Transatlantic Telephone Cable System — Planning and Over-All Performance

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(Manuscript received October 10, 1956)

The transatlantic telephone cable system was designed as a link connecting communication networks on the two sides of the Atlantic. The technical planning of the system and the objectives set up so that this role would be fulfilled, are the principal subjects of this paper. Typical performance characteristics illustrate the high degree with which the objectives have been realized. Optimum application of the experience of the British Post Office with rigid repeaters and the Bell System with flexible repeaters, together with close cooperation among three administrations, have played a large part in achieving the objectives.

INTRODUCTION

The transatlantic telephone cable system was planned primarily to connect London to New York and London to Montreal, and thus serve as an interconnection between continent-wide networks on the two sides of the Atlantic. Thus, the system has to be capable of serving as a link in wire circuits as long as 10,000 miles, connecting telephone instruments supplied by various administrations and used by peoples of many nations. This role as an intercontinental link has, therefore, been a controlling consideration in setting the basic objectives for the system.

The end sections of the system utilize facilities which are integral parts of the internal networks of the United States, Great Britain and Canada, but the essential new connecting links, extending between Oban, Scotland, and the United States-Canada border, and forming the greater part of the system, were built under an Agreement between the joint owners — the American Telephone and Telegraph Company and its subsidiary the Eastern Telephone and Telegraph Company (operating in Canada), the British Post Office, and the Canadian Overseas

* Bell Telephone Laboratories. † British Post Office. ‡ Canadian Overseas Telecommunication Corporation.

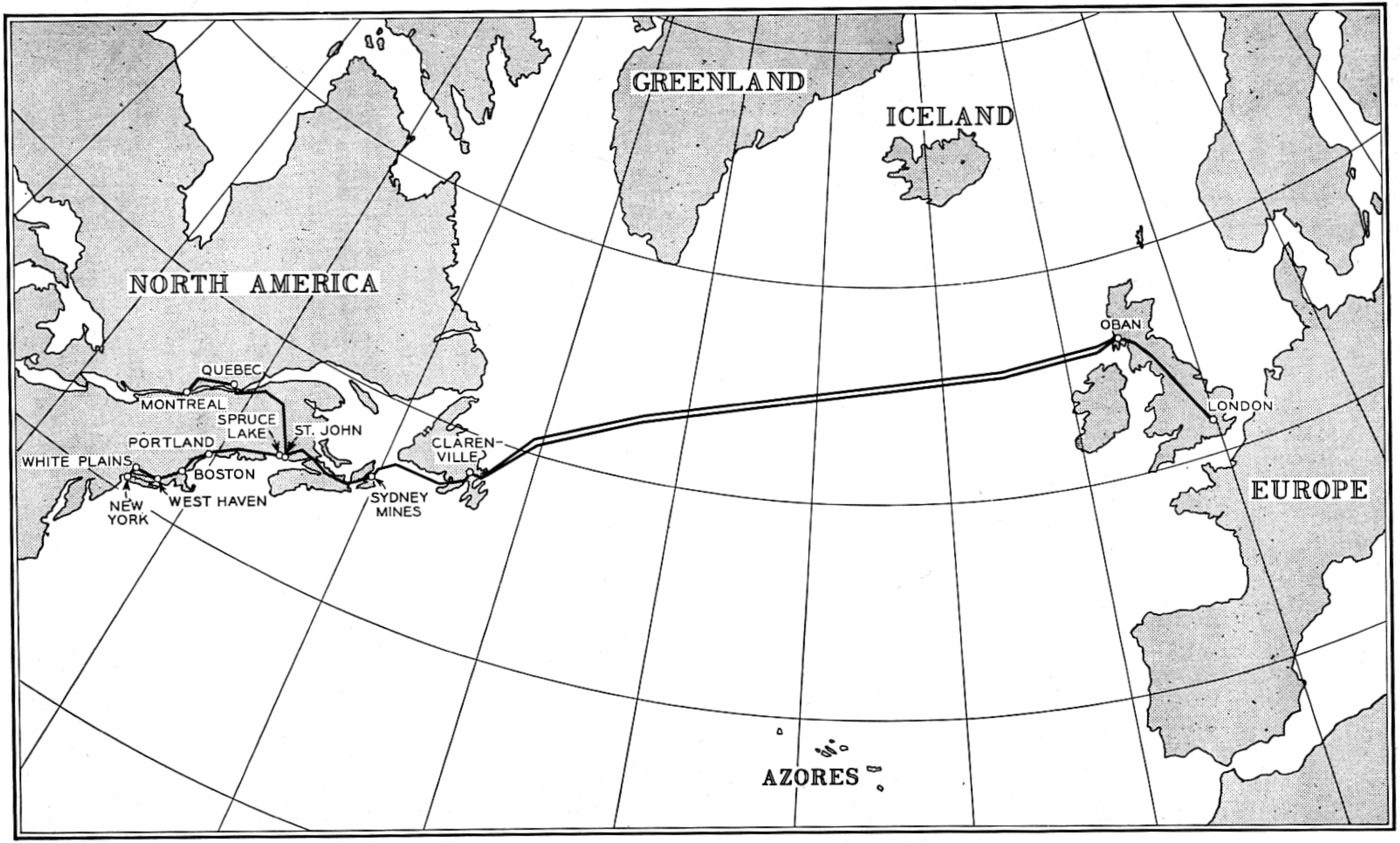

FIG. 1 — Route of the transatlantic submarine telephone cable system.

Telecommunication Corporation. It is thus the joint effort of three nations.

In planning the system, the main centres of interest were, naturally, the two submarine cable sections, Scotland to Newfoundland, and Newfoundland to Nova Scotia, each of which had to meet a unique combination of requirements imposed by water depth, cable length and transmitted bandwidth.

OVER-ALL VIEW OF THE SYSTEM

The transatlantic system provides 29 telephone circuits between London and New York, six telephone circuits between London and Montreal, and a single circuit split between London — New York and London — Montreal; this split circuit is available for telegraph and other narrow band uses. There are also 24 telephone circuits available for local service between Newfoundland and the Mainland of Canada, and there is considerable excess capacity over the radio-relay link that crosses the Maritime Provinces of Canada.

A map of the system is shown in Fig. 1; the facilities used, together with the approximate route distances are shown in Fig. 2. It will be seen that the over-all lengths of the London to New York and London to Montreal circuits are 4,078 and 4,157 statute miles respectively. Seven of the New York to London circuits are permanently extended to European Continental centres — Paris, Frankfurt (2), Amsterdam, Brussels, Copenhagen and Berne. The longest circuit is thus New York to Copenhagen, 4,948 miles.

Starting at London, which is the switching centre for United Kingdom and Continental points, 24-circuit carrier cables provide two alternative routes to Glasgow and thence to Oban by a new coaxial cable. Between London and Oban the two routes are fed in parallel at the sending ends, so a changeover can be effected at the receiving ends only. At a later date, an alternative route out of Oban will be provided by a new coaxial cable to Inverness.

From Oban a deep-sea submarine link connects to Clarenville, Newfoundland. This link is in fact two parallel submarine cables, one used for east-to-west transmission, the other for transmission in the reverse direction. Each cable is roughly 1,950 nautical-miles in length and lies at depths varying between a few hundred fathoms on the continental shelf and about 2,300 fathoms at the deepest point. Each cable incorporates 51 repeaters in flexible housings which compensate for the cable attenuation of about 3,200 db at the top frequency of 164 kc. These

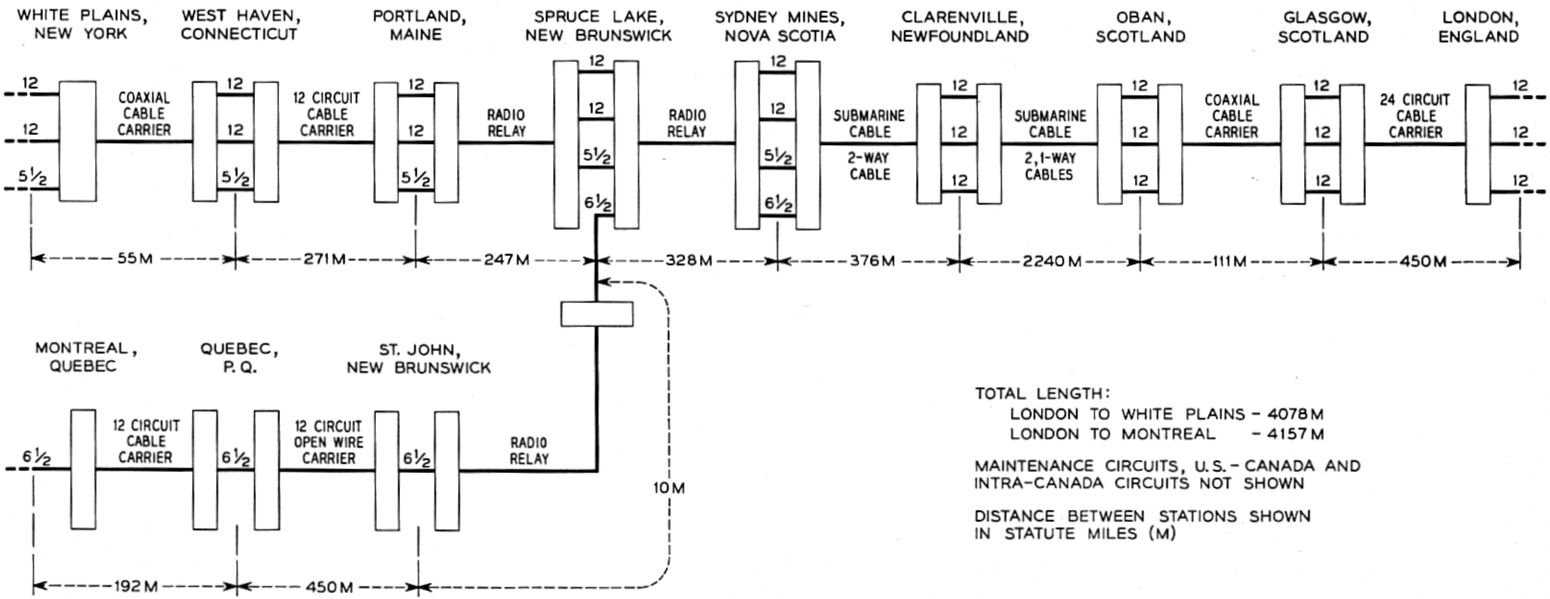

Fig. 2 — Facilities used for the transatlantic submarine telephone cable system. Maintenance circuits, U.S.-Canada and intra-Canada circuits are not shown.

cables carry 36 telephone circuits plus maintenance circuits and establish the present maximum capacity of the transatlantic system.

At Clarenville, connection is made with Sydney Mines, Nova Scotia, by a second cable system which goes 63 statute-miles over land to Terrenceville, Newfoundland, and thence about 270 nautical-miles in coastal waters at a depth of about 250 fathoms. Although this system is partly on land, it is basically a submarine system in design, the two portions differing only in the protection of the cable. In this link, the two directions of transmission are carried by the same cable, a low-frequency band being used from west-to-east and a high-frequency band in the opposite direction. In addition to the necessary maintenance circuits, a total of 60 two-way circuits are provided, 36 being used for transatlantic service, and the remainder being available for service between Newfoundland and the Mainland. Sixteen two-way repeaters in rigid containers provide close to 1,000 db gain at this system's top frequency of 552 kc.

From Sydney Mines, transmission is by radio-relay to the United States-Canada border and thence to Portland, Maine; this system operates at about 4,000 mc and includes 17 intermediate stations. From Portland, standard 12-circuit carrier and coaxial cable facilities are used to connect with White Plains, New York, the American switching center 30 miles north of New York City, where connection is made to the Bell System network.

The Montreal circuits leave the radio-relay route at Spruce Lake, a relay station near the Border, from which point a short radio spur connects to St. John, New Brunswick, thence to Quebec on a 12-circuit open-wire carrier system and thence to Montreal on a 12-circuit cable carrier system.

BACKGROUND TO THE SUBMARINE CABLE SYSTEMS

The submarine cable sections have been built upon a long background of experience. Some of the cable laying and design techniques go back to the early telegraph cables of almost a century ago, and Lord Kelvin's analysis of the laying process is still the standard mathematical treatise on the subject. It is also interesting to note that the firm which provided most of the cable is a subsidiary of the organization that manufactured and laid the first successful transatlantic telegraph cable some 90 years ago.

In addition to the long experience in submarine telegraphy, the transatlantic system has drawn on over a quarter of a century of experience of telephone cable work in the British Post Office and the Bell System.

Experience in these two organizations has been quite different, but each in its own way has been invaluable in achieving today's system.

British Experience

In Great Britain, communication to the Continent dominated the early work in submarine telephony and led to systems providing relatively large numbers of circuits over short cables laid in shallow water. Early systems were un-repeatered, but the advantages of submerged repeaters were apparent. Experimental work, started in 1938, culminated in the first submerged repeater installation in an Anglesey-Isle of Man cable in 1943. Currently, there are many repeaters in the various shallow water cables radiating from the British Isles.

These repeaters, although of a size and mechanical structure well suited to shallow water applications, are not structurally suited to Atlantic depths. In 1948, the Post Office began to study deep water problems, and the first laying tests of a deep-water repeater housing were conducted in the Bay of Biscay in 1951. This housing was rigid, like the shallow-water ones, but smaller and double-ended so that the repeater was in line with the cable. Thus the rotation of the repeater, which accompanies the twisting and untwisting of the cable as tension is increased and decreased during the laying operation could be tolerated. The housing now used by the British Post Office is basically the same as this early deep-water design, although minor modifications have been made to improve the closure and water seals.

A serious study of transatlantic telephony was begun by the Post Office in 1950 when a committee was set up to report on future possibilities of repeatered cables. As a result, it was decided in 1952 to engineer a new telephone cable to Scandinavia, 300 nautical-miles in length, as a deep-water prototype, even though the requirements of depth, length, and channel capacity all could have been met by existing shallow-water designs.

All of the Post Office submarine systems are alike in that they use but a single cable, the go and return paths being carried by different frequency bands. The adoption of this plan was greatly influenced by the conditions under which the art developed. Because North Sea and Channel cables were highly subject to damage from fishing operations, it was desirable to limit the effects of such damage as much as possible. A single cable system is obviously preferable under these circumstances to a system using separate go and return cables which could be put out of service by damage to either cable. Since these systems were designed for shallow water use, the additional container size required for two-way repeaters was of no great moment compared to the advantages of a single-cable system.

United States Experience

In the United States, the cable art developed under very different circumstances. There was, of course, need for communication to Cuba, Catalina, Nantucket and other off-shore locations, some of which involved conditions similar to those existing around the British Isles. The application of carrier to several of these cables occurred at an early date, but the repeater art was not directed at these shallow water applications.

For many years, telephone communication to Europe had been an important goal and some thirty-five years ago a specific proposal was made by the Bell System to the Post Office for a single, continuously-loaded, nonrepeatered cable to provide a single telephone circuit across the Atlantic.

This system was never built, partly because of the economic depression of the early thirties and partly because short-wave radio was able to meet current needs. Cable studies and experiments in the laboratory and field were continued, however, and largely influenced subsequent developments. It was at this time that the physical structure of the cable now used in the transatlantic system was worked out. It was also at this time that the harmful effects of physical irregularities in the cable were demonstrated. As cables are laid in deep water, high tensions are developed which unwrap the armor wires that normally spiral about the central structure. As tension changes during the laying process, twisting and untwisting occurs which is harmless if distributed along the cable. But obstructions in the cable which prevent rotation, or any other process such as starting and stopping of the ship which tends to localize twisting, are likely to cause kinking of cable and buckling of the conductors.

By 1932, electronic technology had advanced to a point where serious consideration could be given to a wideband system with numerous long-life repeaters laid on the bottom of the ocean and powered by current supplied over the cable from sources on shore.

The hazardous effects of obstructions in the cable, demonstrated in early laying tests, indicated that the chances of a successful deep-sea cable would be greatest if the repeaters were in small-diameter, flexible housings which could pass through laying gear without stopping the ship and without restricting the normal untwisting and twisting of the cable. The structure ultimately evolved, consisting of two over-lapping layers of abutting steel pressure rings within a flexible waterproof container, was an important influence on the electrical design, since it placed severe limitations on size and placement of individual components.

Because these repeaters were to lie without failure for many years on the ocean bottom, it was necessary either to provide a minimum number of components of the utmost reliability, or to provide duplicate components to take over in case of failure. The size limitation favored the former approach. Similarly, the need for small size and minimum number of components militated against the use of two-way repeaters with their associated directional filters.

Out of these considerations grew the Bell System approach to solving the transatlantic problem by the use of two cables, each with built-in flexible amplifiers containing the minimum number of components of utmost reliability and a life objective of 20 years or better.

It was not until the end of World War II that such a system could be tried. At this time it was decided to install a pair of cables on the Key West-Havana route to evaluate the transatlantic design which had evolved in the prewar years. After further laying trials, this plan was completed in May, 1950, with the laying of two cables. Each of these had three built-in repeaters lying at depths up to 950 fathoms. These cables, each about 120 nautical-miles in length, carry 24 telephone circuits. They have now been in continuous service for over six years without repeater failure or evidence of deterioration.

EARLY TRANSATLANTIC TECHNICAL DECISIONS

Early in 1952, negotiations concerning a transatlantic cable were again opened between the American Telephone and Telegraph Company and the British Post Office. As indicated above, at that time each party had been laying plans for such a system. Thus it became necessary to evaluate the work on each side of the Atlantic to evolve the best technical solution.

To do this, a technical team from the Post Office visited Bell Telephone Laboratories in the fall of 1952 to examine developments in the United States. The work of the preceding 30 years was reviewed in detail with particular emphasis on the development and manufacture of the 1950 Key West-Havana cables. This was followed by a visit to the Post Office by a Bell Laboratories' team to review similar work in Great Britain. Again the review was comprehensive, covering shallow-water systems as well as plans for deep-water repeaters. Each visit was characterized by a frankness and complete openness of discussion that is perhaps unusual in international negotiations.

As is apparent from the previous discussion, it was found that the basic features of a deep-water design had been completed by the Bell System. Not only had many of the components been under laboratory test for many years, but a complete system had been operating for $2\frac{1}{2}$ years between Havana and Key West. To use a phrase coined at the time, the design had proven integrity.

Because of the years of proof and the conservative approach adopted to assure long life, the design was far from modern. The electron tubes, for example, had characteristics typical of tubes of the late 1930's, when, in fact, they were designed. Similarly, other components were essentially of prewar design.

The Post Office, on the other hand, had pioneered shallow-water repeaters and were pre-eminent in this field. Their deep-water designs were still evolving and had not yet been subjected to the same rigorous tests as the Bell System repeaters. This later evolution, however, made possible a much more modern design. The electron tubes, for example, had a mutual conductance of 6,000 micromhos as compared to about 1,000 in the Bell System repeater, and thus had a potentiality for much greater repeater bandwidths.

It was apparent from these reviews that only the American design was far enough advanced to assure service at an early date. It also appeared to have the integrity so essential to such a pioneering and costly effort as a transatlantic cable. On the other hand, the more modern Post Office design had many elements of potential value. If deep-water laying hazards could be overcome and proof of reliability established, it gave promise of greater flexibility and economy for future systems.

It was on these grounds that Dr. Mervin Kelly for the Bell System and Sir Gordon Radley for the Post Office jointly recommended that the Bell System design be used for the long length and great depths of the Atlantic crossing and the Post Office design be used for the Newfoundland-Nova Scotia link where the shallower water afforded less hazard and better observation of this potentially interesting design. The decision to use the Post Office design was subject to technical review after deep-sea laying tests and further experience with circuits and components. This review, made in June of 1954, confirmed the soundness of the original recommendation.

SYSTEM PLANNING

Planning of the individual systems began as soon as the technical decision just mentioned had been reached. By the time administrative agreements had been reached and the contract signed on November 27, 1953, both parties were ready to set up system objectives and an over-all system plan. This work, too, was accomplished by a series of technical meetings held alternately in the United States and the United Kingdom, with additional meetings in Canada.

At the first of these meetings, a decision of far-reaching importance was made. It was agreed that each technical problem would be solved as it arose in so far as possible on the best engineering basis, putting aside all considerations of national pride. Adherence to this principle did much to forward the technical negotiations.

The initial joint meeting was also responsible for establishing most of the basic performance objectives of the system. The target date for opening of service, December 1, 1956, had been settled even earlier and was, in the event, bettered by nearly 10 weeks.

Service Objectives

A statement of the manner in which the system would be used and the services to be provided was a necessary preliminary to establishing performance objectives.

It was agreed that the system should be designed as a connecting link between the North American and European long distance networks. As such it should be capable of connecting any telephone in North America (ordinarily reached through the Bell System or Canadian long distance networks) with any telephone in the British Isles or any telephone normally reached from the British Isles through the European continental network. The system would be designed primarily for message telephone service but consideration would be given to the provision of other services such as VF carrier telegraph, program (music), and telephotograph as permitted by technical and contractual considerations. It was also agreed that the two submarine cable links should be so planned that it would be possible to utilize the full bandwidth in any desired manner in the future. Thus, for example, repeater test signals should be outside the main transmission band.

All elements in the submarine cable systems were to be planned for reliable service over a period of at least 20 years.

Transmission Objectives

The term "objective" was used advisedly in describing the aims of the system. It was agreed that such objectives were not ironclad requirements but rather desirable goals which it was believed practical to attain with the facilities proposed. Reasonable departure from these goals, however, would not be reason for major redesign.

Since the transatlantic circuits were to connect two extensive networks, the broad objective was to add as little loss and other forms of impairment as practical. To this end, they were to be designed essentially to the standards of international circuits as defined by the C.C.I.F.* and of circuits connecting main switching points in national networks, as for example, "Regional Centers" in the Bell System network and "Zone Centers" in the Post Office network.

The possibility of increasing the circuit capacity of the system by using channel spacings less than 4 kc was obvious. It was decided, however, to adopt, initially at least, the 4-kc spacing commonly used by long distance systems on both sides of the Atlantic. This would make possible the use of standard multiplexing arrangements, and it was believed that the number of circuits provided would be adequate for the first few years of operation. It would undoubtedly be desirable to increase the number of circuits in later years, but a decision on the method to be used was left until completion of exploratory work on several methods which promised capacity increases with less degradation than narrow-band operation.

The decision to use standard terminal equipment led naturally to acceptance of the principle that the 36 circuits across the Atlantic would be assembled as three 12-channel groups in the range 60–108 kc and the 60 circuits between Newfoundland and Nova Scotia as five 12-channel groups and thence as a supergroup in the range 312–552 kc. These are standard modulation stages in the multiplexing arrangements for broadband carrier system on both sides of the Atlantic. Two of the 12-channel transatlantic groups would be connected to New York and the third would be split to provide $6\frac{1}{2}$ circuits to Montreal and $5\frac{1}{2}$ to New York in accordance with the Agreement.

To provide for program circuits, three eastbound and three westbound channels in each of the three transatlantic groups would be made available when required; equipment would be provided to replace either two or three 4-kc message telephone channels by a music channel. In order to avoid the agreed group pilot frequencies and to provide service to Montreal, it was agreed to utilize the frequency bands 68-76 kc and 64–76 kc in the 12-channel groups for this purpose. Terminals of British Post Office design would be used at all points for translation between program and carrier frequencies. The normal Bell System terminals could not be used since they occupy the frequency ranges 80–88 kc and

* The International Consultative Committee on Telephony (C.C.I.F.) bases its recommendations on a circuit 2,500 km (1,600 miles) in length, with implied pro rata increases for noise impairment.

76–88 kc which are not compatible with the split group arrangement or with the 84.08 kc end-to-end pilot.

Net Loss

The nominal 1,000-cycle net loss objective between London and New York for calls switched to other long distance trunks at each end (i.e., the via net loss) was set at 0.5 db. For calls terminating at either New York or London, the loss would be increased by switching a 3.5-db pad in London, as recommended by the C.C.I.F., and a 2-db pad at New York as standard in the Bell System. Thus a New York to London call would have a net loss of 6 db.

Variations from these nominal net losses owing to temperature effects, lack of perfect equalization and regulation, etc., are to be expected and a standard deviation of 1.5 db was set as the objective for such variations in the absence of trouble. The allocation of this variation to the various links is shown in Table I.

It is interesting to note that a smaller variation was allocated to the submarine links than to the over-land links. It was believed that the more stable environment on the ocean floor would make it possible to meet the rather small variation assigned to these links.

While these loss variations are consistent with normal long distance trunk objectives, they would not be satisfactory if compandors were found necessary to meet the noise objectives, and it was agreed that any of the links lying between such compandors would have to meet objectives half as large as those in Table I.

Frequency Characteristics

For telephone message circuits, the frequency characteristic recommended by the C.C.I.F., Fig. 3, was adopted with the expectation that it could be bettered by a factor of two, since channel equipments would be included at the circuit terminals only, as described later.

TABLE I — STANDARD DEVIATIONS OF NET LOSS OBJECTIVE

Link	Standard Deviation (db)
New York-Portland	0.75
Portland-Sydney Mines	0.75
Sydney Mines-Clarenville	0.5
Clarenville-Oban	0.5
Oban-London	0.75
Total (Assuming rms addition) New York-London, Montreal-London	1.5

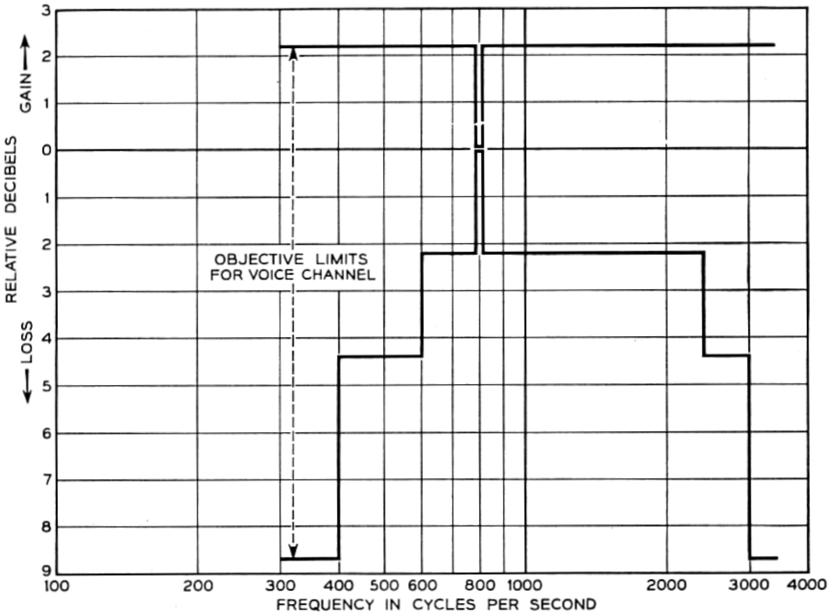

Fig. 3 — C.C.I.F. objectives for frequency characteristic of voice channel.

No specific objectives were agreed upon for the frequency characteristics of the 12-channel groups as such, but there was an expectation that ± 2db could be achieved except for frequencies adjacent to the filters in the split group.

For program channels, the C.C.I.F. recommendations were also adopted in respect of the two-band (6.4 kc) and three-band (10 kc) arrangements. To meet the requirements of these channels and of telegraphy, an overall frequency stability objective of ± 2 cycles was adopted.

Noise and Crosstalk

Noise objectives were established to be reasonably consistent both with Bell System and C.C.I.F.* objectives for circuits of transatlantic length.

The objective for the rms circuit noise at a zero level point in the

* The methods specified by these two bodies for the assessment of circuit noise differ in three respects, the units employed, the frequency weighting employed, and the fraction of the busy hour for which the specified noise may occur. The meters concerned are the Bell System 2B noise meter (F1A weighting network) reading in dba and the C.C.I.F. psophometer (1951 weighting network) reading in millivolts across 600 ohms. The relationship between readings on the two meters is discussed in a later paper and it will suffice here to note that, for white noise dbm (CCIF) = dba (Bell) − 84.

TABLE II — RMS NOISE OBJECTIVES IN BUSY HOUR

Link	Approx. mileage	Noise dba
New York-Sydney Mines / Montreal-Sydney Mines	1,000	31
Sydney Mines-Clarenville	400	28
Clarenville-Oban	2,000	36
Oban-London	500	28
Total: New York-London / Montreal-London		38

busy hour was agreed as 38 dba (i.e. −46 dbm or 3.9 mv). This was allocated between the various links as in Table II.

For the program channels, the agreed noise objective was −50 dbm as measured on a C.C.I.F. psophometer with a 1951 program weighting network.

Statistical data on probable speech levels and distributions at London and New York terminals were provided as a basis for repeater loading studies.

Early planning studies indicated that these objectives would probably be met on all, or nearly all channels without resort to compandors. If, as the system aged, the noise increased owing to increasing misalignment, the use of compandors would offer a means for reducing message circuit noise below the objectives.

The minumum equal-level crosstalk loss between any two telephone channels was set at 56 db for any source of potentially intelligible crosstalk. For channels used for VF telegraph, the equal-level crosstalk loss between go and return directions was set as a minimum of 40 db; for all program channels the minimum crosstalk attenuation would be 55 db.

Restrictions of Telegraph and Other Services

Since the system was being designed primarily for message telephone service, it was agreed that a channel used for any other service should not contribute more to the system rms or peak load than if this channel were used for message telephone, except by prior agreement between Post Office, Bell System and Canadian Overseas Telecommunication Corporation engineering representatives.

Signalling Objectives

In order to conserve frequency space, it was decided to transmit all calling and supervisory signals within the telephone channel bands and, to avoid transmission degradation, it was agreed that the signaling power and duration would not amount to more than 9 milliwatt-seconds in the busy hour at a zero level point; this would not contribute unduly to the loading of the system.

It was agreed that, for initial operation, ringdown signaling would be employed, but the system design should be such as to permit the use of dialing at a later date.

Echo Suppressors

Echo control was considered essential, since the via net loss of the transatlantic circuits would be only 0.5 db, with a one-way transmission time of 35 milliseconds. Echo suppressors would be provided initially at New York and Montreal only, and arrangements made in London to cut out such suppressors as may be fitted there on Continental circuits, when these are used for extension of the transatlantic circuits. It was recognized, however, that other suppressors might be encountered in the more remote parts of Continental and United States extensions. The general problem of how best to arrange and operate echo suppressors on very long switched connections is one which remains for consideration later.

Maintenance and Operating Services

Telephone Speaker and Telegraph Printer Circuits

The need for telephone and telegraph circuits for maintenance and administration was recognized, and it was agreed to provide the following circuits on the submarine links at frequencies immediately outside the main transmission bands where inferior and somewhat uncertain characteristics might be expected (Fig. 4):

(a) A 4-kc band, possibly sub-standard in regard to noise, equipped with band splitting equipment (EB Banks) to provide two half-bandwidth telephone (speaker) circuits, and

(b) two frequency-modulated telegraph (printer) circuits.

These circuits would be extended over the land circuits to the terminal stations by standard arrangements as needed and would be used to provide the following facilities:

(I) An omnibus speaker circuit connecting the principal stations on the route, including Montreal.

(II) A speaker circuit for point-to-point communication between the principal stations — i.e., non-continuous.

(III) A direct printer circuit between London and White Plains.

(IV) An omnibus printer circuit as (I) above.

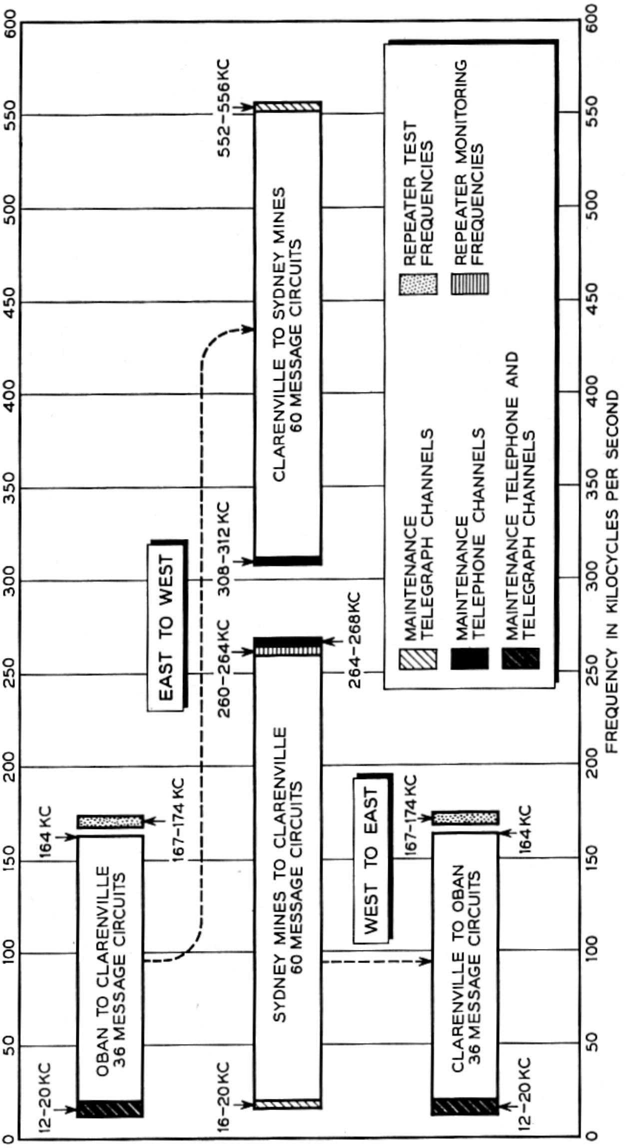

Fig. 4 — Frequency allocations in submarine cable links.

Repeater Test Frequencies

In each submarine cable link, test frequency bands were required for monitoring repeater performance; and these are indicated in Fig. 4.

Pilot Frequencies

It was agreed to provide pilot facilities throughout the route for line-up maintenance and regulation purposes. In addition to the usual pilots on the inland networks, there would be provided:

(a) a 92-kc pilot in each 12-channel group, continuous only in a particular section of the route and fitted with a recording voltmeter at the receiving end of that section, and

(b) an 84.08-kc overall pilot in each 12-channel group as recommended by the C.C.I.F. This would transmit continuously over the entire route and would be monitored and recorded at every main station.

Connections between Component Links

At the time that the objectives were being established, a far-reaching decision was made to employ channel equipment at London, New York, and Montreal only, and to adopt the frequency band 60–108 kc as the standard frequency for connecting the various parts of the over-all system. By adopting this band as standard for the transatlantic system, it also became possible to interconnect readily with land systems at each end.

This agreement also facilitated decisions on responsibility for design and manufacture of equipment. For example, it became logical to define each submarine system as the equipment between points where the 60–108-kc band appeared, i.e., the group connecting frames. Thus, these systems would include not only the cable, repeaters, and power supplies, but also the terminal gear to translate between 60–108 kc and line frequency of the submarine system. It also became logical to assign responsibility for manufacture of all of this equipment to the administration responsible for the specific system design, i.e., responsibility for the Oban-Clarenville link to the Bell System and the Clarenville-Sydney Mines link to the Post Office.

THE REALIZATION OF THE SYSTEM

With decisions reached on the system objectives and interconnecting arrangements, it became possible to lay out jointly a detailed over-all plan and for each administration to proceed with developing and engineering the links under its jurisdiction.

There was an understanding that there should be no deliberate attempt to make the characteristics of one link compensate for those of another, and so it would be incumbent on the administrations to produce the best possible group characteristic on each link.

The overall plan for the system, as finally developed, is shown in Fig. 2. Except for the necessity to split one of the three transatlantic groups in each direction to provide 6½ circuits to Montreal and 5½ to New York, which required specially designed crystal filters, no unusual circuit facilities were required.

Special equipment arrangements were called for at Sydney Mines and Clarenville to provide security for the Montreal-London circuits where they appeared in the same office with White Plains-London circuits. In these cases, a special locked room was constructed to house the equipment associated with the channel group containing the Canadian circuits.

The details of how the two all-important submarine cable links were designed and engineered to meet their individual objectives are given in companion papers. The efficiency and integrity of these two links are the highest that could be devised by engineers on both sides of the Atlantic.

Finally, each section of the connecting links was lined-up and tested individually before bringing them all together as an integrated system.

OVER-ALL PERFORMANCE OF THE SYSTEM

The system went into service on September 25, 1956, so soon after completion of some of the links that it was not possible to include all the final equalizers. Nevertheless, after completion of the initial overall line-up, the performance has been found to meet very closely the original objectives. The system went into service without the use of compandors on any of the telephone circuits, but compandors are included in the program equipment. At the time of writing, only the 2-channel program equipment is available for use.

Frequency Characteristics of 12-channel groups

Fig. 5 shows the frequency characteristic of one of the 12-channel groups, link by link and over-all, measured at group frequencies corresponding to 1,000 cycles on each channel. In both of the complete London-New York groups the deviation from flat transmission is within ±1.5 db, and some further improvement is to be expected when the equalization is finalized. For the split group, the characteristics are similar except for the effect of the splitting filters.

Variation of Over-all Transmission Loss

The system has, of course, only been completed for a short time, but the indications so far are that the standard deviation of the transmission loss, as indicated by the 84.08-kc group pilots is well within the objective of 1.5 db. Alarms operate when the received pilot level deviates by ±4 db and, so far, these alarms have not operated under working conditions.

Frequency Characteristics of Telephone Circuits

Fig. 6 shows the measured frequency characteristic of a typical circuit in the two directions of transmission as measured in the through and terminated conditions. Half the C.C.I.F. limits are met on most circuits.

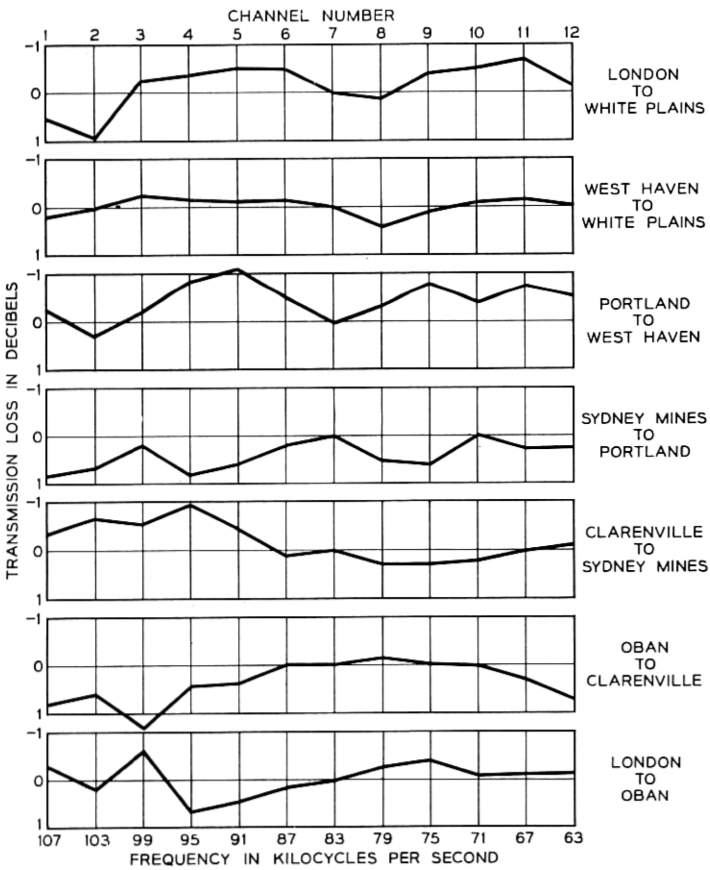

Fig. 5 — Frequency characteristic of typical London-New York channel group. (Measured at group frequencies corresponding to 1,000 cycles.)

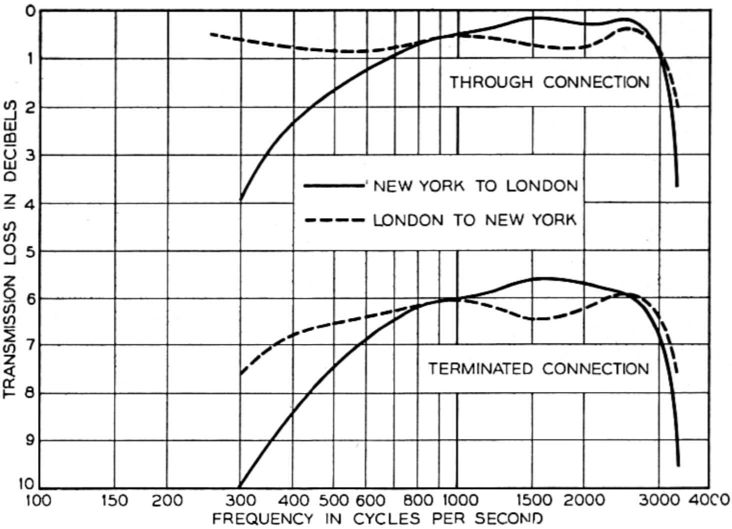

Fig. 6 — Frequency characteristic of typical telephone circuit.

Circuit Noise

The circuit noise, referred to a zero level point is as follows:

London-New York	Best 30 dba;	worst 36 dba
New York-London	Best 29 dba;	worst 41 dba
London-Montreal	Best 30 dba;	worst 33 dba
Montreal-London	Best 30 dba;	worst 31 dba

Two circuits at present exceed the objective of 38 dba in the New York-London direction only; the higher noise levels refer to the high frequency channels in the Oban-Clarenville cable. After additional data on the effect of cable temperature variations are accumulated, refinements will be made in the equalization and adjustment of levels on the Oban-Clarenville link. It is expected that the two worst channels can then be made to meet the objectives — still without the use of compandors.

Frequency Characteristics of Program Channels

Fig. 7 shows the measured frequency characteristic of a London-New York program channel; this is typical.

Telegraph Channels London-Montreal

In the Agreement it was envisaged that at least six 50-baud telegraph channels could be provided in each direction in the Canadian half circuit. In fact, eleven such channels have been provided using carriers spaced

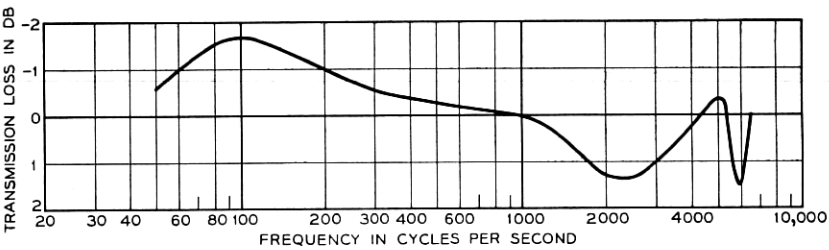

Fig. 7 — Frequency characteristic of typical program channel, London-New York.

at 120 cycles and frequency modulation. The telegraph distortion due to the cable system with start stop signals is about 4 per cent in every case, thus making the circuits suitable for switched connections, without regeneration, up to the same limits as inland systems.

Tests over the system indicate that the channel speed can be raised satisfactorily to 80 bauds on at least ten of the channels. By the adoption of synchronous working, it appears that time division multiplex systems can be operated on these ten channels to double their capacity at a later date.

CONCLUSION

The transatlantic cable system has presented unique problems in system planning and design. It has been necessary to design the system to connect the facilities of many countries and to provide for cable communication of unprecedented length. But the stringent design objectives necessary to meet these requirements have not been the only challenge to the designer. It has been necessary to meet these objectives with a system which for over 2,000 miles of its length could not be altered to the slightest extent once it had been placed on the ocean bottom. Except for the adjustments which can be made at the shore terminals of the submarine links it has not been permissible to make any of the multitude of small design changes, substitutions and adaptations which are so commonly required in new systems to achieve the design objectives.

The success achieved in meeting the original objectives is a measure of the realism of the early planning as well as the diligence with which the project was carried forward to completion and is a tribute to all who took part in planning, designing and building the system.

The accomplishment of getting into commercial service a working system with many complex links six weeks after the final splice was dropped overboard, and nearly ten weeks ahead of schedule, is a further tribute to the close cooperation of the technical people of three nations.