures as required, and anchored off Terrenceville on May 3.

Preparations for landing the end were at once put in hand and the ship's motor launches towed the end of the cable towards the cable landing, the cable again being supported by empty oil drums. This end was jointed and spliced to a piece of cable which had been laid previously from the Terrenceville cable hut to a sand spit which juts across the head of Fortune Bay, about a mile away.

Upon completion of the splice, overall tests were made from the ship to the Terrenceville cable hut, and all being well, paying out toward the buoyed end off Sydney Mines was begun on May 4.

The first repeater went over about two hours after the start of laying and the others followed at approximately $4\frac{3}{4}$ hour intervals.

On May 7 the cable buoy on the Sydney Mines end was recovered and the end hove inward. After tests in both directions, the final joint and splice were made. This operation was completed on May 9, and on receipt of a signal that all was well, *Monarch* proceeded into harbor at Sydney to land testing equipment, a spare equalizer and other equipment.

Equalization and Testing

The cable had been loaded into the ship in repeater section lengths, so cut that when laid at estimated mean annual sea temperature, the expected attenuation would be 60.0 db at 552 kc. A correction for the change in attenuation of the cable when coiled in the factory tanks and when laid in about 100 fathoms had been determined from tests on two 10-mile lengths of cable, laid off the Island of Skye. The correction amounted to a decrease in attenuation when laid of 1.42 per cent. This was essentially an empirical result, and as the mechanism of the change was not fully understood, a possible further inaccuracy of equalization might arise.

Sea bottom temperatures along the route were obtained from information supplied by the Fisheries Research Board of Canada, but unfortunately, this information was rather meager and varied considerably with locality.

Since the cable equalization built into the repeater differed appreciably from the final determination on laid cable, it was found necessary at a comparatively late stage to introduce an undersea equalizer into the center of the sea section. This was intended to eliminate a flat peak of loss of 3.5 db, expected at about 100 kc. So that the last repeater should not lie too near the beach at Sydney Mines, a network simulating 9 miles of cable was also inserted in the undersea equalizer.

The repeaters were spliced into the cable lengths on board *Monarch* and tests were made at every stage of the buildup of the system. The equalizer was permanently jointed to the first half section of 7 repeaters and left with an excess length of tail which could be cut as desired during the laying operation to further improve the equalization. The first and second halves of the system were temporarily connected through power separation filters so that the whole system could be energized just prior to laying.

The test routine carried out included attenuation measurement at 5 frequencies in each direction of transmission, noise, pulse and loop-gain, supervisory measurements, dc and insulation resistance and capacitance. *Monarch* test room contained, therefore, two sets of terminal equipments similar to those installed at Clarenville and at Sydney Mines.

It was decided to energize the system continuously during the laying except for the few hours when power had to be removed to make the equalizer splice. This enabled a continuous order (speaker) circuit to be operated over the cable and minimized the number of energizing and warm-up periods. The only disadvantage, considered to be slight, was the necessary omission of insulation resistance and capacitance measurement during laying, except in the course of the equalizer splicing operation.

The plan was to lay from Terrenceville in the direction of the high-frequency band and to test the system to *Monarch* during the laying from this shore station. The overland section between Clarenville and Terrenceville, which contained two repeaters, was connected on with appropriate equalization after the submarine section had been satisfactorily completed and tested.

At Terrenceville, after the cable end had been taken ashore and the beach joint completed, the system was energized from *Monarch* with a dc power ground at Terrenceville for the necessary 4 hour minimum warming up period. The first set of routine measurements of the laying operation was then carried out. Thereafter, a complete set of measurements on the Terrenceville half of the system was made after every 10 miles of cable laid. An occasional check set of measurements was also made on the Sydney Mines half of the system in the tanks.

The primary object of these tests was to determine what length of cable should be inserted between the equalizer and the 8th undersea repeater to obtain the optimum system. In practice this resulted in arranging for a length of cable such that the output level of the 8th repeater at 522 kc should be equal to that at the output of the first repeater at the assumed mean annual temperature of 35.1°F.

The estimated length of cable required for this purpose was plotted after each measurement. It became evident soon after laying the 5th repeater (94.6 nautical miles of cable laid) that the linear relation obtained could be extrapolated with adequate accuracy to safely specify a length of 6.06 nautical miles of cable between the equalizer and the adjacent repeater.

This decision on length was taken, and after removing power the equalizer was accordingly jointed in, the operation being completed before it was necessary to pay out the splice. During this period capacitance and conductor and insulation resistances were checked on each half. During the laying of the second half, measurements were made as for the first half. On arrival at the buoyed shore end a final complete set of measurements was made and these suitably corrected for the shore end length, transmitted to Sydney Mines so that the first measurements from Sydney Mines to Clarenville could be checked with those obtained on the ship.

SIDELIGHTS

Weather

Weather is the big question mark in cable laying and repair activities. With few exceptions the transatlantic project was blessed with remarkably good weather. The exceptions were, however, noteworthy.

Heavy snow squalls were encountered off Terrenceville during the operation in that vicinity. At Rockall Bank on the first lay one heavy storm came up as the last repeater in the 1,200-mile section was going over, and made this launching and the subsequent buoying of the end very difficult operations. Both were accomplished successfully as a result of the superb seamanship of *Monarch's* commander, Captain J. P. F. Betson, and his officers and crew.

A second, and worse storm was encountered upon the return to Rockall. This was a manifestation of hurricane Ione, with wind velocities above 100 mph and very high seas. The ship had given up searching for the buoy (later reported drifting more than 500 miles away off the Faeroe Islands) and was grappling for the cable, when the storm hit. Fortunately, the cable had not yet been found, so the ship could head into the wind and ride it out. She was driven many miles off course in the process, and the seas will be long and vividly remembered by all present. Incidentally, the cable was picked up shortly after the storm had moderated.

Generally speaking, the effect of the weather on the engineering supernumeraries on board was not severe, although *Monarch's* stock of dramamine was somewhat depleted by the end of the project.

Miscellaneous Events

At the start of the first transatlantic lay, several icebergs were encountered. One, a small one at the mouth of Random Sound, lay in the planned path of the cable and caused an involuntary, though minor, revision of the route. The others, beyond the mouth of Trinity Bay, were larger but also farther away.

Whales and grampuses got to be common sights, although much film was expended at first by the uninitiated.

An occasional bird rested on the ship far from land, obviously exhausted from its long and presumably unintended journey.

Progress Bulletins

Daily progress bulletins were radioed to headquarters of all partners during the laying.

In addition, because a telephone cable system differs considerably from submarine telegraph cables, the officers and crew were briefed by the engineering personnel as to the repeater structure, the need for equalization and the general objectives of the venture. This proved to be a very profitable move indeed, for the cooperation of all hands was everything that could be wished. As a follow up, daily performance bulletins were posted in strategic parts of the ship so that everyone no matter what his duties, could know just how the evolving system was performing with respect to objectives.

Cable Order Circuit

One way conversation from shore to ship over the cable was possible all the time the repeaters were energized. This was a source of very great satisfaction to the shipboard test crew, as it was concrete evidence that the cable was working, and working well. When power was turned down, the recourse to radio telephone provided a comparison which generally left no doubt as to the future value of the cable.

ACKNOWLEDGEMENTS

When the final splice was slipped into the water of Clarenville Harbor, on August 14, 1956, there was completed a venture quite unique in the annals of submarine cable laying. And in the laying perhaps more than in any other phase of the transatlantic project did the successful conclusion provide evidence of the friendly and harmonious relationships between the different organizations and nationalities involved, and of the close coordination of their efforts.

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