System Design for the Newfoundland–Nova Scotia Link

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The design and engineering of the section of the transatlantic cable system between Newfoundland and Nova Scotia were the responsibility of the British Post Office. The transmission objectives for this link having been agreed in relation to the overall objectives, the paper shows how these were translated into system and equipment design and demonstrates how the objectives were realized.

INTRODUCTION

Under the terms of the Agreement,[1] it was the responsibility of the British Post Office to design and engineer the section of the transatlantic cable system between Newfoundland and Nova Scotia. In common with other parts of the system, all specifications were to be agreed between the Post Office and the American Telephone and Telegraph Company, but as both the British and the American types of submerged repeater had been carefully studied and generally approved by the other party prior to the agreement, the basic pattern of the system was clear from the beginning.

The service and transmission objectives for the overall connections London-New York and London-Montreal were agreed[2] in early joint technical discussions in New York and Montreal and the agreed total impairments were divided appropriately between the various sections. In this way, the transmission objectives for the Newfoundland-Nova Scotia link were established.

ROUTE

The choice of Clarenville as the junction point of the two submarine sections of the transatlantic system was determined primarily in relation

* British Post Office.

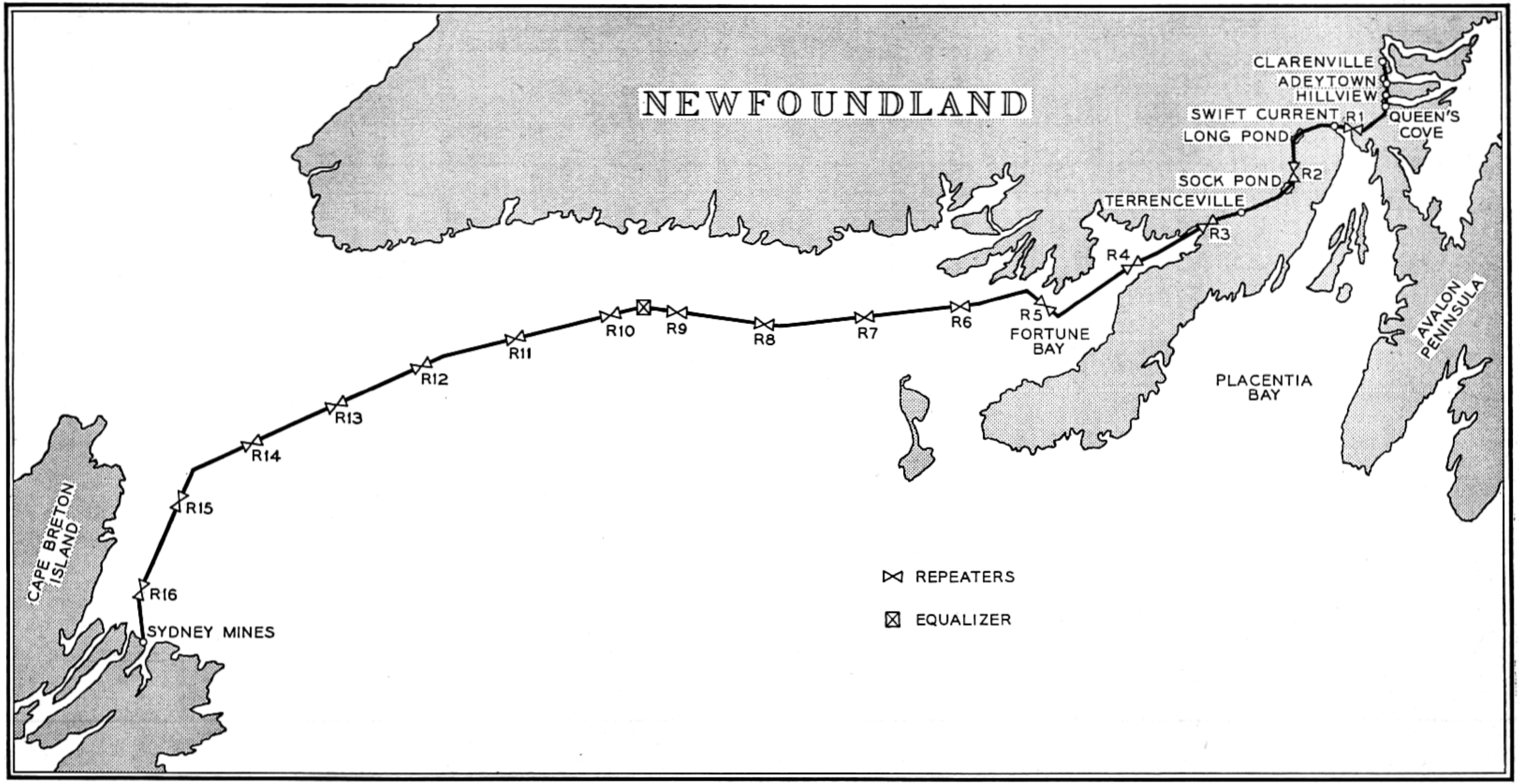

Fig. 1 — Map of route.

to the Atlantic crossing and the desire to follow a transatlantic route to the north of existing telegraph cables.[3] There were a number of possibilities for the route between Clarenville and the east coast of Cape Breton Island, the most easterly point which could be reached reliably by the radio-relay system through the Maritime Provinces of Canada. One possibility, which had been considered earlier, was to cross Newfoundland by a radio-relay system and to employ a submarine-cable link across Cabot Strait only. The final decision to build a cable system between Clarenville and Sydney Mines raised a number of problems in respect of the route to be followed, concerned primarily with potential hazards to the cable brought about by:

(*a*) The existence of very extensive trawling grounds on the Newfoundland Banks.

(*b*) The location of considerable numbers of telegraph cables in the vicinity.

(*c*) Grounding icebergs.

The route finally selected after thorough on-the-spot investigations[3, 4, 5] (Fig. 1) is satisfactory in respect of all these hazards, involving no cable crossings and being inshore of the main fishing grounds. The straight-line diagram of the route is shown in Fig. 2; the total cable length is 326 nautical miles, of which 54.8 nautical miles are between Clarenville and Terrenceville, Newfoundland, where the cable finally enters the sea. The maximum depth of water involved is about 260 fathoms.

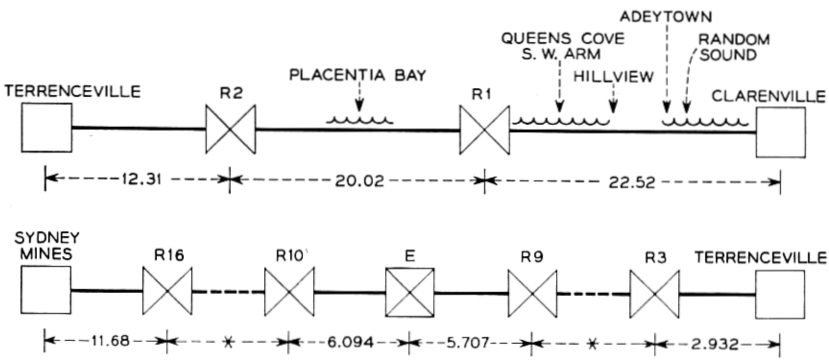

Fig. 2 — Straight-line diagram of route. R. Repeater. E. Equalizer. All distances are in nautical miles.

*Repeater spacing R3-R9 and R10-R16, 20.4 n.m.

CABLE

Choice of Design

Since 1930, when the Key West-Havana No. 4 cable was constructed,[6] it has been usual to extrude the insulation of coaxial submarine cables to a diameter of about 0.62 inch, and most of the cables in the waters around the British Isles are of this size. The experience of the British Post Office with submerged repeaters[7] in its home waters, dating from 1944, when the first repeater was laid between Anglesey and the Isle of Man,[8] has therefore been mainly with 0.62 inch cables, first with para-gutta as a dielectric and later with polyethylene. Most of these cables were originally operated without repeaters, and the 60-circuit both-way repeaters which are now installed on the routes were designed to match their characteristics.

In planning a new system, the size of cable will be determined by one of the following considerations:

(i) Minimum annual charges for the desired number of circuits.

(ii) Terminal voltage required to feed the requisite number of repeaters.

(iii) Maximum number of repeaters or minimum repeater spacing which is considered permissible.

(iv) Maximum (or minimum) size of cable which can be safely handled by the laying gear in the cable ship.

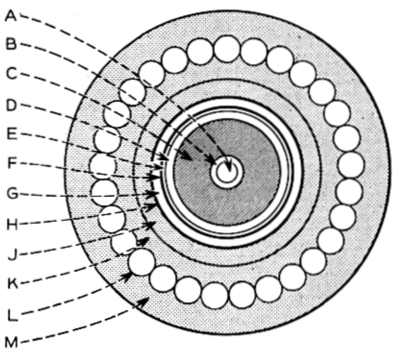

Fig. 3 — Cross-section of cable across Newfoundland showing make-up. A. Centre conductor, 0.1318-inch in diameter copper. B. Three 0.0145-inch copper surround tapes. C. Polyethylene to 0.620-inch diameter. D. Six 0.016-inch copper return tapes. E. 0.003-inch overlapped copper teredo tape. F. Impregnated cotton tape. G. Five iron screen tapes. H. Impregnated cotton tape overlapped. J. Polyethylene sheath to 1.02-inch diameter. K. Inner serving of tanned jute yarn. L. Armour wire 29 x 0.128-inch diameter. M. Outer serving of tarred jute yarn.

When the 36-circuit system between Aberdeen, Scotland, and Bergen, Norway, was planned in 1952, the route length (300 nautical miles) greatly exceeded that of any other submarine telephone system, and it was decided to use a core diameter of 0.935 inch, first, to keep the number of repeaters as low as seven, and second, because the system was intended as a prototype of a possible Atlantic cable. The cable dielectric is polyethylene (Grade 2) with 5 per cent polyisobutylene.

For the Clarenville-Sydney Mines link it proved possible to design for minimum annual charges. With increasing experience and confidence in submerged repeaters, it was no longer considered necessary to restrict the number of repeaters as for Aberdeen-Bergen, and the terminal voltage requirements were reasonable. At the current prices of cable and repeaters in Great Britain the optimum core diameter for 60 both-way circuits is about 0.55 inch, but the increased charge incurred by using 0.62-inch cable is less than 5 per cent (0.62-inch core is optimum for 120 both-way circuits). In order to facilitate manufacture and the provision of spare cable, it was therefore logical to adopt the same design as that proposed for the Atlantic crossing and described elsewhere.[3, 9]

After investigating various possible types of cable for the overland section in Newfoundland, it was decided to use a design essentially the same as the main cable but with additional screening against external interference.[4] As far as the outer conductor and its copper binding tape, the construction (Fig. 3) is identical with that of the main cable except that the compounded cotton tape is overlapped. Outside this are five layers of soft-iron tapes each 0.006-inch thick, the innermost being longitudinal and the others having alternate right- and left-hand lays at 45° to the axis of the cable. After another layer of compounded cotton tape there is extruded a polyethylene sheath 0.080 inch thick, and the whole is jute served and wire armoured. As a check on the efficiency of the screening, the maximum sheath-transfer impedance at 20 and 100 kc was specified as 0.005 ohm per 1,000 yards.

It was thus possible to treat the entire link from Clarenville to Sydney Mines as a uniform whole, using the same type of repeater on land as in the sea. A small hut at Terrenceville contains passive networks only.

Attenuation Characteristics

When the system was designed, precision measurements of cable attenuation were not available. The design of the Oban-Clarenville link was based on laboratory measurements on earlier 0.62-inch cable of a similar type, but the available data applied only to frequencies up to about 180 kc, whereas the Clarenville–Sydney Mines link was to operate at frequencies up to 552 kc; extensive extrapolation was therefore involved. As soon as the first production lengths of cable became available in February, 1955, laying trials were carried out off Gibraltar, and it was found that there were serious changes of attenuation on laying, over and above those directly attributable to temperature and pressure effects, and that the assumed characteristics were inaccurate. Although the attenuation in the factory tanks had been in reasonable agreement with that of the earlier cable, there were changes on transfer to the ship's tanks and again on laying, amounting in all to a reduction of about 1.5 per cent at 180 kc. This would have been comparatively unimportant had the discrepancy been of 'cable shape', i.e., the same fraction of the cable attenuation at all frequencies and therefore exactly compensated by a length adjustment of the repeater sections. As this was not so, and as the cable-equalizing networks in the repeaters were settled by this time, it was clear that precise information must be obtained in order that suitable additional equalizers could be provided for insertion in the cable on laying. There are a number of factors which can lead to small changes of attenuation on laying, but most of these tend to increase the losses. The primary reason for the observed changes appears to be contact variations between the various elements of the inner and outer conductors, i.e. the wire and three helical tapes forming the centre conductor and the six helical tapes forming the return conductor. These contact resistances tend to change with handling, and as a result of a slight degree of 'bird caging' when coiled, it seems that the attenuation decreases as the coiling radius increases, and vice versa. Also, the effect of sea pressure is to consolidate the conductors and thereby further reduce the attenuation — an effect which appears to continue on a diminishing basis for a long time after laying.

To obtain reliable data for the Clarenville-Sydney Mines link, 10 nautical miles of cable with A-type armour was laid at about the mean depth of the system (120 fathoms), off the Isle of Skye. The attenuations, coiled and laid, are shown in Fig. 4, due allowance having been made for temperature and pressure. The ordinates — attenuation versus frequency — are such that the value should be approximately constant at high frequencies.

In making a final determination of the cutting lengths for the repeater sections, it was assumed that the factory measurements of attenuation would be reduced by 1.42 per cent at 552 kc on laying, that the temperature coefficient of attenuation would be +0.16 per cent

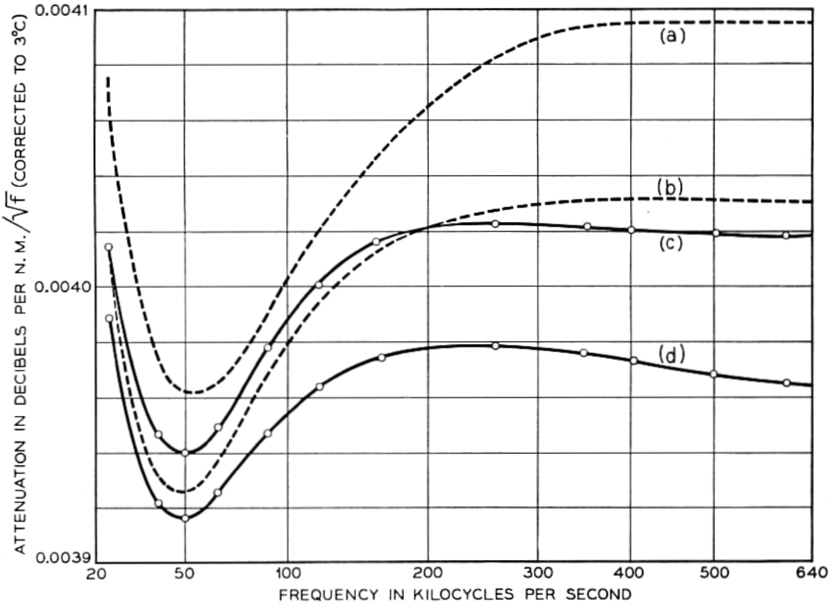

Fig. 4 — Cable attentuation characteristics — Skye trials. (*a*) Characteristic originally assumed. (*b*) Characteristic measured in factory tank (flooded). (*c*) Characteristic measured in ship's tank (flooded). (*d*) Characteristic measured after laying.

per deg C and that the true pressure coefficient of attenuation was negligible at the depths involved.

DESCRIPTION OF SYSTEM

Circuit Provision and Frequency Allocation

It was originally thought that a design similar to that of the Aberdeen-Bergen system would be suitable for the Clarenville-Sydney Mines route in that it would provide more circuits (36) than the long section across the Atlantic. This potential excess capacity, which was required for circuits between Newfoundland and the Canadian mainland, disappeared when it was found that 36 circuits could, in fact, be provided over the longer link. The Aberdeen-Bergen design was therefore modified to provide a complete supergroup of 60 circuits, the same capacity as the earlier British projects.[7] The system thus requires broad-band transmission of 240 kc in each direction.

In the earlier British projects the frequency bands transmitted are 24–264 and 312–552 kc, but for the present purpose the lower band is

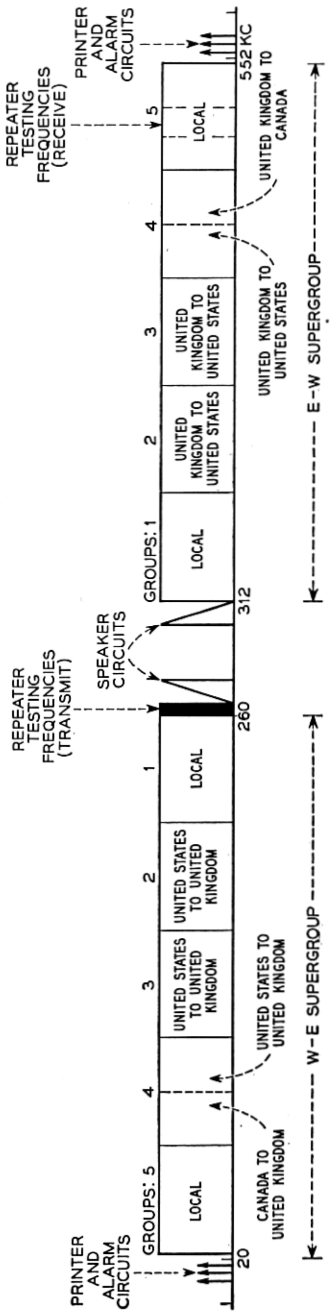

Fig. 5 — Frequency allocation.

dropped by 4 kc to 20–260 kc, so that the lowest frequency is the same as on the Atlantic cables. This enables common frequency-generating equipment to be used at Clarenville for the two links and minimizes crosstalk problems. The main transmission bands and the allocation of the five 12-circuit groups are shown in Fig. 5, together with the ancillary channels; the facilities provided are discussed later.

Submerged Repeaters

The submerged repeaters employed are fully described elsewhere,[10] and it will suffice to note here that they are rigid units, approximately cylindrical in shape, 9 feet long and $10\frac{1}{2}$ inch maximum diameter. They are capable of withstanding the full laying pressure in deep water, although this of little importance in the present application.

They are arranged for both-way transmission through a common amplifier which has two forward paths in parallel, with a single feedback path. The two halves of the amplifier are so arranged that practically any component can fail in one, without affecting the other.

Power-Feeding Arrangements

The submerged repeaters are energized by constant-current dc supplies between the center conductor and ground, the power units at the two ends being in series aiding and the repeater power circuits being in series with the center conductor, i.e., without earth connections, as in Fig. 6. This is the only arrangement by which it is possible to control the supply accurately at every repeater, the insulation resistance of cable and repeaters being sufficiently great that the current in the center conductor is virtually the same at all points. The constant-current feature of the supply ensures that repeaters cannot be overrun in the event of an earth fault on the system.

On the Oban-Clarenville link the anode voltage is derived from the drop across the electron tube heaters. This results in the heaters being at a positive potential with respect to the cathodes, a condition which tends to break down the heater-cathode insulation.[11] In the American electron tubes this insulation is very robust and the risk is considered to be negligible, but in the current British electron tubes, which have a much higher performance, the arrangement is undesirable. In view of the much smaller number of repeaters it was possible to derive the heater and anode supplies as in Fig. 6 and thus to reverse the sense of the heater-cathode voltage and also to provide an anode voltage of 90, against 55 in the longer link.

With this arrangement the link requires a total supply voltage of about 2,300. The power-feeding equipment[12] at each terminal station is designed to feed a constant current of 316 ma at this voltage, and it is permissible to energize the system from one end only, if necessary. The repeater capacitors — the limiting factors in respect of line voltage — are rated very conservatively at 2,500 volts, so that a single-ended supply of 2,300 volts, with the possibility of superimposed ground-potential differences, is near the desirable maximum. The two terminal power units are therefore designed to operate in series and to share the voltage.

With access to the cable provided at Terrenceville it is possible to operate the power system on the following bases:

(*a*) No ground at Terrenceville, power from both ends on a master-and-slave basis (to ensure that the constant-current units do not build up an excessive voltage); this is the normal arrangement.

(*b*) No ground at Terrenceville, power from one end only.

(*c*) Ground at Terrenceville, with the Clarenville and Sydney Mines

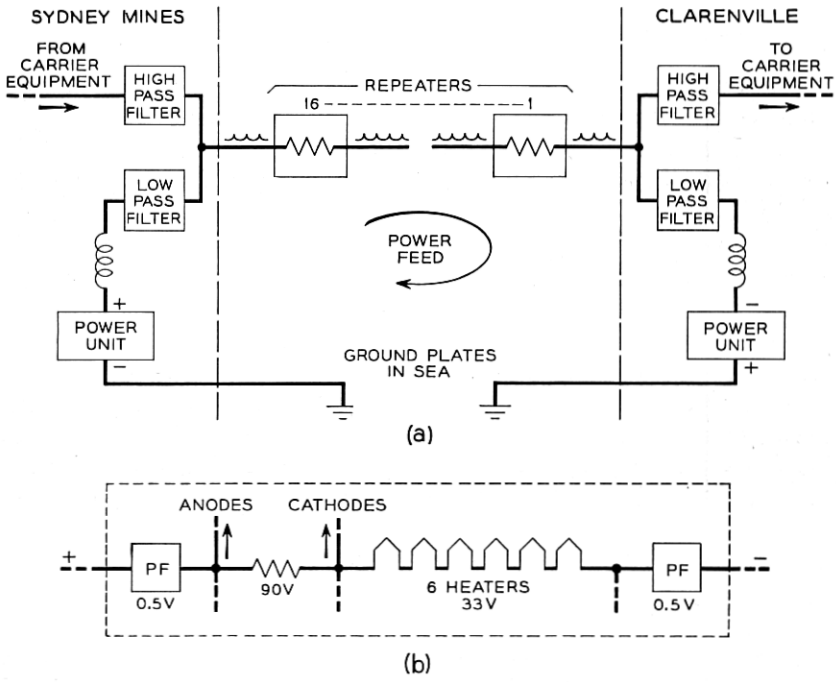

Fig. 6 — Power-feeding arrangements. (*a*) General schematic. (*b*) Repeater power circuit. P.F. — Power filter.

power units energizing the land and sea cables respectively; this arrangement has been particularly useful during the installation period.

The presence of high voltages on the cable constitutes a potential danger to personnel, hence special precautions are taken in the design of the equipment in which the cable terminates and in which high voltages exist or may exist.

The ground connections for the power circuits at the two ends are via special ground cables and ground plates located about half a mile from the main cable, and metering arrangements are provided to check that the current does in fact take this path. These measures ensure that the current returning via the cable armour is never sufficient to cause serious corrosion.

Arrangement of Terminal Equipment

Fig. 7 show the arrangement of the terminal equipment. In accordance with an early agreement defining precisely the various sections of the project, the link is considered to terminate at the group distribution frames at Clarenville and Sydney Mines, i.e. at the 60–108 kc interconnection points.

In addition to the cable-terminating and power-feeding equipments (A and B), the following are provided at the terminals:

(*a*) Submarine-cable terminal equipment (C) consisting of repeaters to amplify the signals transmitted to and received from the cable, equalizers and frequency-translating equipment to convert the line frequencies to basic supergroup frequencies (312–552 kc).

(*b*) Group-translating (group-bank) equipment (D) to convert the basic supergroup to five separate basic groups (60–108 kc) and vice versa.

(*c*) Equipment for the location of cable and repeater faults (E and F).

(*d*) Speaker and printer circuit equipments (G and H) to provide two reduced-bandwidth telephone circuits, two telegraph circuits and one alarm circuit for maintenance purposes. It is clear that such circuits should be substantially independent of the main transmission equipment.

Two principles were agreed very early in the planning; first, that the engineering of the various links should be integrated as far as possible, and second, that the items of equipment at each station should be provided by the party best in the position to do so. In consequence:

(i) Items of standard equipment were provided by the A.T. and T. Co. at Clarenville and Sydney Mines (and by the Post Office at Oban), thus simplifying maintenance and repair problems.

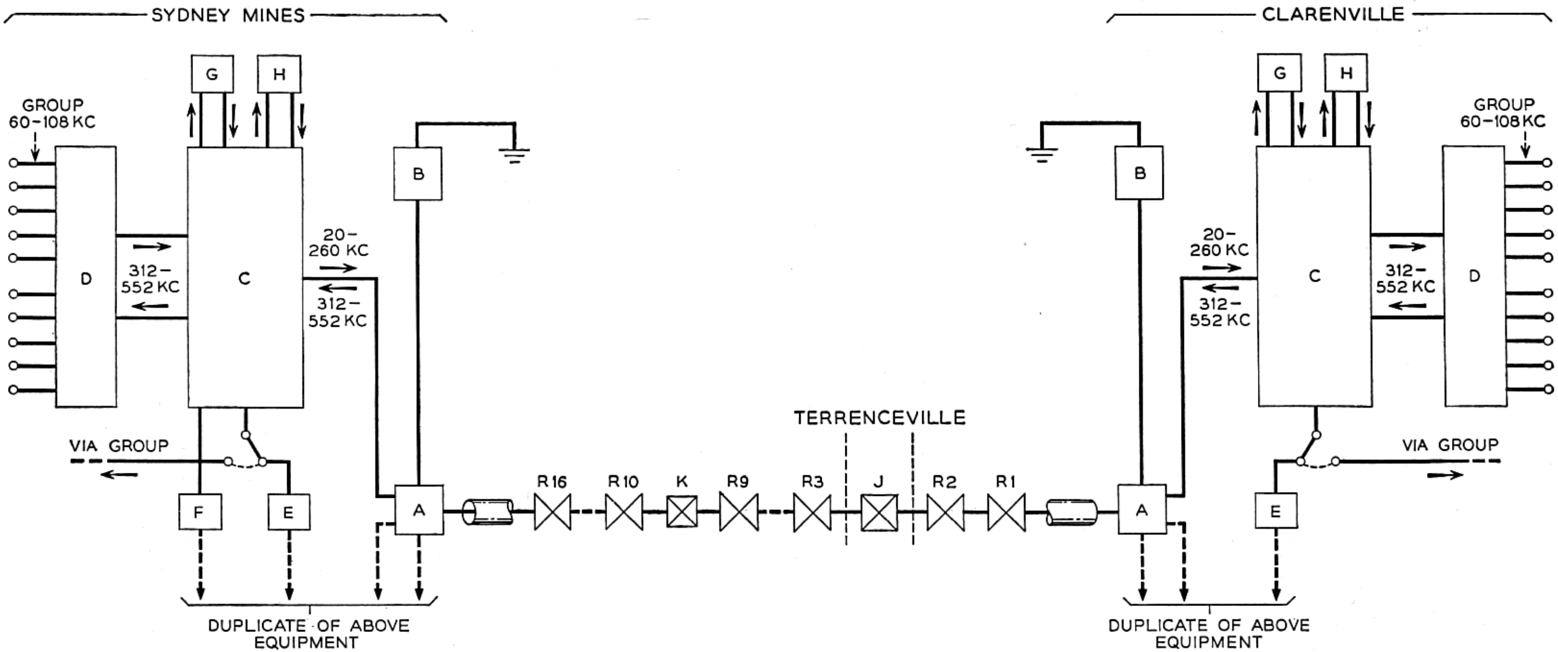

Fig. 7 — Arrangement of terminal equipment and repeaters. A. Cable-terminating equipment. B. Power-feeding equipment (dc). C. Submarine-cable terminal equipment. D. Group-translating equipment. E. Pulse test equipment. F. Loop-gain test equipment. G. Speaker circuit equipment. H. Printer circuit equipment. J. Intermediate cable-terminating equipment, including equalizers. K. Submerged equalizer. R. Submerged repeater.

(ii) Basic power plant and the carrier supplies for supergroup and group translation were provided by the A.T. and T. Co. for both terminal equipments at Clarenville.

(iii) Terminal equipment special to the Clarenville-Sydney Mines link was provided by the Post Office.

In view of the importance of the link, the power-feeding and transmission equipment are completely duplicated.

The submarine-cable terminal equipment is arranged to transmit the basic supergroup, directly over the cable in the east-to-west direction. In the west-to-east direction the supergroup is translated to the range 20–260 kc, using a 572 kc carrier.

DESIGN OF TRANSMISSION SYSTEM

Performance Requirements

The agreed transmission objects for the Clarenville-Sydney Mines link were as follows:

Variation of Transmission Loss.

The variation in the transmission loss of each group should have a standard deviation not greater than 0.5 db; this implies that the variation from nominal should not exceed 1.3 db for more than 1 per cent of the time.

Attenuation/Frequency Characteristics.

Only the overall characteristics of the individual circuits were precisely specified, the limits being the C.C.I.F. limits for a 2,500-km circuit and the target one-half of this. With this objective in view, the group characteristics in each link must clearly be as uniform as is practicable.

Circuit Noise.

The total noise contributed by the link to each channel in the busy hour (i.e., including intermodulation noise) should have an r.m.s. value not exceeding +28 dba* (corresponding to −56 dbm) at a point of zero relative level.

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* This refers to the reading on a Bell System 2B noise meter (FIA weighting network); the noise level (dba) is relative to a 1 kc tone at −85 dbm. In Europe, noise is measured on a C.C.I.F. Psophometer (1951 weighting network), which is calibrated in millivolts across 600 ohms; this is commonly converted to picowatts (pw). The white noise equivalence of the two instruments is given by $\text{dba} = 10 \log_{10} \text{pw} - 6 = \text{dbm} + 84$; the agreed limit of +28 dba is therefore equivalent to 2513 pw (1.23 mv or −56 dbm). The corresponding C.C.I.F. requirement at 4.0 pw/km would be 2,400 pw, this value not to be exceeded for more than 1 per cent of the time.

Crosstalk.

The minimum equal-level crosstalk attenuation should be 61 db for all sources of potentially intelligible crosstalk; this was accepted as a target for both near- and distant-end crosstalk. Although go-to-return crosstalk is not important for telephony (it appears as sidetone) and a limit of 40 db is satisfactory even for voice-frequency telegraphy, it assumes great importance for both-way music transmission; also, it was desired to be non-restrictive of future usage.

Assessment of Requirements

The design of the high-frequency path to meet the agreed requirements involves consideration of:

(*a*) Noise, including fluctuation (resistance and tube) noise and intermodulation.

(*b*) Wide-band frequency characteristics, including the effects of the directional filters at the terminal and in the repeaters.

(*c*) Variations of (*a*) and (*b*) in respect of temperature and aging.

The noise requirement is by far the most important factor in the design of the line system.

The choice of route and cable having been made, the total loss was known and it was necessary to determine the minimum number of repeaters to compensate for this loss and to meet the noise requirement with adequate margin for inaccurate estimates of cable attenuation after laying, temperature variations, aging and repairs. An attempt to achieve the necessary gain with too few repeaters would result in excessive noise.

Design of the amplifiers in the British repeaters is such that, with both forward paths in operation, the overload point is about +24 dbm, and with a loading of 60 channels in each direction, this permits planning levels of about −4 dbm at the amplifier output after allowing reasonable margins for errors and variations.[10] Previous experience shows that, at such output levels, intermodulation noise can be neglected and the full noise allowance allotted to fluctuation noise. The effect of tube noise is to increase the weighted value of resistance noise by about 1 db to −137.5 dbm, or −53.5 dba, at the input to the amplifier in each repeater.

At the highest transmitted frequency the equalizers, power filters and directional equipment introduce losses of about 1 db and 4 db at the input and output of the amplifier respectively; these losses must, effectively, be added to the loss in the cable.

Two other pieces of information are necessary before the repeater system can be planned — the permissible transmitting and receiving levels at the shore stations. The transmitting equipment provided at Clarenville can be operated at channel levels up to +20dbm, and it is logical to allow the same receiving level at the shore end as at intermediate repeaters.

On the above basis it is possible to construct a curve (Fig. 8) relating the total circuit noise to the number of intermediate repeaters, and it is seen that the minimum number is 15, each of which must have an overall gain of 59 db (amplifier gain, 64 db) at 552 kc. The actual provision is 16 repeaters, each having a gain of 60 db at 552 kc, the additional gain being absorbed in fixed and adjustable networks at points along the route, as indicated in the following section.

Level Diagram

The actual level diagram (planning levels are shown in Fig. 9) differs somewhat from that which can be deduced directly from the preceding because of the following considerations:

(*a*) The location of the first repeater from Clarenville (i.e., on land)

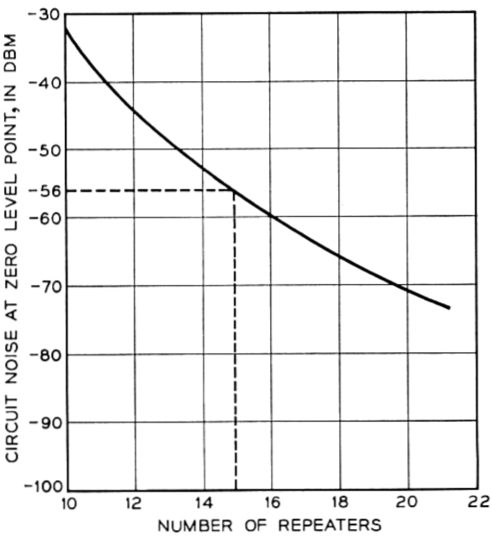

Fig. 8 — Variation of circuit noise with number of repeaters.

was dictated by topography and the desire to locate both it and the second repeater in ponds; thus the transmitting level at Clarenville is substantially lower than the permissible maximum.

(*b*) There are equalizing networks at Terrenceville and facilities for their adjustment to compensate for temperature variations.

(*c*) Because of the difference between the actual cable attenuation and that for which the repeaters were planned (see section on *Attenuation Characteristics*) it was necessary to include an equalizer unit in the sea, midway between Terrenceville and Sydney Mines. Loss equivalent to 9 nautical miles of cable was also introduced at this point to ensure that repeater No. 16 would be sufficiently far from the shore at Sydney Mines.

(*d*) Cable simulators are included in the cable-terminating equipment at Sydney Mines to build out this section to a standard repeater section; the actual cable length was, of course, unknown until the cable was complete.

Taking into account the existence of the intermediate networks, the repeater spacing is such that when both land and submarine cable sections are at mean temperature the compensation is as accurate as possible. In general the highest frequency is of greatest importance in this respect. Since the low-frequency channels experience less attenuation than the high-frequency channels, it is permissible to transmit them at a somewhat lower level, thereby increasing the load capacity of the amplifiers which is available to the high-frequency channels.

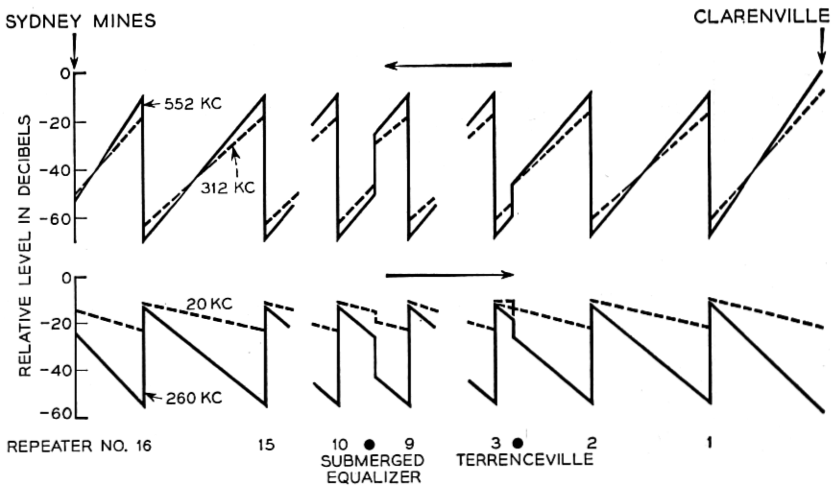

Fig. 9 — System level diagram.

Temperature Effects and their Compensation

The effect of temperature changes is likely to be somewhat complex. The land-and-sea cable sections are expected to behave in different ways in this respect, but data on the manner of variation are not very precise. The submarine cable crosses Cabot Strait, where melting icebergs drifting down from Labrador as late as June can be expected to keep the sea-bottom temperature low until well into the summer; temperatures just below 0° C were, in fact, recorded when the cable was laid in May. On land, the cable is buried 3 feet deep in bog and rock, and traverses many ponds; some data on temperatures under similar conditions in other parts of the world were available.

For planning purposes it was clear that the assumptions made would have to be somewhat pessimistic, and the assumed ranges of temperature, with the corresponding changes of attenuation at 552 kc, were:

Sea section	2.3 ± 3° C;	±4 db
Land section	7.5 ± 10° C;	±3 db

A possible method of circuit adjustment for temperature changes is to increase the gains equally at the sending and receiving terminals as the temperature rises and to reduce them equally as it falls. Under such conditions the effect of temperature variations on resistance noise is not very important; the levels at repeaters near the center of the route remain substantially constant, and the increase in noise from the repeaters whose operating levels are reduced is partly compensated by the reduction in noise from those whose levels are increased. The effect of the level changes on repeater loading is, however, more important as it is undesirable that any repeater in the link should overload, and additional measures which can be readily adopted to avoid serious changes in repeater levels are clearly desirable.

The estimated change of attenuation of the land sections is seen to be roughly equal to that of the submarine section, so that, from the point of view of temperature changes, Terrenceville is near the electrical center of the link. It was thus both desirable and convenient to provide adjustment at this point: Fig. 10 illustrates the advantage of seasonal changes in equalizer setting at Terrenceville, showing the way the output levels of repeaters are likely to vary along the route. The system of temperature compensation adopted therefore involves adjustable networks at both ends of the system and at Terrenceville. All the networks are cable simulators; hence the process of temperature compensation consists, effectively, in adding 'cable' when the temperature falls and removing it when the temperature rises.

At Terrenceville, the networks permit adjustments equivalent to ±1 nautical mile of cable (3 db at 552 kc), but at Clarenville and Sydney Mines adjustments equivalent to 0.5 db at 552 kc are provided. It should therefore always be possible to maintain the overall loss of the system within ±0.25 db, and the level at any repeater should never change by more than ±2 db.

System Pilots

The use of pilot tones applied at constant level at the input of a system with indicating or alarm meters at the receiving end is standard on land systems on both sides of the Atlantic, although the philosophies underlying the methods of use differ. On the submarine cables round the British Isles, with or without submerged repeaters, pilot tones are used

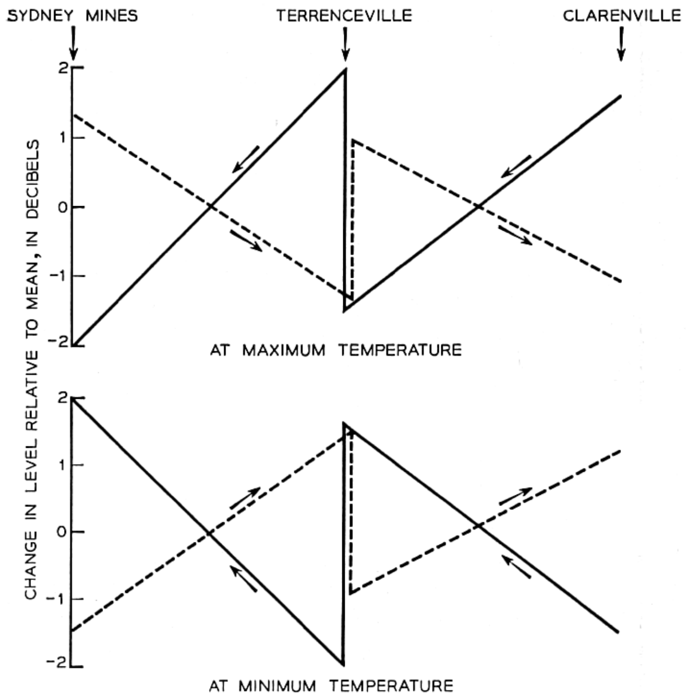

Fig. 10 — Deviation from mean of transmission levels with optimum adjustments of equalizers at Sydney Mines, Terrenceville and Clarenville.
- - - - W-E at 260 kc.
——— E-W at 552 kc.
Maximum deviation in the two directions occurs at the above frequencies.

to indicate the attenuation of the transmission path; these pilots are normally located just outside the main transmission bands in each direction. In the Clarenville-Sydney Mines system the frequency bands just outside the main transmission bands are occupied by telephone speaker and teleprinter circuits and by monitoring frequencies associated with the repeaters (see Fig. 5); this prevents the use of out-of-band pilots.

Fortunately, the standard Bell System group equipment is designed to apply 92-kc pilots to each group and to measure the corresponding received level. Although these are essentially group pilots, being applied and measured at points in the 60–108-kc band, it was decided that they could reasonably replace the out-of-band pilots. These pilots are blocked at each end of the system and therefore function as section pilots only.

Normal Post Office practice, both on land and submarine systems, is to use recording level meters to provide a continuous and permanent record of the pilot levels. In the present system such recording meters are used on the 92-kc pilots of two groups in each direction of transmission.

In addition to the section pilots the system carries the 84.080-kc end-to-end pilots in each of the three transatlantic groups.

MAINTENANCE FACILITIES

Speaker and Printer Circuits

It was part of the planning of the transatlantic system that two low-grade telephone (speaker) and two telegraph (printer) circuits should be provided over the submarine cables, outside the main transmission bands, and that the speaker circuits in particular should be reasonably independent of the main terminal equipment. One speaker circuit is required for local communication between the terminals of each section, the other to form part of an omnibus circuit connecting the principal stations on the route including Montreal. The arrangement for teleprinter communication was that one channel should be an overall all-station omnibus printer, the other being a direct London-New York printer.

Independent frequency-translating equipment is provided to connect the speaker and printer bands (each 4 kc) to the line. The carrier frequencies required for the speaker are provided by independent oven-controlled crystal oscillators, but for the printer the independent generation of high-stability 572-kc carriers was not considered to be justified and the main station supplies are used.

Two half-bandwidth telephone circuits are provided in the 4 kc speaker bands by the use of standard A.T. and T. band-splitting equipment (EB banks). Signalling and telephone equipment are provided to give the required omnibus facilities on one circuit and local-calling facilities on the other. The arrangement of the speaker and printer equipment at Sydney Mines is shown in Fig. 11.

In the telegraph band a third channel transmits an alarm to the remote terminal when the 92-kc pilots incoming from that terminal fail simultaneously.

Fault Location

The speedy and accurate location of faults in repeatered cables is of very great importance, owing to the number of circuits involved and the difficulty and cost of repairs. The standard dc methods which have been applied in the past to long telegraph cables are, of course, available. The application of these methods is, however, recognized as being rather more

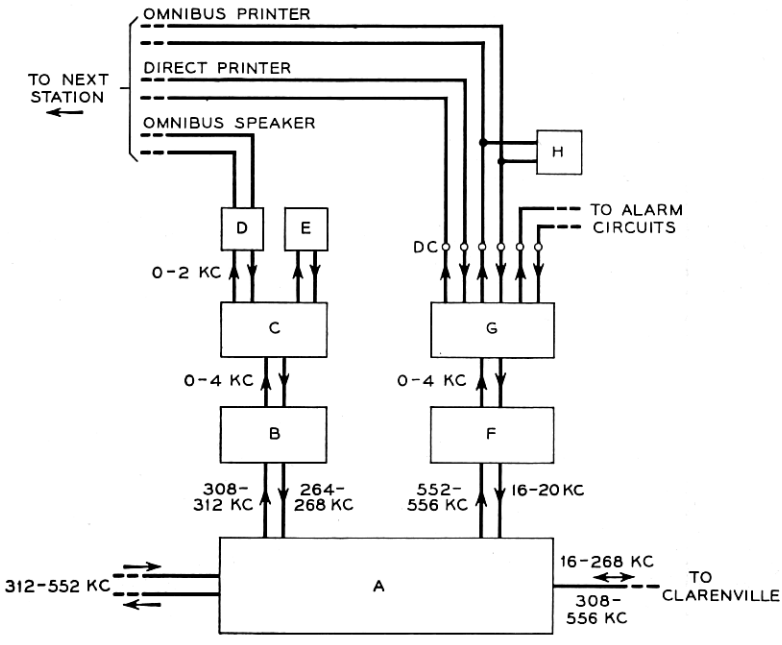

Fig. 11 — Arrangement of speaker and printer equipment at Sydney Mines. A. Submarine cable terminal equipment. B. Speaker circuit equipment. C. Emergency-band bank equipment. D. Omnibus speaker telephone. E. Local speaker telephone. F. Printer circuit equipment. G. Three-channel telegraph equipment. H. Printer.

in the nature of an art than a science and usually requires an intimate knowledge of the behaviour and peculiarities of the particular cable concerned. While the problem appears at first sight to be simple it is complicated by:

(*a*) The presence of ground-potential differences along the cable, sometimes amounting to hundreds of volts; these vary with time.

(*b*) Electrolytic e.m.f. generated when the center conductor is exposed to sea water.

(*c*) Absorption effects in the dielectric of the cable.

When repeaters are added the position is further complicated by:

(*d*) The lumped resistance of the repeaters, which is current-dependent and exceeds the cable resistance.

(*e*) The lumped capacitance of the repeaters with an absorption characteristic which differs from that of the cable.

It is a great advantage of both-way transmission over one cable that, by introducing some form of frequency changer at each repeater, signals outgoing in one direction can be looped back to the sending terminal. There have been a number of developments based on this principle, and in the Clarenville–Sydney Mines link two methods are available for use. Of these, the so-called 'loop-gain' method uses steady tones and depends on selective frequency measurements to discriminate between repeaters; the second is a pulse method in which repeaters are identified on the basis of loop transmission time.

The use of these methods under fault conditions depends on the possibility of keeping the repeaters energized. Work is in progress to develop methods of fault location which are of general application and do not depend on the activity of the repeaters, but these are outside the scope of the present paper.

Loop-Gain Method.

In the loop-gain method, the frequency changer in the repeater takes the form of a frequency doubler and each repeater is identified uniquely by one of a group of frequencies spaced at 120 cycles and located immediately above the lower main transmission band in the frequency range 260–264 kc. Since the frequency changing is in an upward sense, the measuring terminal is Sydney Mines, which transmits the lower band. On the Clarenville side of the directional filters in each repeater is connected, via series resistors, a crystal filter accepting the test frequency appropriate to the repeater [see Fig. 12(*a*)]; this frequency is doubled, filtered and returned to the repeater at the same point at which

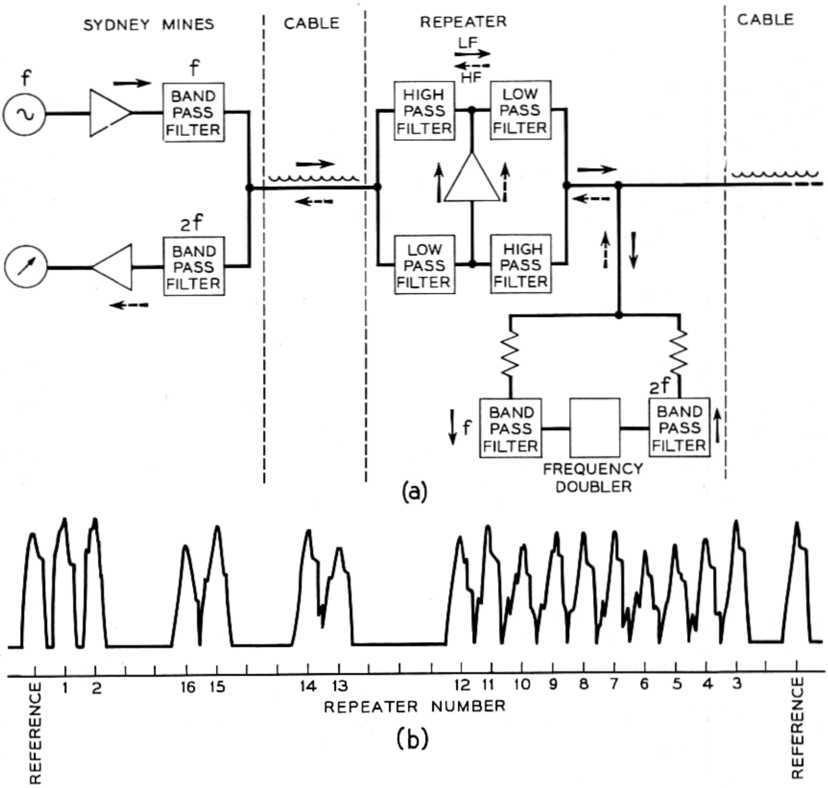

Fig. 12 — Fault location — loop-gain method. (*a*) Block schematic. Frequency *f* is in the band 260–264 kc. (*b*) Diagram of display.

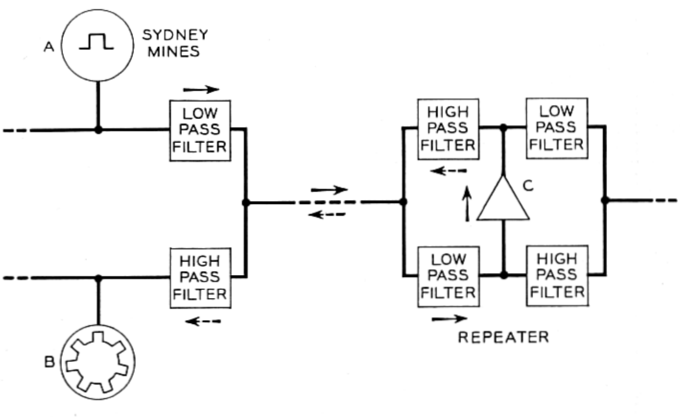

Fig. 13 — Fault location: pulse method. A. Pulse generator. B. Display of received pulses. C. Point of intermodulation (output of amplifier).

the original frequency is selected. From this point it passes via the high-pass directional filters through the amplifier and back to Sydney Mines, where the level is measured on a transmission measuring set. Information obtained in this way on each repeater can be compared at any time with that obtained when the system was installed and any gain variations localized. The test equipment provided has the additional facility of an automatic sweep of the test frequency at 4 cycles and a display of the returned-signal levels on a cathode-ray tube as in Fig. 12(*b*).

Although the transmitted signals lie outside the band of the W-E supergroup, the received signals, 520–528 kc, lie within the band of the E-W supergroup, and two channels must be removed from traffic to carry out the tests; these channels are in a "local" group.

Pulse Method.

As applied to the present system, the pulse method utilizes the overload characteristic of the amplifier to effect the frequency change in the repeater. At Sydney Mines a continuous train of single-frequency pulses is applied in the lower transmission band, such that either the second or third harmonic is returned in the upper band, as in Fig. 13; at Clarenville two-frequency pulses are applied in the upper band such that either a second- or third-order difference product is returned in the lower band. The pulse length is 0.15 millisecond, and the frequencies used are given in Table I. At Sydney Mines the signals can be sent and received either on the line itself or via the group equipment; in the latter case only one group need be taken out of service. At Clarenville line measurements only are provided for.

The primary display is on a cathode-ray tube with a circular time-base, and any one returned pulse can be accurately compared with the reference pulse on a second tube with a linear time-base. The pulse selected for such measurement is automatically blacked out on the primary display.

TABLE I

Station	Send to line		Product	Receive
	f_1	f_2		
	kc	kc		kc/s
Sydney Mines	216	—	$2f_1$	432
	144	—	$3f_1$	432
Clarenville	530	380	$f_1 - f_2$	150
	530	340	$2f_2 - f_1$	150

Usefulness of the Loop-Gain and Pulse Methods.

Both methods require that all the repeaters between the testing terminal and the fault can be energized. If the fault is in the cable there is a very high probability that the center conductor will be exposed to the sea, in which case the power circuit can be maintained on one side of the fault at least, although it may be somewhat noisy. Because the system is short, it is permissible to energize the link fully from one end only. The condition can never arise — as it can in the Oban–Clarenville link — that the line current is limited by the maximum permissible terminal voltage.

The loop-gain test is concerned with the amplifiers in their linear regime and gives no indication of the overload point; for this the pulse test must be used. On the other hand, the pulse test does not permit accurate measurement of levels, since the pulse level reaching a particular repeater may be restricted by the overload of an earlier repeater in the chain. The pulse test is particularly useful in providing a check that both sides of each amplifier are in operation and in locating a fault of this type.

Each method depends for its operation on non-linearity at a point within each repeater and can only identify a fault as lying between two such consecutive points in the link. It is therefore desirable that these points should be as close as possible to the terminals of the repeater in order to ensure that the faulty unit can be identified. In this respect the loop-gain test has the advantage over the pulse test.

EXECUTION OF WORK

Problems due to the remoteness of the site were overcome without undue difficulty with the co-operation of the other parties concerned in the project, but the present paper would be incomplete without a brief reference to the cable- and repeater-laying operations in Newfoundland and at sea.

The terrain and conditions in Newfoundland were quite unlike those with which the British Post Office normally has to contend, involving trenching and cabling through bog, rock and ponds in country of which no detailed survey or maps were available. Maps were constructed from aerial survey, and alternative routes were explored on foot before a final choice was made. As much use as possible was made of water sections in the sea, river estuary and ponds; some 22 miles were accounted for in this way, leaving about 41 miles to be trenched by machine or blasted. A contractor was engaged for this purpose and to lay the cable in the trench, but all jointing was done by the Post Office. The standards of conductor and core jointing were the same as those in the cable factories and on ship, portable injection-moulding machines and X-ray equipment being specially designed for handling over the bog. A single pair cable was also laid in the main cable trench to provide speaker facilities between Clarenville and Terrenceville (which has no public telephone), with intermediate positions for use of the lineman. As a measure of protection against lightning strikes, two bare copper wires were buried about 12 inches apart and 6 inches above the cable. Both the constructional work in Newfoundland[4] and the laying operation at sea[5] have been described elsewhere.

TEST RESULTS

In the interval between the completion of the link in May, 1956, and its incorporation in the transatlantic system, tests were carried out to establish its performance and day-to-day variations; an assessment of the annual variations has, of course, been impossible at this date.

Variation of Transmission Loss

Close observation of the transmission loss of the 92 kc pilots on Groups 1 and 5 leads to the following tentative conclusions:

(*a*) Over periods of 1 hour the variations are not measurable, i.e., less than ±0.05 db.

(*b*) Over periods of 24 hours there are no systematic changes; apparently random changes of about 0.1 db are probably attributable to the measuring equipment.

(*c*) Over a period of eight weeks (July and August, 1956) there was a systematic increase in loss of about 0.3 db. By means of the loop-gain equipment it has been possible to deduce that most of this change has occurred in the land section.

The results indicate that the submarine cable link has better day-to-day stability than the best testing equipment which it has been possible to provide. Many more data will clearly be necessary before the annual variations can be definitely established, but the present indications are that these will be less than those assumed in the design of the link.

Attenuation/Frequency Characteristics

The frequency characteristics of the supergroup in the two directions of transmission are shown in Fig. 14. It will be seen that in no transatlantic groups does the deviation from mean exceed ±0.35 db.

Circuit Noise

Table II shows the noise level on Channels 1 and 12 of each of the five groups measured without traffic on the system.

To assess the magnitude of intermodulation noise, all channels in one direction were loaded simultaneously with white noise and measurements taken on each channel in the opposite direction. From the talker volume data assumed in the design of the system, the expected mean talker power is −11.1 dbm at a point of zero relative level, with an activity of 25 per cent. For an equivalent system loading, therefore, the level of white noise applied to each channel under the above test conditions should be −14.1 dbm. Since this loading gave no sensible increase in the circuit noise, the test levels were raised until a reasonable increase in the noise level was obtained. In order to raise the channel noise to the specified maximum of 28 dba it was necessary to raise the channel levels to about −1 dbm and −4 dbm in the lower and upper bands respectively. These levels, some 13 db and 10 db above the assumed maximum loading of the system, give noise levels at least 26 db and 20 db above normal, and it is seen that adequate margins exist for variations and deterioration of the link.

Closely allied to the problem of intermodulation is the overload characteristic of the system. Table III shows the measured overload point of the link expressed as an equivalent level at the output of the amplifier in the repeater nearest to the transmitting terminal. It also shows the margin between the channel level at that point and the overload point of the system; according to Holbrook and Dixon[13] the minimum requirement in this respect is 18 db.

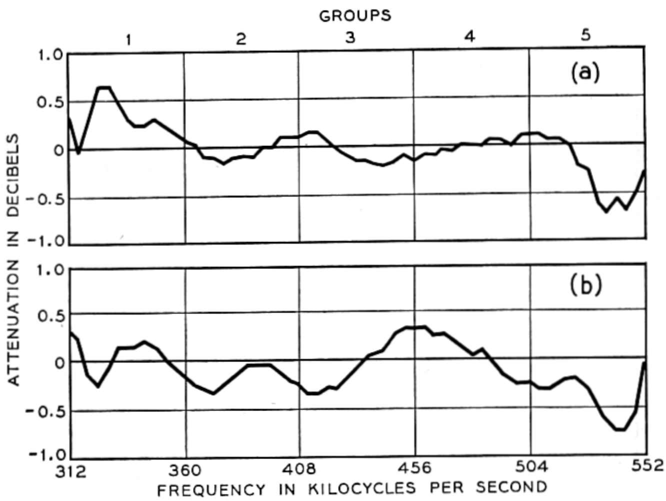

Fig. 14 — Attenuation versus frequency characteristics of supergroup. (*a*) Sydney Mines—Clarenville. (*b*) Clarenville—Sydney Mines.

TABLE II

Group	Channel	Noise level	
		Sydney Mines	Clarenville
		dba	dba
1	1	25.0	24.5
1	12	24.5	23.2
2	1	24.0	22.5
2	12	23.5	22.0
3	1	24.0	20.5
3	12	25.0	17.5
4	1	24.5	17.5
4	12	24.5	16.5
5	1	24.5	17.5
5	12	27.0	18.0

These results justify the assumption made in the design of the link, that intermodulation noise is negligible.

Crosstalk

The crosstalk requirements are met in all respects.

CONCLUSIONS

The submarine-cable link between Clarenville, Newfoundland, and Sydney Mines, Nova Scotia, was completed in May, 1956, and provides five carrier telephone groups, each capable of carrying twelve high-grade telephone circuits or their equivalent. The transmission objectives have been met in every respect.

Three 12-circuit groups are connected to the three groups across the Atlantic between Scotland and Newfoundland; the other two groups are available to provide 24 circuits between Newfoundland and the mainland of Canada.

TABLE III

Frequency	Equivalent at amplifier in first repeater		
	Channel level	Overload	Margin
kc	db	db	db
552	−2	+20	22
312	−4	+24	28
260	−5	+25	30
20	−5	+25	30

ACKNOWLEDGMENTS

It has been the authors' privilege to present an integrated account of the work of many of their colleagues in the Post Office and in industry. Post Office staff have been responsible for designs and for inspection and testing at home and in the field, as well as the laying of the submarine-cable system by H.M.T.S. *Monarch*. In Great Britain, Submarine Cables, Ltd., and the Southern United Telephone Co., Ltd., provided the submarine and overland cables respectively, while Standard Telephones and Cables, Ltd., supplied and contributed much to the design of the submerged repeaters and terminal equipment. On site, the assistance rendered by the Ordnance Survey of Great Britain, the Canadian Comstock Co., Ltd., who laid the cable across Newfoundland, the Northern Electric Co., Ltd., who carried out the terminal equipment installations, and by the other partners in the project, the American Telephone and Telegraph Co. Inc., the Canadian Overseas Telecommunication Corporation and the Eastern Telephone and Telegraph Co., has been invaluable. The permission of the Engineer-in-Chief of the Post Office to make use of the information contained in the paper is gratefully acknowledged.

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