The Toronto-Barrie Toll Cable *

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General

DURING 1937 a 60-mile toll cable was completed between Toronto and Barrie which, in several respects, is unique. Among the interesting features in the design and construction of this toll cable were the use of non-quadded exchange cable and loading, a 60-mile repeater spacing, planning for future carrier operation, and extended pole spacings.

Prior to the installation of this toll cable, the territory to the north and northwest of Toronto was served by three open-wire pole lines. Figure 1 shows these lines and the territory served by them. The Toronto-Owen Sound lead entering Toronto through a 7-mile entrance cable was poorly located in towns and on highways, and was paralleled by power lines which caused considerable noise on the longer circuits. The Toronto-Collingwood and Toronto-Barrie lines, which were common for some distance north of Toronto on a 6- and 5-arm lead, entered Toronto through an 11-mile entrance cable which had been in place about four years, and contained a number of spare conductors due to its having been designed for two additional lines.

It was realized that, if open wire were to be continued, circuit growth would require a new line arranged for carrier operation and a general rebuilding, rerouting and retransposing for carrier operation of the existing lines. In addition, carrier operation would necessitate expensive carrier loading of the entrance cables at Toronto, and the length of these entrance cables would limit the length of the carrier circuits for operation without intermediate repeater stations.

Studies Prior to Construction

With large expenditures foreseen for the continuance of open wire, it was only natural that a study should be made of the possibility of the use of a toll cable on a basic route and the use of as much as possible of the existing lines as feeders to the cable. Cost studies on an annual charge basis for a twenty-year period of open wire with superimposed 3-channel carrier systems, and for a 2-wire 19-gauge quadded cable

* The unusual solution of a difficult toll cable problem which is described in this paper will be of interest because of its novelty rather than because of any expected general application of this type of construction to toll cable routes.

with H88-50 loading with open wire or cable feeders, depending on the length and numbers of feeder circuits, indicated the cable plan to be best. In addition to the indicated money savings of the cable plan over the period of the cost studies, other indicated advantages in the toll cable plan were improved service continuity (the southerly section of the territory under study is one of heavy sleet conditions) and reduced noise from power induction.

The quadded cable plan, however, had one disadvantage in that it required a repeater station approximately 45 miles north of Toronto, in a territory remote from any town or village with unfavorable living conditions and subject to isolation during winter snow storms. The nearest feasible location to the ideal, at Cookstown, involved such an increase in length of cable and added expenditure that the cost advantage changed to the open-wire plan. Also, the use of B88-50 loading with a repeater spacing of 50 miles appeared to offer no advantage in that the additional cost of loading became an important factor.

These difficulties in the use of the standardized type of toll cable led to a review of the possibility of employing some combination of conductor and loading which would permit a 60-mile repeater spacing, thus eliminating any need for an intermediate repeater station between Toronto and Barrie. If such a cable were to have the same unit attenuation as 19-gauge H88-50 cable, then it must have considerably improved crosstalk and return loss characteristics. On the other hand, if a cable could be obtained with crosstalk and return loss characteristics about equal to that of 19H88-50 cable, it must have an attenuation of about ¾ that of 19H88-50 cable.

Of the standard types of cable and loading, 19-gauge non-quadded exchange cable having a capacity of about 0.083 mf. per mile with B-135 loading appeared to have an attenuation of about the value required to meet the second of the two requirements noted above. It was estimated that such a cable would have the following transmission characteristics:

1000-cycle attenuation at 68° F.	0.26 db per mile
Passive singing point at repeater exceeded by 72% of circuits	25 db
Maximum crosstalk gain	14 db
Overall active balance [1]	6.0 db
Overall circuit loss 8 db (PO-TC) with 4 db pad at PO.	

These assumed limits required a 72 per cent return loss of 26 db or better at the critical frequency which was expected to be about 2600 cycles, and a 1 per cent maximum near-end crosstalk of 74.5 db. Based

[1] Computed by summation of the 72 per cent singing points at individual repeaters with a 5 db end path.

on these values and limits, and assuming that Toronto would be the only gain switching center directly involved, a study was made of the transmission possibilities for each group of circuits that was expected to be routed through the cable. This study indicated that, provided the return loss and crosstalk values required of the cable by the assumed singing points and crosstalk gain could be met, all circuits could be 2-wire between Toronto and Barrie with some transmission margin and also that this type of cable could be extended at least another 20 miles to Orillia.

A cost study, assuming a 101-pair cable, of this type, indicated that while, due to the additional loading costs of the closer loading spacings, the cable costs were very nearly the same as for a quadded 19-gauge H88-50 cable, the considerably reduced repeater and repeater station costs made this plan appreciably less costly than any open wire plan. The elimination of any intermediate repeater station removed the repeater station difficulties of the quadded cable plans.

As no installation of such a length of this type of cable had been made, some confirmation of the estimated values for the transmission study, and particularly of the return loss and crosstalk, was considered necessary. An 8-mile H-44 loaded 19-gauge exchange cable, which had just been erected near Toronto, was chosen for study. Near-end crosstalk measured on 286 combinations of pairs indicated 99 per cent better than 81 db with an average of 91.7 db which, when modified for impedance and length differences, indicated 99 per cent better than 72.5 db, and an average of 83.2 db for the proposed cable. While these values were somewhat poorer than required, the size of the sample and one or two other factors indicated that the proposed cable could be erected to meet the crosstalk requirements. However, to obtain as much crosstalk margin as possible, arrangements were made for the manufacturer to use 6 lengths of twist, alternating 3 in each layer, rather than the 4 twists which had previously been used for this type of cable. It is felt that the excellent crosstalk results obtained as outlined in more detail later are in large part due to this feature.

Singing measurements on 10 pairs averaged 19.6 db. It was evident from impedance frequency measurements that these singing points could be raised to the desired value of 25 db by some modification in the networks. Accordingly an adjustable precision type network was developed.

Also, four 1500-foot lengths of the proposed type of cable were obtained from the manufacturer and tested for mutual capacitance of pairs and capacitance unbalance between pairs. On statistical analysis, these tests indicated a probable average near-end crosstalk of 79 db and that for return loss 63 per cent of the circuits would be better than 27.0 db or 72 per cent would be better than 26 db at 2600 cycles, provided the following features were incorporated:

(*a*) Manufacture of complete length of cable in one continuous production with reasonably careful control of variables.
(*b*) Capacity equalization splicing at the mid-point of each 3000-foot loading section.
(*c*) Reel lengths be assigned as to location on the basis of average reel length capacity.

On the basis of these preliminary studies, it was decided to proceed with the cable plan, using the B-135 standard 19-gauge exchange cable. Figure 2 shows the plant layout finally adopted for the cable and its feeders.

At the Toronto end it was essential to use pairs in a recently placed 19- and 16-gauge quadded toll entrance cable (mutual capacity .062 mf. per mile) about eleven miles long in order to keep the cost of the cable to a minimum. This appeared feasible, using the same type loading coils as in the main cable, if the loading spacings were extended to provide the same loading section capacity as in the main non-quadded cable, and if the cable were sufficiently well respliced to break up the side-to-side (within-quad) adjacencies so that the crosstalk coupling would be comparable to that obtained in the main (non-quadded) cable.

Route

It was necessary to select the shortest practicable route passing as close as possible to the places to be served (see Fig. 2). The route selected is, for the most part, on a road which lies about midway between the main highways serving the territory north of Toronto. It is expected that the location chosen will be reasonably free from highway changes. Also, for the portion of the route south of Aurora, an existing open wire pole line was suitable for supporting the cable on long span construction.

At one point three miles of swamp covered with bush intervened on the direct route, the avoidance of which meant an increase in expenditure for right-of-way, as well as lengthening of the cable. It was decided to go straight through the swamp, using swamp fixtures, as shown in Fig. 3. An interesting sidelight on securing the route through the swamp was the fact that an original road right-of-way was shown on the map. On searching the records the surveyor found the original survey notes made in 1860 and eventually confirmed the location by finding some old pottery which, according to the records, had been

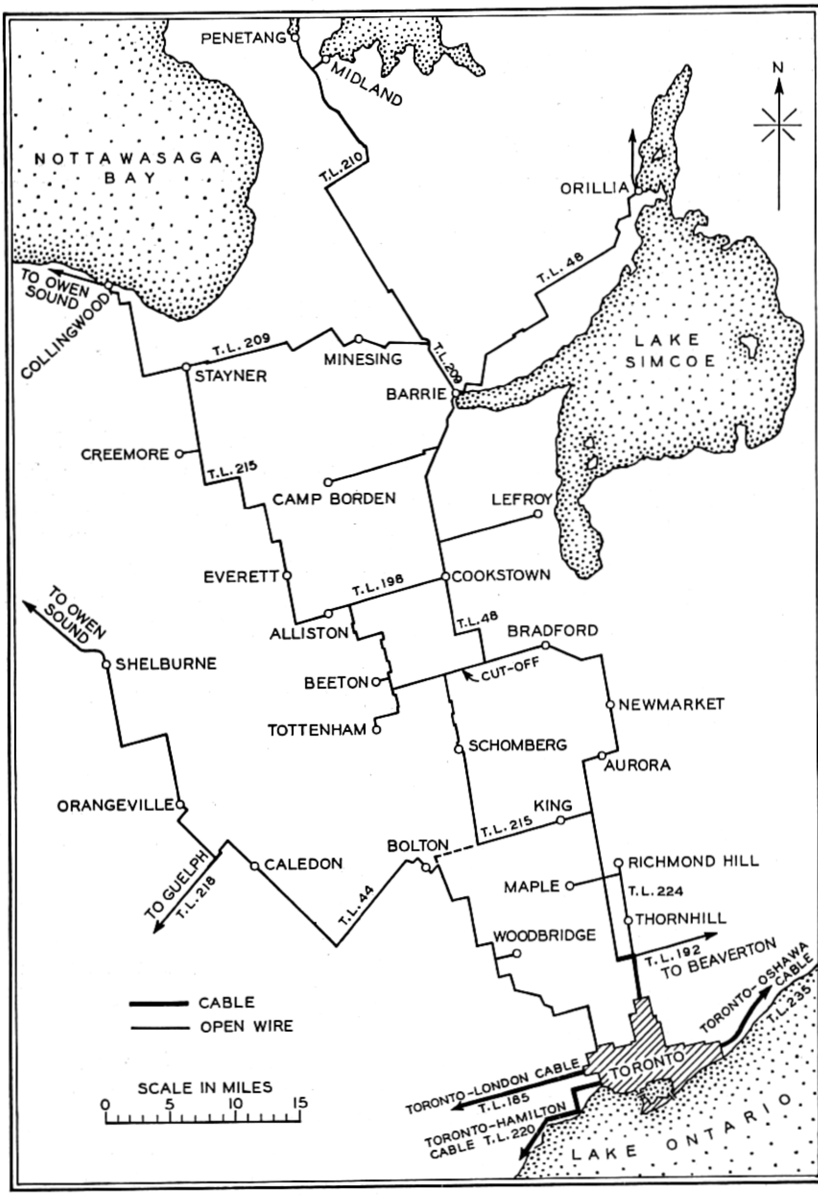

Fig. 1—Toll lines before construction of the Toronto-Barrie cable.

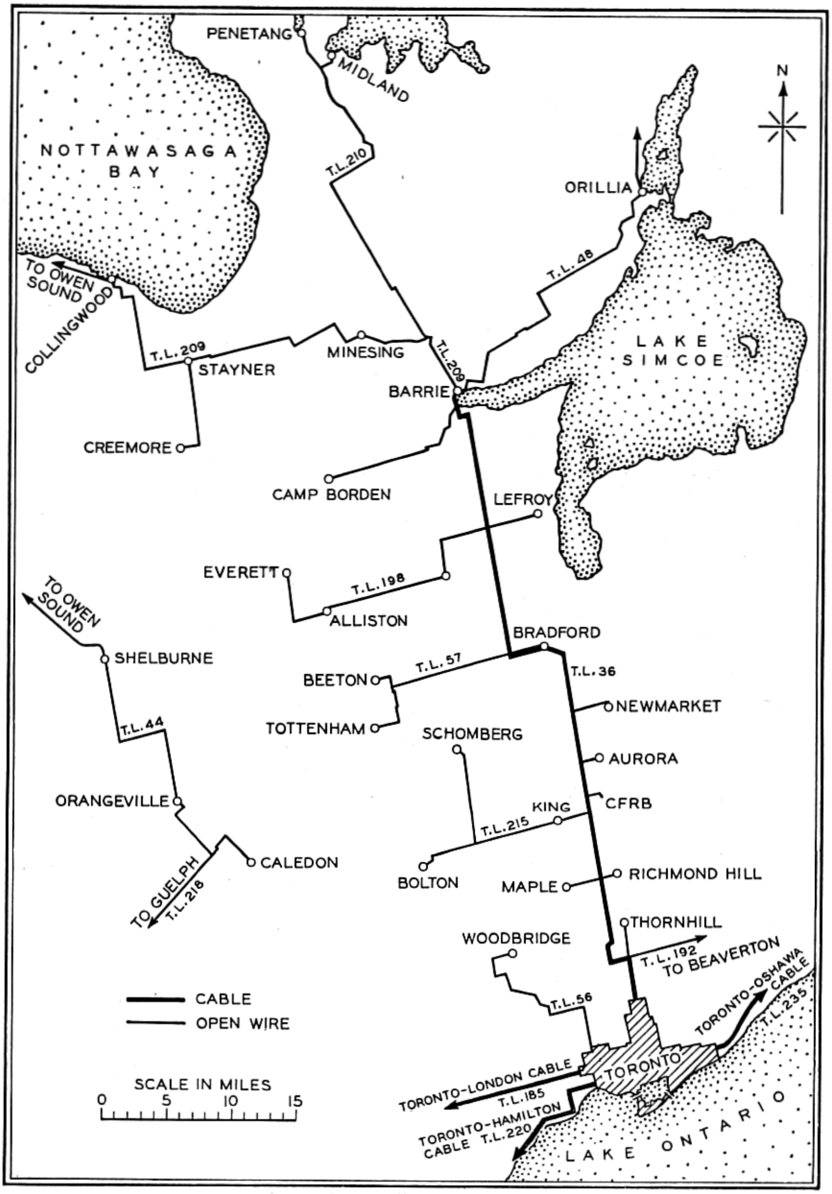

Fig. 2—Toronto-Barrie cable.

Fig. 3—Swamp construction.

buried at the road intersections. During the late summer and the autumn, when the swamp had dried out, a 60-foot right-of-way was cleared. As the soil was still moist and soft, the brush and small trees were uprooted by a tractor, a method of clearing which proved quick and economical. The swamp fixtures were placed before the ground froze, and the cable during the winter.

Pole Line

The cable was erected on the existing pole line between Toronto and Aurora. The size of the cable erected on 10 M. strand permitted the removal of every other pole in the old line, with a resultant 185-foot average spacing. As is shown in Fig. 4, where it was necessary to change an existing pole, a new pole was placed and fastened to the old pole by means of stub reinforcing bands, thus eliminating the expense of transferring the open wire. Upon the release of the open wire by transfer of circuits to the cable, the wire and old poles were removed.

The new section of pole line was erected on a 200-foot spacing, with occasional spans up to 250 feet, as shown in Fig. 5. This increased pole spacing was also expected to reduce ring cutting and bowing.

Construction Details and Tests

At a number of points open wire loops connected directly to the cable. At these junctions there were installed open space protectors having a lower breakdown than the cable pairs, and connected between the open wires and the cable sheath; also a few spans from the junction, 1000-volt protectors were connected between the open wires and driven grounds. This arrangement was more economical than the use of protection cable. The cable has gone through two complete lightning seasons without any failures or even permanent protector operations due to lightning.

In so far as manufacturing and storage facilities permitted, the reel lengths of the cable were assigned to their locations on the basis of obtaining as close an average loading section capacitance to the nominal value of 0.085 mfd per mile as was feasible. All reel lengths for the aerial sections were manufactured 1508 feet long, this length being sufficient to permit the assignment of a reel at any point in the line. Particular care was taken in this respect towards the ends of the cable where departures from the average would have the greatest effect on the return loss. To ensure proper assignment of reels, a route map was made up to scale with the manufacturer's reel number shown in its proper location.

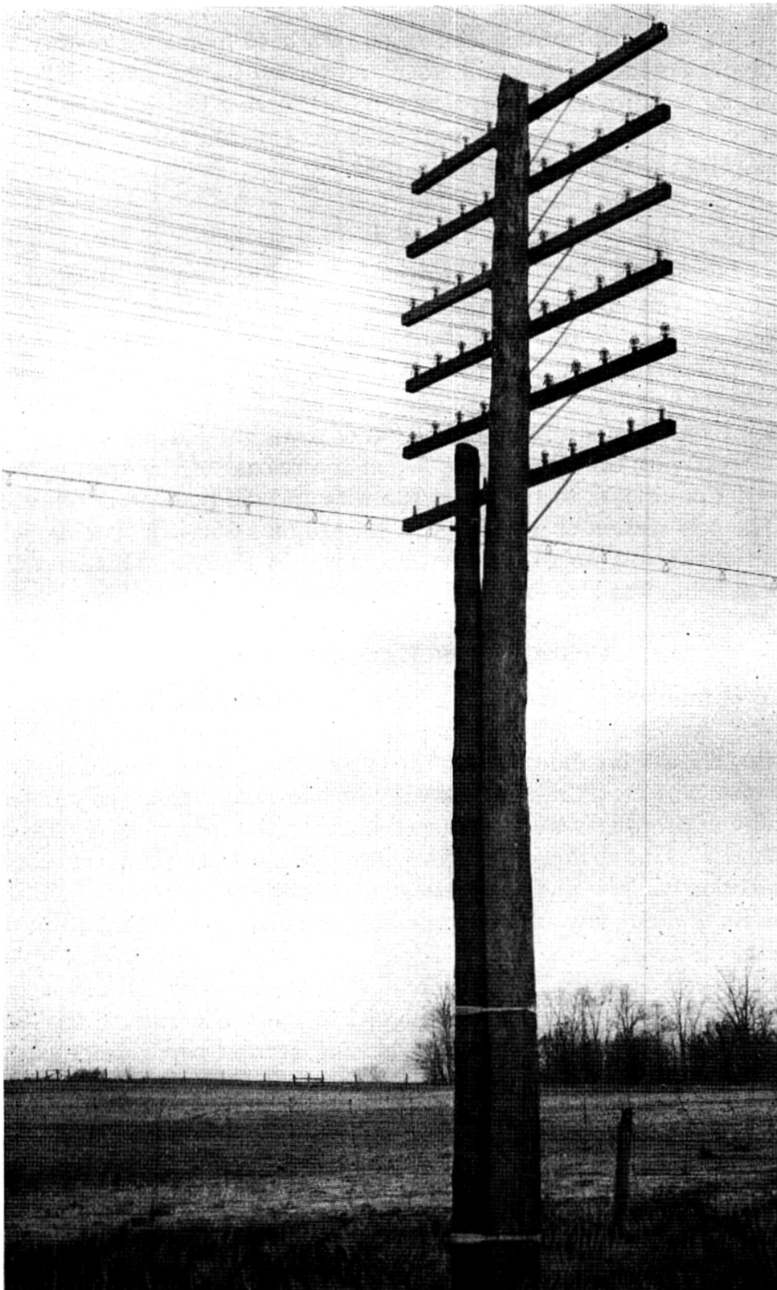

Fig. 4—Replacement of old pole with new creosoted pine pole.

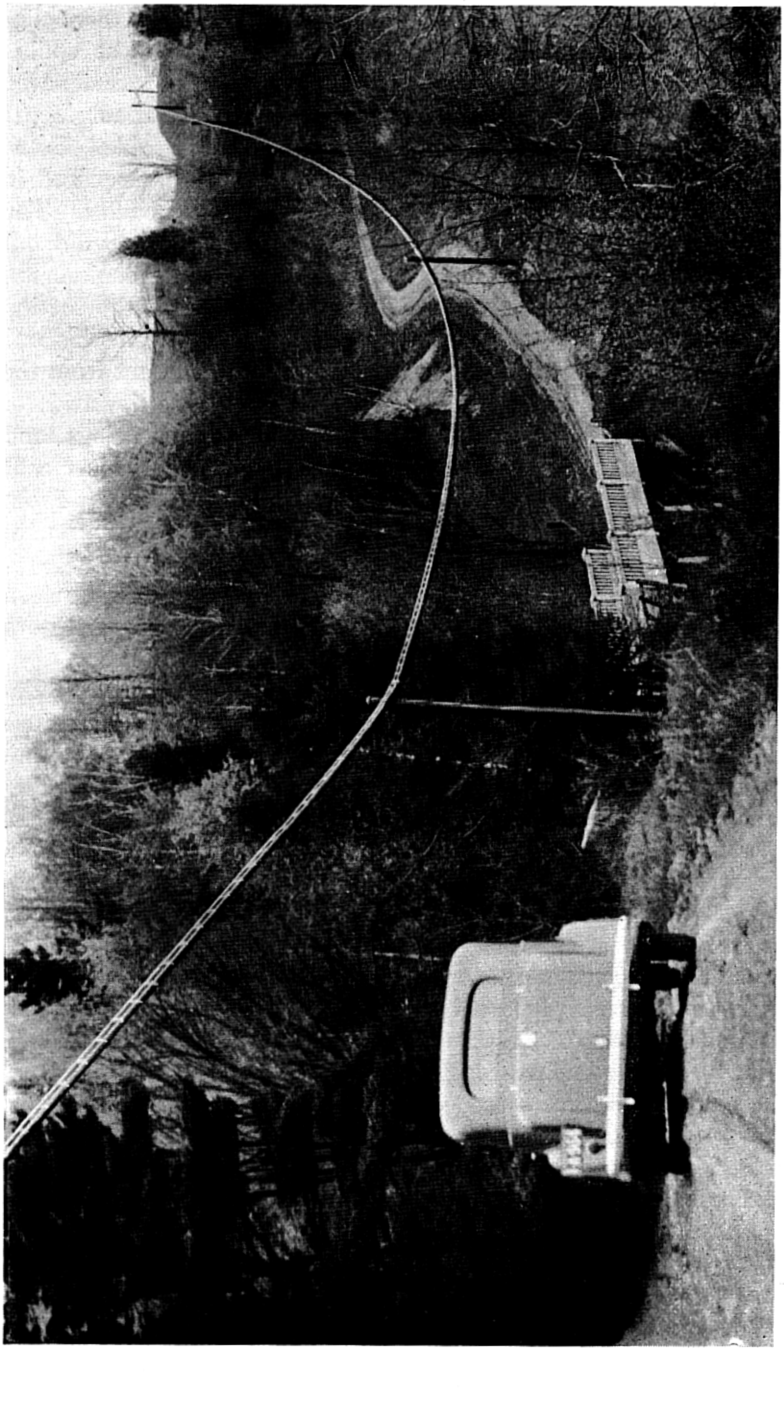

Fig. 5—Long span cable construction.

In addition, at the mid splice of each loading section, a test splice was made to equalize the capacity deviations. For these splices special linen boarding strips were used, each with 40 holes designated by a capacity ranging from about 15 per cent below to about 15 per cent above the expected average capacity of 1500 feet of cable. Small inexpensive capacity meters were used, and each pair was placed in the hole in the boarding strip corresponding to its capacity. The pairs were then spliced high to low capacity. This method did not require special testers, and substantially reduced splicing manhours.

Upon the completion of the splicing in each section, the section capacity of each pair was measured and recorded, and from this was determined the root mean square of the capacity deviations from the average capacity. These deviations combined with the deviation of the loading section average capacitances, loading coil spacings, and loading coil inductances, gave an irregularity function of 2 per cent which is almost identical with that for 19-gauge B88-50 cable. From this irregularity [2] function a 63 per cent return loss frequency curve was obtained, which is shown as curve '*A*' in Fig. 8.

When 15 miles of the cable had been completed south from Barrie, a 100-pair cross-connecting box was temporarily spliced in so that data could be obtained as a further check on the design estimates.

For crosstalk tests each pair was terminated at the box in a 1700 ohm resistance, and measurements were made of all pair combinations (approximately 5000). For these measurements a 15A oscillator and 2A Noise Measuring Sets were used, thereby very materially reducing the manhours required as compared with the labour that would have been required had crosstalk measuring sets been used. Analysis of these tests indicated 99 per cent of combinations better than 76.0 db, an average of 86.6 db and 99.5 per cent meeting the required 74.5 db of the preliminary studies.

For attenuation measurements, the pairs were looped back at the cross-connecting box. In order to obtain a value of the attenuation at a known temperature, a complete set of measurements was made at about 6 o'clock in the morning after the resistance of one of the pairs had been found to have ceased dropping due to temperature change and the outside temperature at the Barrie office had been very nearly constant for about one-half hour. During the time the attenuation measurements were being taken, air temperatures were measured at four places along the 15-mile length of cable. From these tests the average 1000 cycle attenuation at 62° F. was found to be 0.26 db per

[2] See "Irregularities in Loaded Telephone Circuits," George Crisson, *Bell System Technical Journal*, October 1925.

mile. In Fig. 6 is shown the mean of the attenuations of three pairs plotted against frequency. On one pair the measurements were made at frequencies up to 6500 cycles, from which cut-off was determined to take place at 4000 cycles. Assuming a 60-mile circuit, the frequency at which the attenuation is about 10 db greater than 1000 cycles, is about 3500 cycles.

Before the return loss tests were made, impedance-frequency measurements were taken on two of the balancing networks for each of the three adjustments provided, and on a representative number of cable pairs, to determine the optimum network adjustment. The resistance component of the impedance for one of the networks and one cable

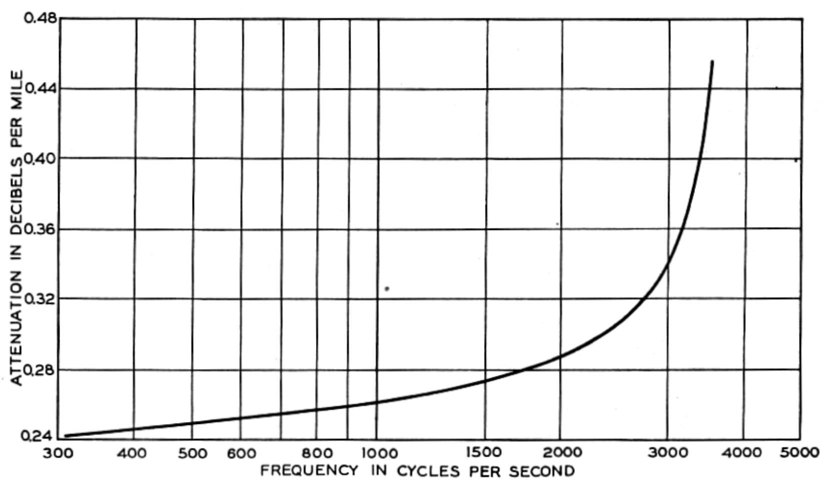

Fig. 6—Attenuation-frequency characteristic; mean of measurements on three pairs.

pair is shown in Fig. 7 (the two networks were found to be identical). From these tests the optimum network adjustment was determined to be that corresponding to a cable capacitance of 0.088 mfd per mile, which adjustment was then used for the return loss measurements.

As it was desired to obtain the singing point to be expected under operating conditions, the return loss measurements were made with the building-out condenser on the return loss set adjusted for optimum return loss at 2600, 2700 and 2800 cycles. The results of these measurements are given in Fig. 8 for comparison with the computed curve '*A*' mentioned previously. The improvement at the higher frequencies of the actual over the computed values is due almost entirely to the method employed in making the tests, and indicates the advantage to be derived from individual adjustment of each circuit.

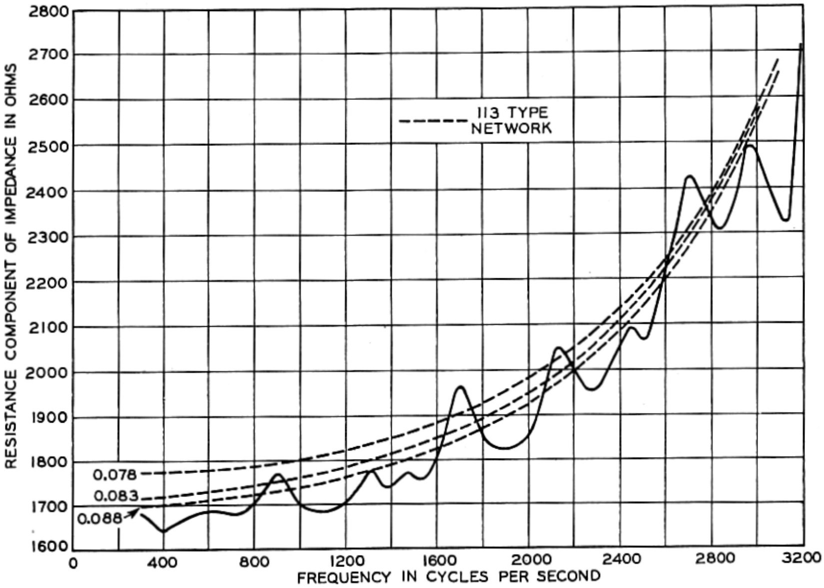

FIG. 7—Resistance component of impedance. 30.8 mile circuit, 19 CNB–B135. Termination, 113 type network.

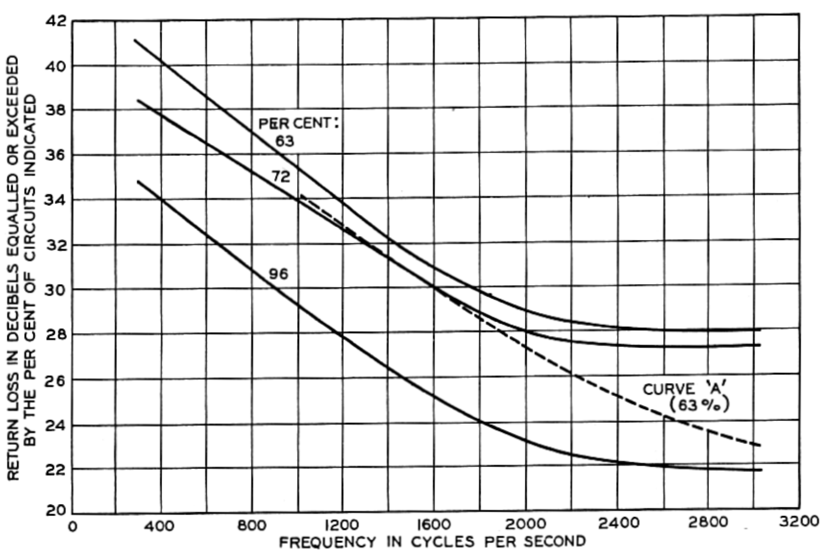

Fig. 8—Return loss—frequency characteristics. Measured on 61 circuits 30.8 miles long. Building-out condenser adjusted on each circuit for optimum return loss in the frequency range 2600, 2700 and 2800 cycles. Curve 'A' is the 63 per cent return loss computed from attenuation and irregularity function measured on cable.

These return loss measurements were made on pairs looped back at the cross-connecting box and terminated at Barrie in one of the networks.

Completion Tests

Upon completion of the cable, further overall tests were made. Particular attention was paid to those tests made from the Toronto end, to determine the effects of the use of the reloaded and respliced toll entrance cable.

Attenuation measurements at 1000-cycles were found to agree closely but, due to the effects of the toll entrance cable at Toronto,

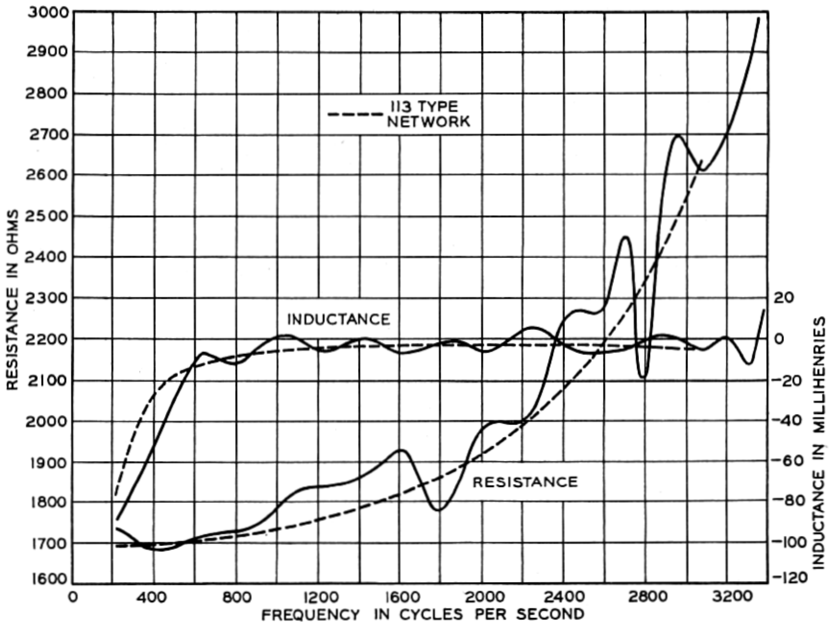

Fig. 9—Impedance measured at Toronto. Termination at Barrie, 113 type network. Sending-end, half section. Makeup from Toronto, 10.8 miles 16-ga., 0.062 mf. per mile, 0.0483 mf., 32.8^{w} per load section; 48.7 miles 19-ga., 0.085 mf. per mile, 0.0483 mf., 48.9^{w} per load section.

not to lend themselves to such rigorous analysis as those previously made.

To show one of the effects of the Toronto toll entrance cable, Figs. 9, 10, and 11, showing the resistance and inductance components of the impedance measured at Toronto, are included. These indicate that the important departure from the network characteristic for these pairs occurs in the inductance component at the lower frequencies. This departure is probably due to the difference in the loading section

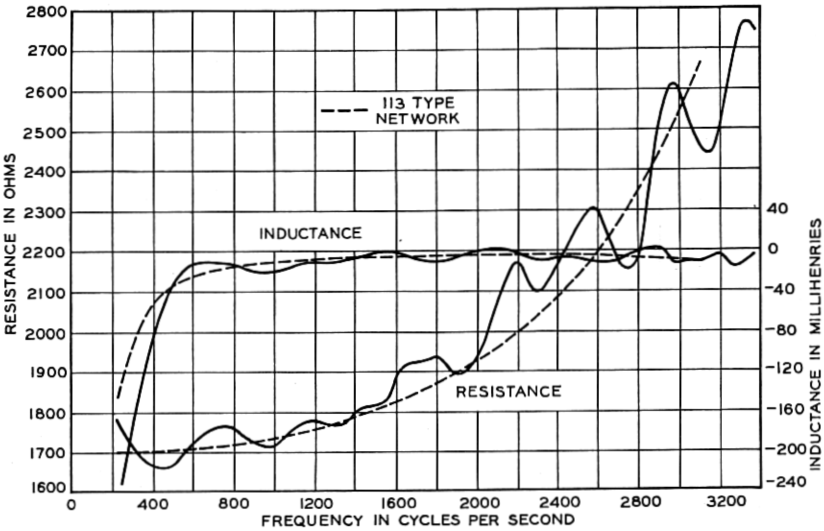

Fig. 10—Impedance measured at Toronto. Termination at Barrie, 113 type network. Sending-end, half section. Makeup from Toronto, 9.5 miles 19-ga., 0.062 mf. per mile, 0.0483 mf., 66.8ʷ per load section; 1.3 miles 16-ga., 0.062 mf. per mile, 0.0483 mf., 32.8ʷ per load section; 48.7 miles 19-ga., 0.085 mf. per mile, 0.0483 mf., 48.9ʷ per load section.

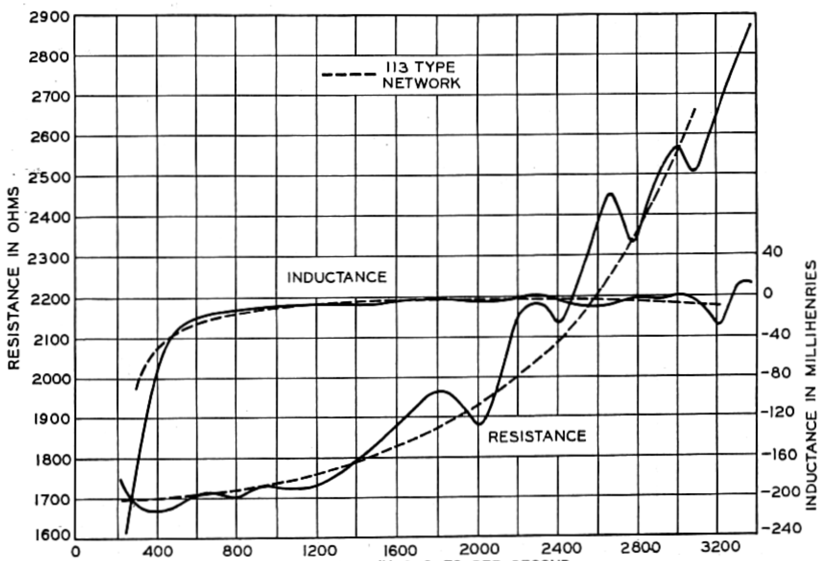

Fig. 11—Impedance measured at Toronto. Termination at Barrie, 113 type network. Sending-end, half section. Makeup from Toronto, 9.5 miles 19-ga., 0.062 mf. per mile, 0.0483 mf., 66.8ʷ per load section; 50.2 miles 19-ga., 0.085 mf. per mile, 0.0483 mf., 48.9ʷ per load section.

resistance from that of the main cable. (The geographical spacing on the quadded 0.062 mf. cable was 4100 feet as compared to 3000 feet on the non-quadded cable.)

Since representative return loss data had already been obtained for circuits under working conditions (Fig. 8), the completion return loss measurements were made for the network building-out capacity conditions assumed for the theoretical return loss characteristic (curve '*A*,' Fig. 8). The results thus obtained are shown in Fig. 12 for Barrie and Fig. 13 for Toronto. In Fig. 12, the theoretical curve is shown for

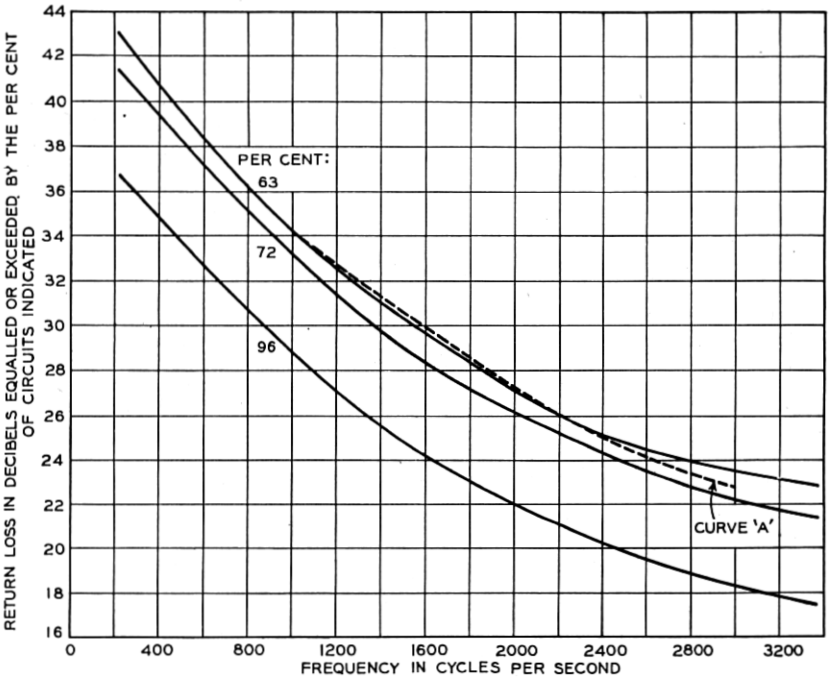

Fig. 12—Return loss—frequency characteristics. Measured from Barrie to Toronto on 53 pairs; building-out condenser adjusted to theoretical value; curve '*A*' is the 63 per cent return loss computed from attenuation and irregularity function measured on cable.

comparison, and it is to be noted that the agreement with actual results is remarkably good. The results obtained at Toronto are better than those at Barrie, except below 600 cycles, which is the frequency range of the impedance departures discussed in connection with Figs. 9, 10, and 11.

Analysis of the near-end crosstalk measurements indicated that at Barrie 98.8 per cent, and at Toronto 96.3 per cent of the combinations were equal to or better than the 74.5 db assumed for the preliminary calculations. Investigation of the combinations poorer than 74.5 db indicated that most of the pairs involved could be assigned either to non-repeatered short circuits or to repeatered short circuits on which the repeater gains were considerably lower, with consequent lower crosstalk gains, than on the full length circuits assumed for the limit of 74.5 db crosstalk. This required the opening of one splice near Toronto for pair rearrangement.

It was decided to place the cable under permanent gas pressure in order to control service interruption as far as practicable. As there was no previous experience available for cables of this size, an investiga-

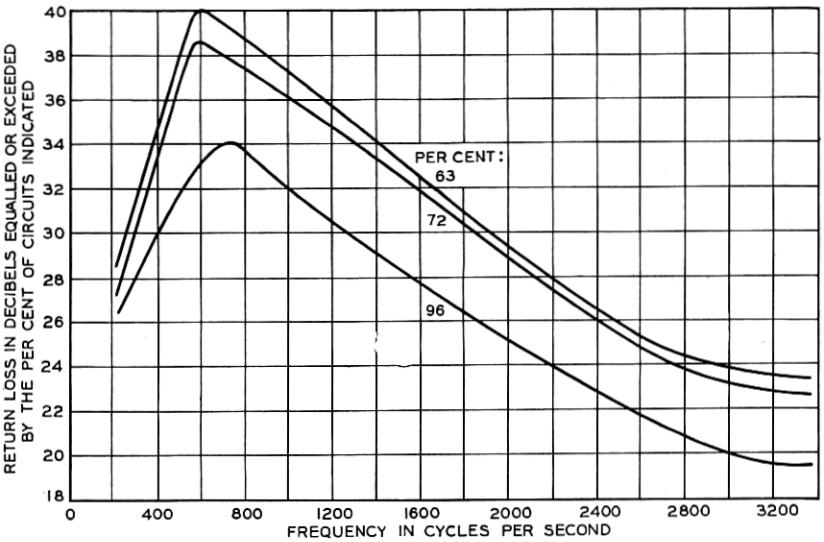

Fig. 13—Return loss—frequency characteristics; measured from Toronto to Barrie on 87 pairs; building-out condenser adjusted to theoretical value.

tion on the job was undertaken to obtain the information necessary for successful application of the gas pressure installation. Based on the results obtained, the installation of gas pressure was completed satisfactorily.

Acknowledgment

The design and installation of this cable represent the coordinated efforts of many people—members of the organizations of the Bell Telephone Laboratories Inc., the American Telephone & Telegraph Company, Northern Electric Company, Western Electric Company and the Bell Telephone Company of Canada—too many for anyone to be specifically mentioned. To all of these credit is due and is here given.