Interstitial Channels for Doubling TD-2 Radio System Capacity

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The TD-2 microwave radio relay system at the present time provides six broadband channels in each direction of transmission in the frequency band between 3700 and 4200 mc, each channel being capable of transmitting several hundred voice circuits. This paper describes arrangements and some of the technical problems involved whereby the number of broadband channels can be doubled with no significant penalty to the existing channels.

I. USE AND GROWTH OF TD-2 SYSTEMS

TD-2 routes were installed at a rapid rate after the first TD-2 system[1] was placed in service between New York and Chicago in September 1950. During the following eight years there was a large demand for additional intercity television, message and private line circuits to meet the expanding business requirements. Because the TD-2 system gives excellent transmission performance and also has economic advantages over other systems, especially where new routes are needed, a large part of the additional Bell System intercity facilities provided during the eight-year period consisted of TD-2 channels.

Long video network circuits were obtained almost entirely from TD-2 channels, and side connections to the backbone video networks were usually TD-2 facilities. These channels were also widely used to obtain intercity voice and private line circuits. By using the type L carrier terminal equipment, up to 600 voice circuits were assigned to one TD-2 radio channel. This technique uses baseband frequencies only up to about 3 mc for the 600 voice circuits, although the baseband capability of the TD-2 channel is considerably higher. It was found, however, that, when the TD-2 channel was loaded with more than 600 voice circuits, the noise and intermodulation distortion on the voice circuits were often too high to meet circuit objectives.

By the end of 1958 a microwave network had been established which connected together most of the large cities in the United States and Canada, as shown in Fig. 1. This network was comprised of over 30,000

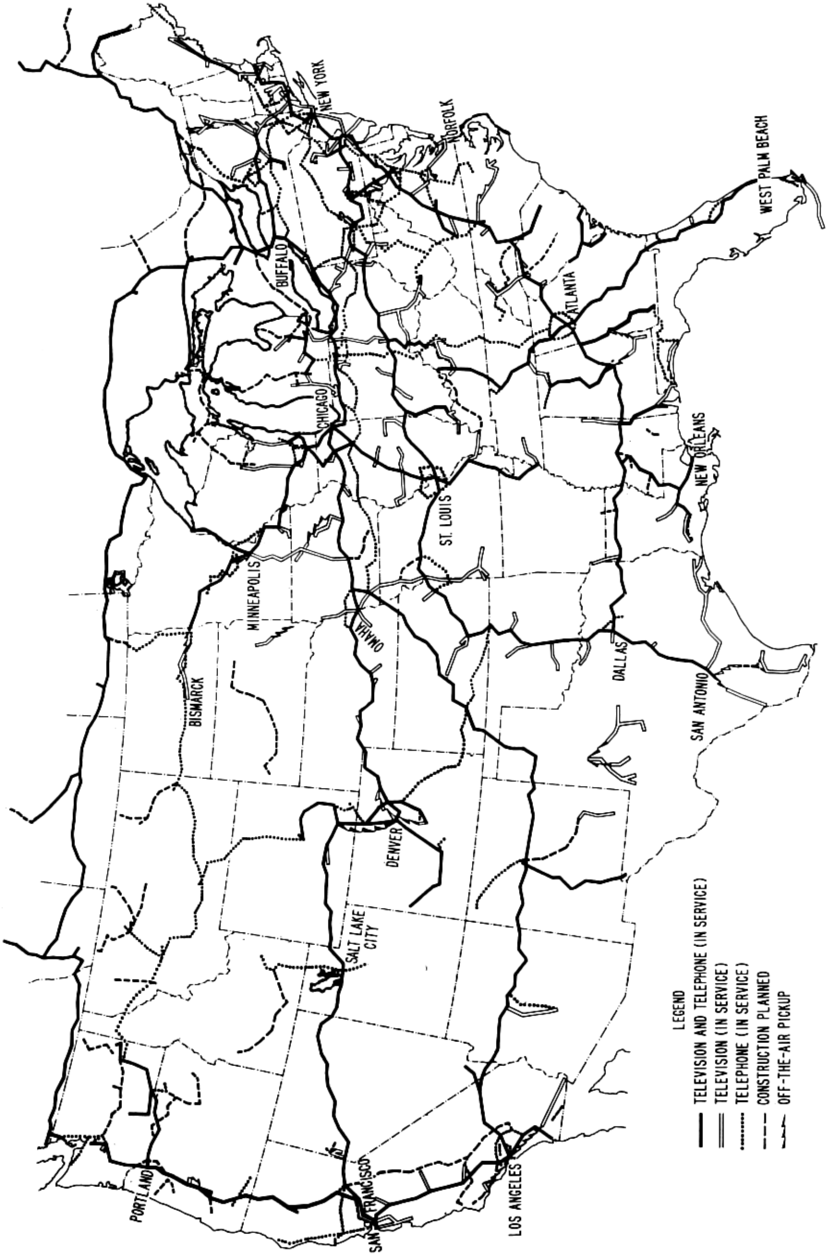

Fig. 1— TD-2 routes in 1958.

TD-2 route miles between some 1300 individual stations scattered throughout the country. These routes provided about 67,000 miles of intercity television circuits and about 20,000,000 telephone circuit miles. The TD-2 radio channels installed over the approximately eight-year period comprised about 80 per cent of all intercity video and about 35 per cent of all long distance telephone circuit mileage in the Bell System plant.

II. NEED FOR ADDITIONAL TD-2 CHANNELS

Before 1958 many of the existing backbone routes had all six channels in at least one direction of transmission either in service or planned for service; it was becoming increasingly apparent that six radio channels would not be adequate to take care of the wideband channel needs, and that construction of parallel backbone routes would be necessary.

Television requirements for circuits resulted in some routes having more channels in service in one direction of transmission than in the other direction. These unbalanced requirements, together with other needs for two-way circuits, resulted in a number of routes reaching their capacities in at least one direction of transmission.

Additional TD-2 channels could be obtained in some circumstances by constructing new TD-2 routes, and this was done where practicable. Such new routes required new radio towers and buildings to house the equipment and power plants. This was expensive, particularly where the geographical length of the routes had to be increased in order to avoid interference to existing routes.

Other radio systems which would use frequencies in other common carrier bands and give high-quality circuits meeting long distance transmission requirements were not yet available. The new TH microwave system is expected to be available for service about the end of 1960, and each individual TH broadband channel will provide about three times the circuit capacity of a TD-2 channel.[2] The TH channels will usually be installed along routes where their high telephone circuit capacity is needed and where higher costs per radio channel will be justified.

The possibility of adding interstitial channels between the regular TD-2 channels had been considered, in view of the unused 20-mc interstitial frequency space available between channels, but a study revealed that it was not practicable with the delay lens antenna and associated rectangular waveguide system.[3] Starting in 1955, the horn-reflector antenna with the associated circular waveguide system became standard for all new installations, and it then became possible to cross-polarize signals between adjacent TD-2 channels to obtain additional discrimination between adjacent channel signals.[4] By the beginning of 1958 the necessity of providing more circuits along fully loaded TD-2 routes resulted in the investigation of the feasibility of adding interstitial channels on TD-2 routes.

III. DESCRIPTION OF TD-2 SYSTEM

The TD-2 system has been described extensively in the literature, but, for the purpose of the present paper, certain features will be reviewed briefly.[5] Each baseband channel has a frequency capacity extending from about 30 cycles to 6 to 10 megacycles per second depending on the length of the system. Frequency modulation is employed to raise each channel to an intermediate frequency of 70 mc, from which each is shifted to its proper location in the microwave frequency spectrum. The frequency plan for a typical repeater point is shown in Fig. 2.

Channels are so assigned that there is always a spacing of 40 mc between the carrier of any transmitter operating in a given direction and

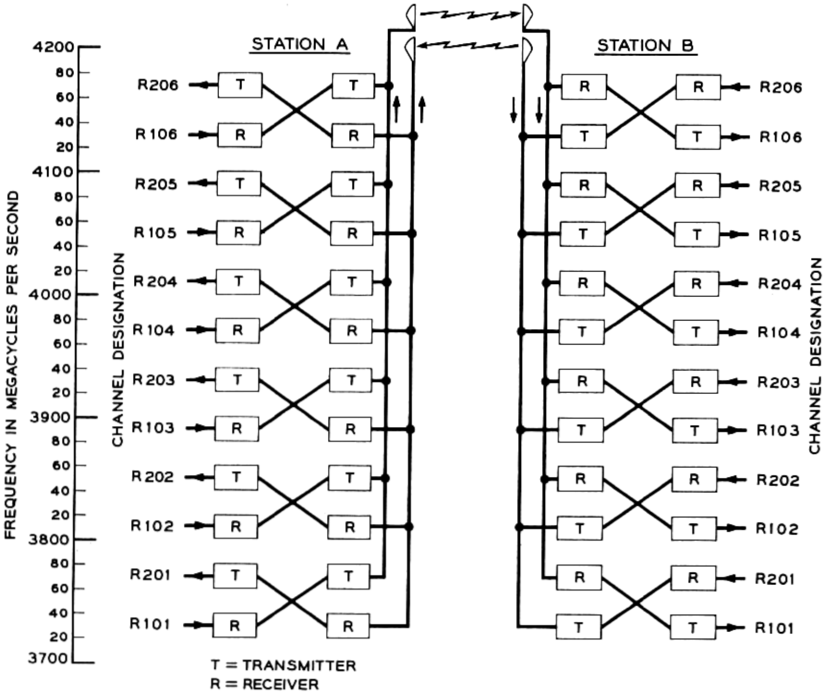

Fig. 2 — Frequency plan for six channels.

the carrier of the nearest receiver operating in the same direction. Since each FM channel potentially occupies a total band of 20 mc, there is a total of six interstitial bands of 20 mc each in each direction in which no significant quantity of energy is present.

Successful operation of the TD-2 system requires freedom from interference between microwave channels under all reasonable conditions. The potential interference which does exist arises from radio-frequency coupling paths. These couplings may, for convenience, be separated into two types. The first, which is called near-end, is due to high-level energy radiated from one antenna on a tower falling into receivers connected to the receiving antenna on the same tower. In the frequency plan shown in Fig. 2, the significant interferences of this type are 40 mc removed from the center of the band of the disturbed channel. The effect of this RF interference is minimized by

(a) the transmission loss between the two antennas,

(b) the selectivity of the RF channel-dropping filters and image-suppression filters,

(c) the discrimination of the IF amplifiers.

The net loss, including antenna gains between horn-reflector antennas side by side and pointed in the same direction, is in excess of 95 db in the absence of foreground reflections. However, measurements at a large number of locations show that the effect of foreground reflections is to distribute the loss over a wide range of values. Fig. 3 shows a cumulative probability distribution curve of 97 measurements of side-to-side coupling loss between horn-reflector antennas. Even the poorest value shown, 61 db, is adequate for six-channel operation. The RF filters offer about 16 db of loss at frequencies 40 mc removed from the center of the channel band. The main IF amplifier, however, provides about 60 db of discrimination at 30 mc and 110 mc relative to 70 mc.

Since the normal transmitting power as measured at the input to the transmitting waveguide is approximately 0.5 watt, or +27 dbm, and the received carrier power at the converter during nonfading conditions is −35 dbm for the average path, the level difference between these two points on the same tower is 62 db. However, the sum of the above enumerated losses, together with those in the IF preamplifier, the transmitter modulator and the first stage of the transmitting RF amplifier, insures complete freedom from near-end interference between microwave channels under all normal conditions.

The second type of RF interference, called far-end, is the result of energy intended for one receiver at a particular point falling into another receiver at the same point. In this case the nearest disturbing channel

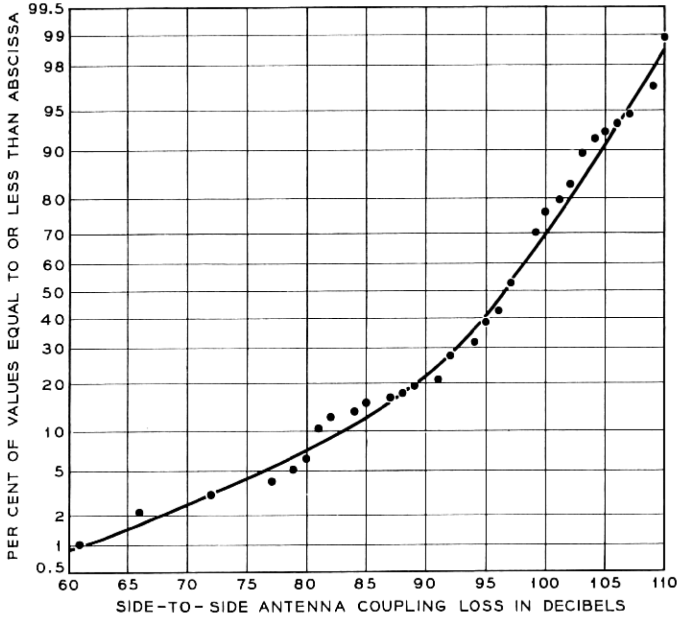

Fig. 3 — Side-to-side antenna coupling loss.

is 80 mc removed from the center of any particular disturbed channel. For example, at Station B in Fig. 2 the carrier from Station A at 4090 mc may, potentially at least, interfere with the similarly directed channels at 4170 mc and 4010 mc. Radio-frequency filters are used which provide about 50 db of loss to frequencies 80 mc removed from the channel operating frequency; here again the sum of all the circuit losses at side frequencies is sufficient to insure freedom from far-end interference.

IV. INTERSTITIAL CHANNELS

Six additional two-way microwave channels may be derived by utilizing the interstitial bands mentioned above. A frequency plan for such operation is shown in Fig. 4, in which the six additional channels are shown as dotted lines. It will be noted that here adjacent receiving channels are only 20 mc apart and, furthermore, the minimum difference in frequency between transmitters and receivers on the same tower is also 20 mc.

Inasmuch as the total discrimination of the repeater to frequencies 20 mc from midband is not great, supplementary means had to be found

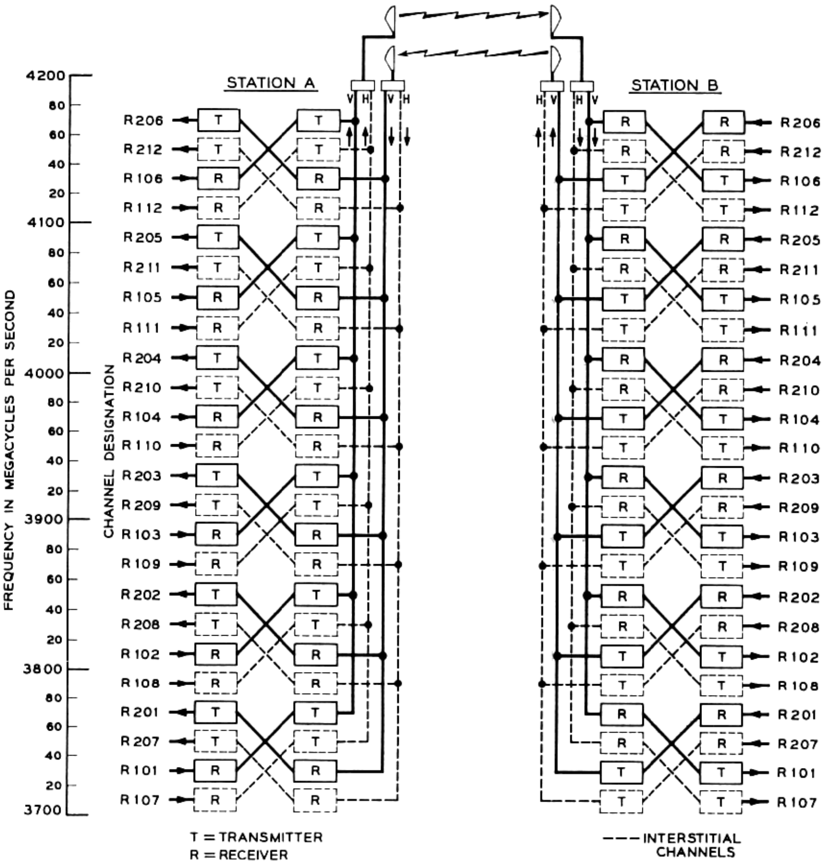

Fig. 4 — Frequency plan for 12 channels.

for improving the discrimination between such closely spaced channels. For far-end interference between similarly directed channels only 20 mc apart, additional discrimination may be obtained by transmitting one set of six channels with vertical polarization and the other set of six channels with horizontal polarization, as shown symbolically in Fig. 4. The two sets of oppositely polarized channels are separated at the receiving waveguide by means of a suitable network.

It is essential that during fading the amplitude of the vertical component of any particular horizontally polarized carrier shall not become excessive relative to the amplitude of the vertically polarized carrier located 20 mc away, and vice versa. Cross-polarization during fading

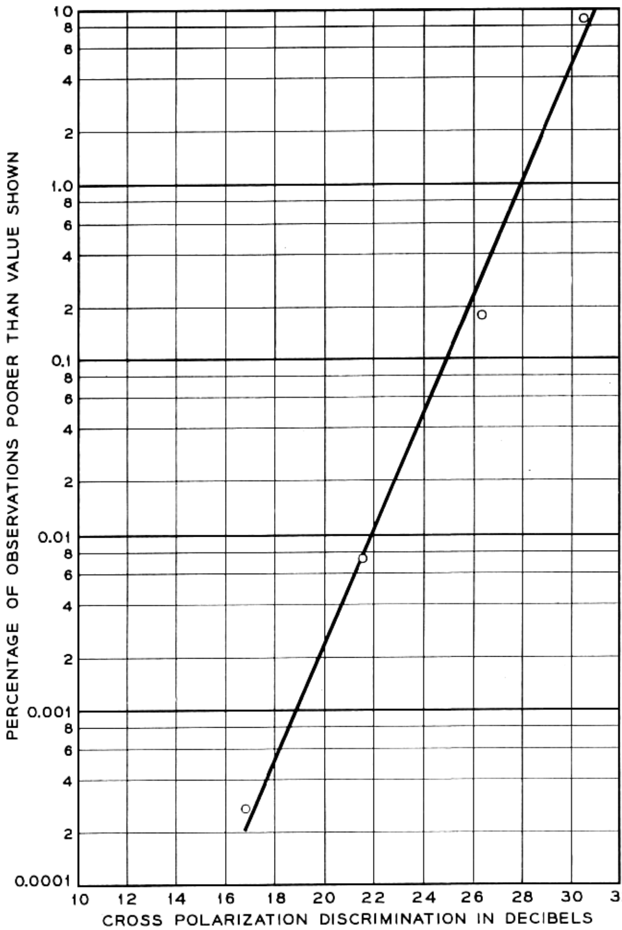

Fig. 5 — Cross-polarization discrimination.

periods was studied experimentally* on a 23-mile path between Murray Hill, New Jersey, and Holmdel, New Jersey. This was done by transmitting a vertically polarized carrier at 4008 mc and a horizontally polarized carrier at 3980 mc, and observing them with a receiver tuned to each but with both receivers arranged to accept only vertically polarized waves. Fig. 5 is a cumulative distribution curve of the instantaneous difference in level between the two received components obtained in

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* This experimental work was carried out by G. M. Snow, formerly of Bell Telephone Laboratories.

the month of September 1954. It should be pointed out that, by nature of the recording means, there is an inherent uncertainty of ±5 db in the observed values of discrimination. Fig. 5 shows that during this period the cross-polarization discrimination was poorer than 20 ± 5 db for only about 0.002 per cent of the time.

While the use of cross-polarization materially improves the interference from far-end couplings, it does not appreciably increase the side-to-side coupling loss between antennas; consequently, near-end crosstalk becomes an important consideration in interstitial channel operation.

V. INTERCHANNEL INTERFERENCE — THEORY

In an ideal FM system, the baseband interference due to a relatively weak interfering FM wave can be computed by beating each component of energy of the interfering (or disturbing) carrier with each component of energy of the interfered-with (or disturbed) FM wave, noting that the amplitude at baseband of any interference component is proportional to (a) the product of the respective amplitudes of the two RF components which produced it and (b) the baseband frequency of the interference component; and further noting that the baseband frequency of the interference component is equal to the difference in frequency of the two RF components.

Since transmission over the TD-2 system uses a relatively low index of modulation, the sidebands associated with the carrier are, for all practical purposes, confined to a band within ±10 mc of the carrier. Thus, with the standard frequency plan described in Section III, in which the nearest disturbing carrier is 40 mc from the disturbed carrier, any interference between the two would fall above a baseband frequency of 20 mc.

If channels were operated in the interstices available under the present frequency plan, potential interference would extend from zero baseband frequency upwards, having maximum power at 20 mc. A quantitative analysis using this theory shows that, for the types of baseband signals normally transmitted over the TD-2 system, the interference falling in the useful baseband frequency range of the TD-2 system would be expected to be negligible if the disturbing carrier at the FM detector were always at least 6 to 10 db below the disturbed carrier.

Preliminary laboratory studies and published information indicated that the interference at baseband was far higher than expected and, furthermore, did not obey the laws indicated by ideal simple FM theory.[6]

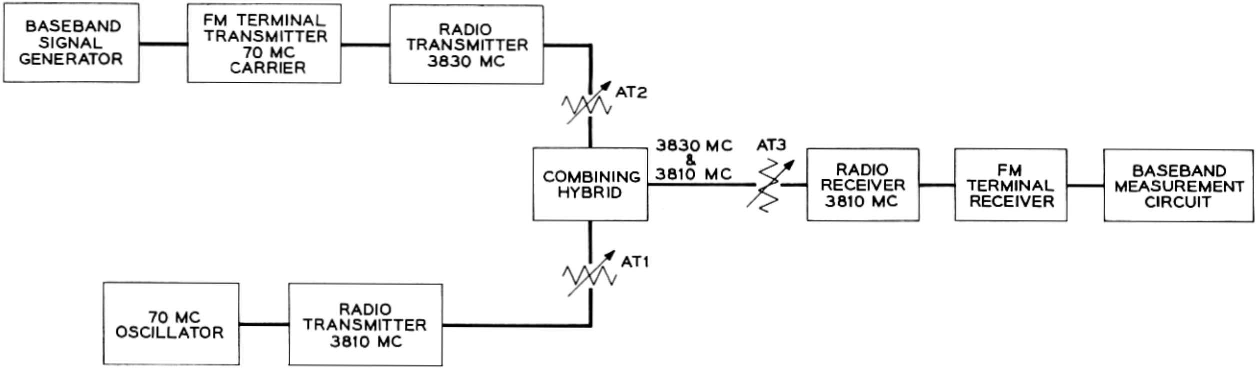

Fig. 6 — Laboratory test arrangement.

For this reason a detailed investigation to establish feasibility of interstitial operation was implemented in the laboratory and continued in the field.

VI. LABORATORY STUDY

Some of the characteristics of direct adjacent channel interference between TD-2 channels 20 mc apart had been studied briefly in the laboratory as early as 1952. The desire to operate the TD-2 system as a 12-channel system using this spacing made it necessary to extend the previous work and to produce an engineering plan for successful operation of the 12-channel system.

A typical laboratory circuit arrangement for testing such a proposal is shown in Fig. 6 in block schematic form. The upper left-hand part of the figure shows the disturbing channel, operating at 3830 mc and modulated by a signal from a baseband signal generator. The equipment in the lower left section provides the 3810 mc carrier that represents the disturbed channel. In the early part of the studies this carrier was unmodulated, as indicated in the figure. The two microwave carriers are combined in the hybrid junction and delivered to the radio receiver, which is tuned to the carrier frequency of the disturbed channel. The 70 mc output of the radio receiver is passed to the FM receiver, which is in turn followed by baseband measuring equipment of appropriate type. The variable attenuator AT1 is used to adjust the 3810 mc carrier power at the input to the radio receiver to any desired value. Similarly, AT2 is used to adjust the received power of the 3830 mc disturbing carrier. The difference between the decibel settings of the two attenuators represents the cross-polarization discrimination, and this proved to be the significant parameter in many of the tests.

Tests were made using single-frequency baseband tones to modulate the disturbing channel while interference in the disturbed channel was observed at the output of the FM receiver connected to the 3810 mc radio receiver. Results of these tests are summarized broadly as follows:

1. Interference appeared in the disturbed channel at exactly the same baseband frequency as was applied to the other channel.

2. A change of 1 db in the carrier ratio of the two channels produced a change in the baseband interference in the disturbed channel of 2 db, provided the disturbing carrier was weaker than the disturbed carrier.

3. A change of 1 db in the level of the baseband input to the disturbing channel produced in general a change of 1 db in the interference observed in the disturbed channel output.

4. The baseband interference was observed to be essentially independ-

ent of the modulation frequency on the disturbing carrier when this frequency was in the 50 kc to 5 mc range.

5. With a fixed difference in level between the disturbing and disturbed carriers, the interference as observed at baseband was independent of the power of the disturbing carrier at the input of the radio receiver.

Certain exceptions to these generalizations were noted but are not considered to be essential to the argument. For example, with low-baseband modulating frequencies, e.g., 50 kc, a change in the frequency deviation from ±4 mc to ±0.4 mc produced a change in interference in the disturbed channel of 26 db rather than 20 db.

Fig. 7 shows some of the characteristic relations between the FM carrier ratios and the baseband interference. The abscissa is the ratio in decibels of the two carrier powers as measured in the receiving waveguide. The ordinate is the observed baseband interference in decibels on an equal-level crosstalk scale.* Over a considerable range of carrier ratios the slope of the curves is essentially 2:1. However, as the carrier ratio begins to approach unity, the slope is considerably greater than 2:1. Since a working system will not be satisfactory when the interference is large, the region where the disturbing carrier is stronger than the disturbed carrier is only of academic interest. While the shapes of the curves are almost the same over the region of interest, the position of the curves with respect to the carrier ratio depends upon the discrimination against the disturbing channel that is provided by the frequency characteristic of the receiver in the disturbed channel. The experimental work indicated that the crosstalk mechanism which is characteristic of adjacent channel interference exists in the limiter of the FM receiver and also at any point in the system where there is a pronounced tendency to compress the signal. Such a mechanism has been suggested in an unpublished memorandum by W. R. Bennett of Bell Telephone Laboratories. This mathematical work shows that, when an unmodulated FM carrier and a weaker sinusoidally modulated FM wave are passed through an ideal clipper limiter, distortion is introduced on the stronger FM carrier, some of which appears at baseband frequencies as interference having the same frequency as that of the modulation on the weaker carrier. The amplitude of this interference varies as (a) the square of the ratio of the amplitude of the two carriers and (b) the square of the ratio of the voltage at which the limiter clips to the signal voltage impressed upon it.

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* On this scale the number −40 means that the measured interference at baseband is 40 db below the value of the baseband tone which would be measured at the output of an FM receiver on the disturbing channel.

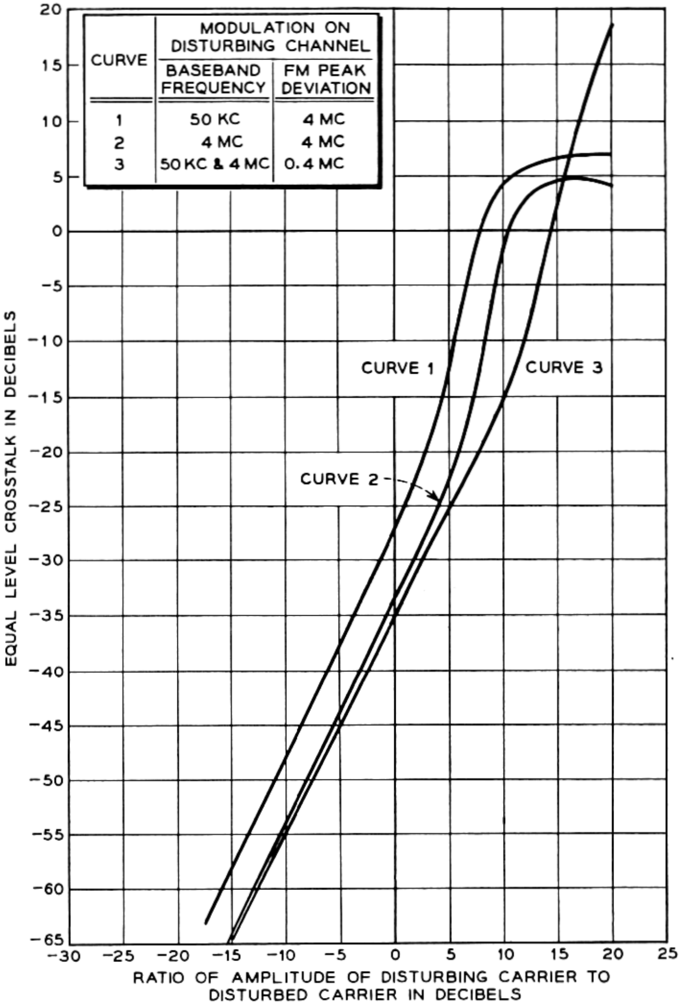

Fig. 7 — Crosstalk between microwave channels — laboratory measurements.

The next series of experiments was undertaken to determine how the frequency discrimination at the edges of the channel passband might be changed to hold the interchannel interference to tolerable limits in the presence of a limited amount of cross-polarization discrimination. It was found that sufficient improvement could be obtained if the frequency discrimination of the disturbed channel was increased in the region of the disturbing carrier and its signal sidebands. Since the strength of these sidebands usually decreases as their frequency spacing from the carrier increases beyond the peak frequency deviation, and since the peak deviation is 4 mc in the TD-2 system, an IF filter which would increase the discrimination markedly in the range of 16–24 mc from the disturbed carrier and somewhat less strongly in the region 10–16 mc removed should be effective. Laboratory models of such a filter were made. The filter was placed in the receiver at a point between the IF preamplifier and the IF main amplifier. This arrangement was also tested in field trials, and both laboratory and field results were encouraging. Fig. 8 shows the shape of the passband of a receiver before and after adding an experimental IF filter. The disturbed carrier would be located at 70 mc and the disturbing signal would be centered either at 50 mc or 90 mc. In many cases, disturbing signals will be located on both sides.

Since the TD-2 system normally operates with compression in the final stage of the microwave transmitting amplifier, this IF filter, for the reason described above, must be applied at each repeater point, and must be located between the point of exposure and the transmitting RF amplifier.

Another part of the general interference problem involves the condition in which the carrier of the disturbing channel has been severely faded or actually lost at some preceding section. In this latter case, the gain of the system is sufficient to amplify the noise originating in the

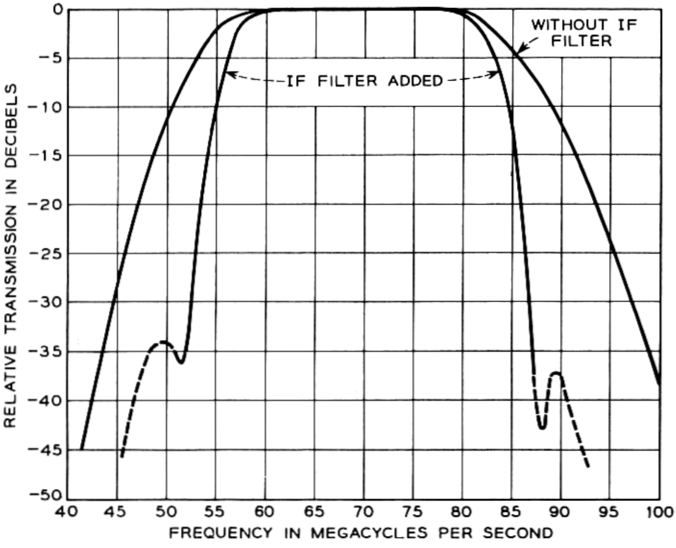

Fig. 8 — Radio receiver gain frequency characteristics.

converters until the transmitter output consists of a broad band of noise whose total power is substantially that of the carrier it replaces. In this situation the energy density at the edge of the band is greater than it is when a carrier with its normal sideband distribution is present. The tendency to interfere or "spill over" into the adjacent channel is greatly increased.

The automatic switching system for TD-2 operates when the high-frequency noise in a broadband channel reaches a predetermined level as a result of a fade or loss of carrier in a preceding section of the system.[7] If spill-over from a failed interstitial channel occurs, a nominally good channel can be impaired and an unnecessary switch will ensue. The filter is not adequate to cope with this situation and, consequently, the repeater gain must be reduced during such periods.

The elements of the engineering plan for interstitial operation can be found in the preceding discussion. A new IF filter and means for reducing the repeater gain during deep fades must be provided at each repeater on an interstitial route. Cross-polarization discrimination is available in the form of a polarization-sensitive 4-kmc microwave network which connects rectangular waveguide into the round waveguide leading to the antenna. This network had been developed as part of the equipment necessary to permit systems operating at 4, 6 and 11 kmc to be simultaneously connected to one horn-reflector antenna.[8]

Field tests of various aspects of the engineering plan were carried out from time to time. Before discussing these tests it seems worthwhile to discuss the objectives against which the results of the field tests were evaluated.

VII. OBJECTIVES

The objective for satisfactory interstitial operation is based on the philosophy that the speech crosstalk from an adjacent channel during a fade should be well masked by the first circuit noise simultaneously present. For systems engineering purposes, this objective must be interpreted in terms of a required ratio of disturbed carrier to disturbing carrier.

In the case of near-end crosstalk as defined above, the desired received carrier is subject to normal fading whereas the disturbing carrier is not. For this condition it has been determined experimentally that, without the special IF filter, if the disturbing carrier is 35 db or more below the disturbed carrier during conditions of free-space transmission, then, during fading, the baseband interference from the interstitial channel into the disturbed channel will always be below the noise in the disturbed channel.

In the case of far-end crosstalk, fading of the disturbing carrier is correlated to a degree with fading of the disturbed carrier, and this in turn leads to an objective somewhat less than 35 db. The limited amount of data at hand indicates that for this case a ratio of about 20 db is adequate. If the fading on the two channels is uncorrelated, the objective will be 35 db for far-end crosstalk as well as for near-end crosstalk.

Fig. 9, taken from Ref. 9, shows how the fluctuation noise and speech

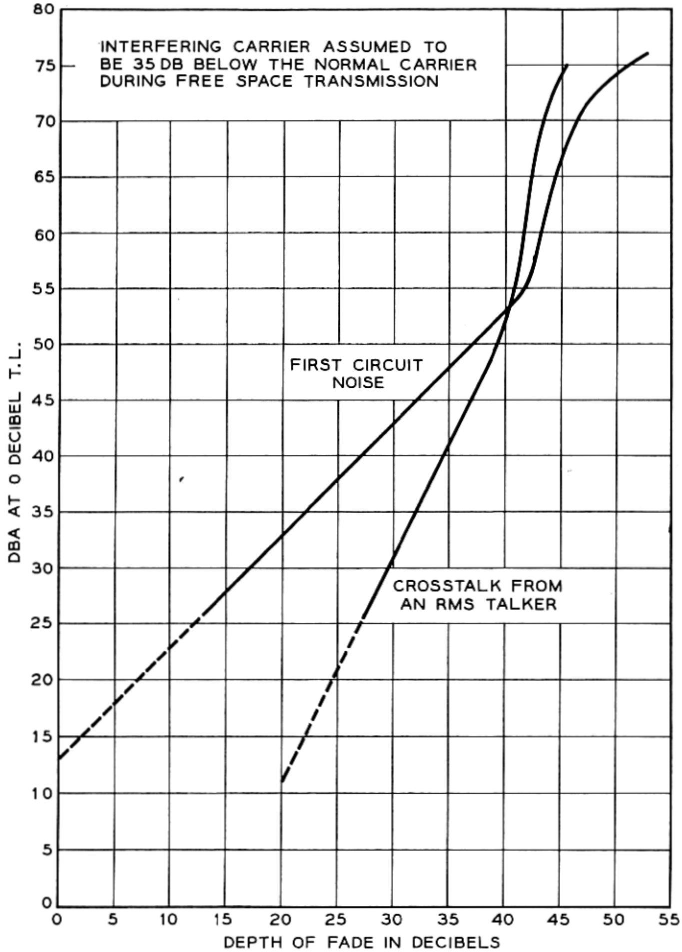

Fig. 9 — Expected noise and crosstalk vs. fade.

crosstalk contributions of one repeater may be expected to increase with depth of fade. Talker volumes are distributed over a wide range, and the volume assumed here is sometimes referred to as the volume of the "rms" talker. This is approximately 10 db below the loudest talker. At a 35 db fade, the point at which service is normally transferred to a nonfaded channel, the speech crosstalk is 7 db below the noise power.

It is also convenient for some purposes to specify the above objective in terms of equal-level crosstalk at baseband frequencies. The conversion can readily be made by means of the experimental relationship shown in Fig. 7. Thus, if the 35 db objective were met, then under free-space conditions the equal-level crosstalk would be completely negligible. For a 35 db fade, the carrier ratio would be 0 db and the corresponding equal-level crosstalk objective would be −35 db.

VIII. FIELD TESTS

In the six repeater sections between West Unity, Ohio, and Grant Park, Illinois, interstitial channels had already been installed, thus providing a suitable location for feasibility field tests. Channels R201 and R207 in the east to west direction and R101 and R107 in the opposite direction (see Fig. 4 for channel nomenclature and frequencies) were used for the tests since R101 could interfere with R107 and produce far-end crosstalk, and similarly, for example, it could couple into R207 and produce near-end crosstalk. Both crosstalk paths involve a spacing of 20 mc.

The following basic tests were among those made:

1. *Sine-Wave Crosstalk*

A sine wave of suitable power was applied to the baseband input of R201, for example, and the magnitude of the crosstalk at this same frequency was observed at West Unity at the baseband outputs of R107 and, at Grant Park, of R207. This was carried out for various values of simulated radio frequency fades at each repeater section on R107 and R207.

2. *Video Crosstalk*

The test detailed above was repeated using a video signal. In this case the outputs of R107 and R207 were examined on a video monitor for evidence of picture crosstalk for simulated fades, as described above.

3. *Noise Spill-Over*

The carrier was removed from one radio channel at the head end of the system, the gain of the subsequent repeaters thereby rising, as described previously, until the repeater output consisted of a broad band of noise. The magnitude of the spill-over of this noise into the adjacent channel was observed for various depths of fades.

4. *Loss of Fading Margin Due to Noise Spill-Over*

In a TD-2 system, one channel out of six is normally set aside as a protection channel. In each operating channel, noise is sensed at a baseband frequency of about 9 mc and, if the noise is excessive, a switch is made to the protection channel if it is available. Noise spill-over increases the noise at the upper video frequencies and hence causes a faded circuit to ask for the protection channel sooner than it otherwise would. This, in turn, ties up the protection channel longer than is actually necessary and, as a result, increases the amount of time a switch cannot be made because the protection channel is unavailable.

Fig. 10 shows typical results of sine-wave crosstalk measurements in which the modulating tone on the interfering channel is 3.59 mc and various repeater sections are faded. The coupling path in this case is between similarly directed channels and generates far-end crosstalk. The results are plotted in terms of equal-level crosstalk.

Using the more severe of the two objectives suggested above for far-end crosstalk, it was shown that this led to an objective of −35 db for equal-level crosstalk loss for a 35 db fade. It is apparent then that three out of the six far-end coupling paths failed to meet this requirement.

The addition of the supplementary IF filter substantially reduced the magnitude of the crosstalk, as shown in Fig. 11. In this case the poorest equal-level crosstalk value for a 35 db fade was −35 db, which meets the stated objective.

Observations showed video crosstalk mixed with the noise for deep fades, but this was eliminated by the application of the supplementary IF filter.

Figs. 12 and 13 show the effect of noise spill-over from channel R201 into R207 as the latter is artificially faded at Kouts. The first of these two figures shows the measured noise spectrum on R207 with R201 operating in normal fashion. These curves exhibit satisfactorily the expected 6 db per octave increase of noise with baseband frequency. Fig. 13, however, shows the effect of removing the carrier from R201

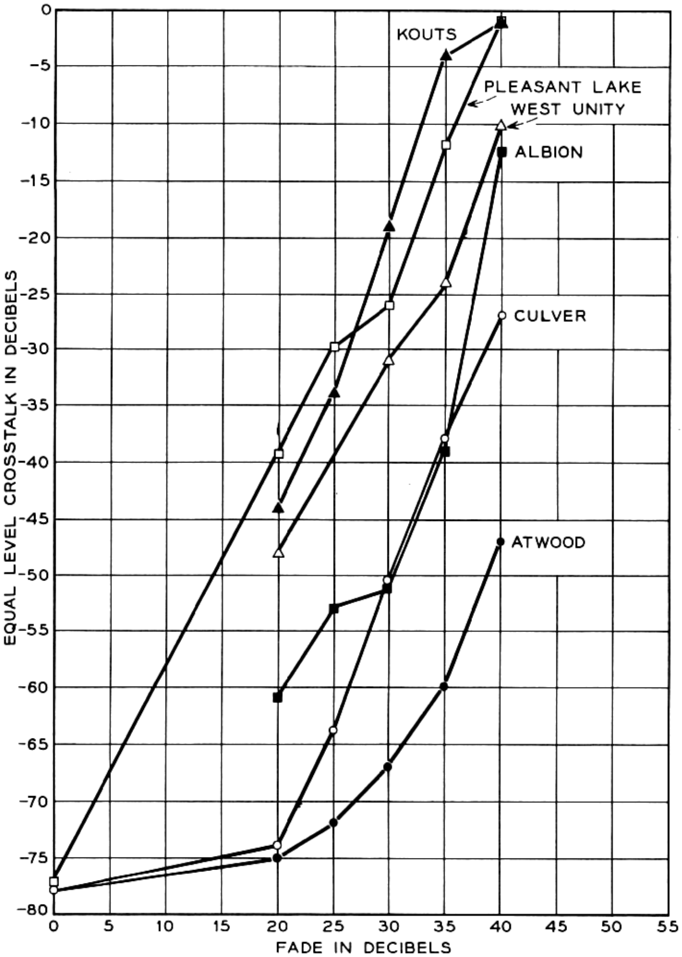

Fig. 10 — Crosstalk vs. depth of fade — IF filters removed

at West Unity. The effect of noise spill-over from R201 is most marked in the region above 6 mc.

IX. APPLICATION TO EXISTING ROUTES

The application of interstitial channels to an existing TD-2 route requires the use of the horn-reflector type of antenna and associated circular waveguide system in order to permit the cross-polarization of

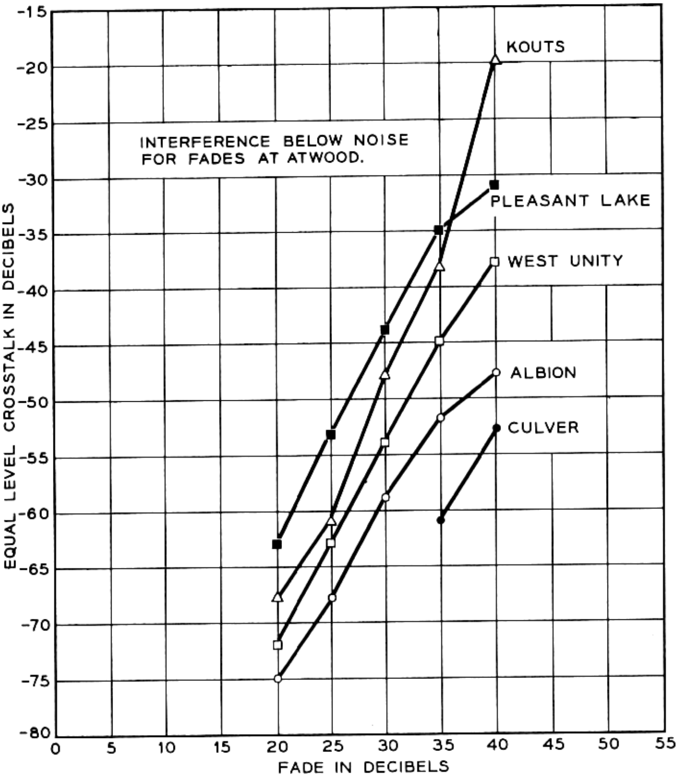

Fig. 11 — Crosstalk vs. depth of fade — IF filter in.

the radio signals for channels having 20 mc frequency separation. The field tests confirmed the results expected from the laboratory measurements and indicated that the discrimination obtained from cross-polarization and IF filters would provide satisfactory discrimination against adjacent channel signals. Existing delay-lens antennas with their associated rectangular waveguides must be replaced and coupling networks must be installed at the bottom of the tower for combining the cross-polarized signals. Temporary arrangements, such as parabolic antennas, may be necessary in order to keep in service the circuits assigned to the existing TD-2 channels and to avoid interruptions during the cutover.

It is planned to operate the interstitial channels added on a route as a system separate from the existing regular channels. The interstitial channels will have their own protection channels, because adjacent channels 20 mc apart will frequently fade at the same time and simultaneously need the same protection channel. Building additions, par-

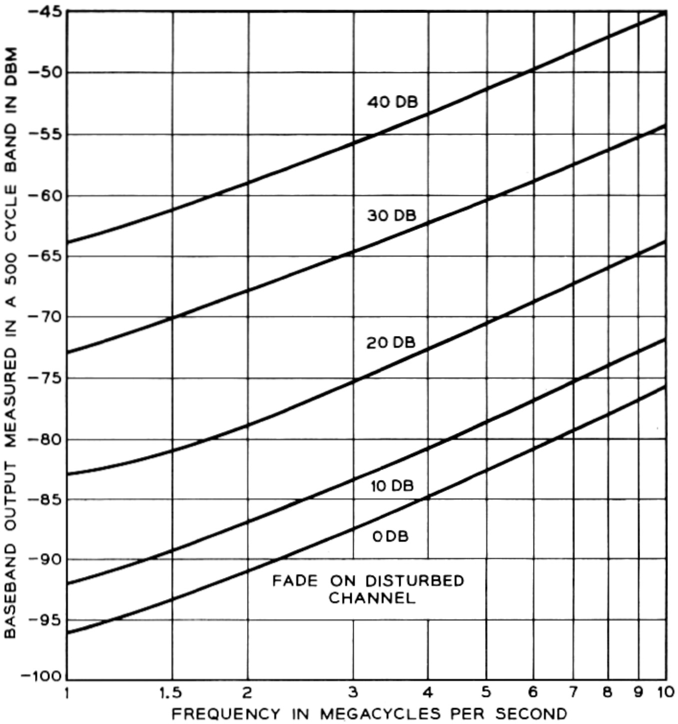

Fig. 12 — Noise spill-over — adjacent channel normal.

ticularly at auxiliary repeater stations, and increased power plant capacity will usually be required for the additional channels. In all other respects TD-2 channels on interstitial routes will operate in a normal manner, since the IF filter and the gain reducing means mentioned in an earlier section are essentially the only additional circuit arrangement required on an interstitial channel route.

Some of the factors affecting the decision as to application of interstitial channels to an existing TD-2 route are the circuit growth needed, the freedom from interferences arising from parallel or branching routes using the same interstitial channel frequencies and the type of antennas already installed. In some cases there may be interference from other radio routes such as sidelegs or converging routes which might limit the number of interstitial channels that could be added.[9]

TD-2 routes having horn-reflector antennas are particularly attractive candidates for interstitial channel applications from an economic standpoint. The cost of replacing the delay-lens antennas and rectangu-

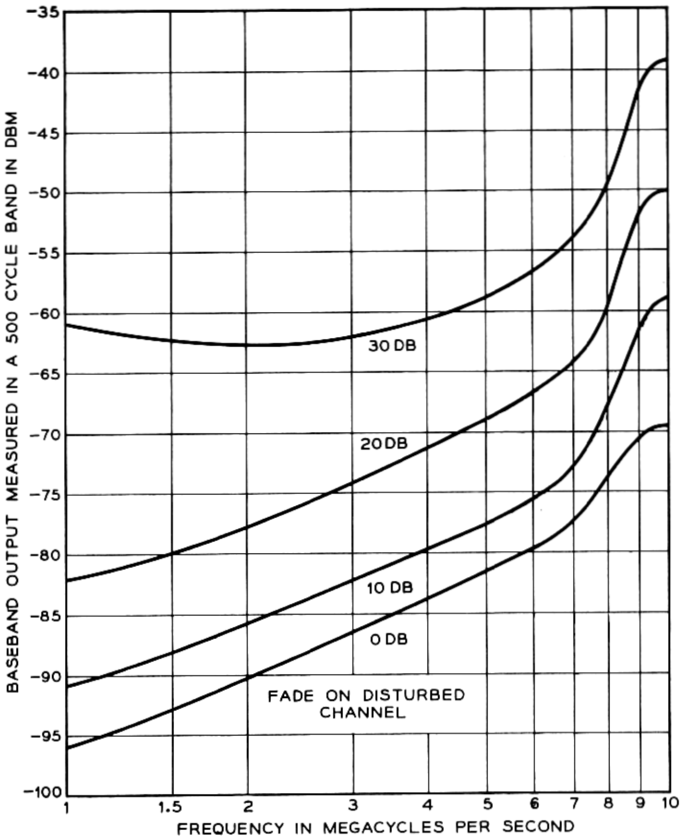

Fig. 13 — Noise spill-over — adjacent channel open.

lar waveguides by horn-reflector antennas and circular waveguides, and at the same time maintaining existing service, is substantial.

In general, the same factors apply for sideleg routes as for main through routes. However, in sideleg route cases it will be necessary to make sure that the addition of interstitial channels on the sidelegs will not restrict the number of such channels which could be added on main routes because of possible frequency interferences.

X. CONCLUSION

It appears that widespread use of TD-2 interstitial channels is possible, since the results of the field trial indicate that the interference between nearby and branching TD-2 routes would in general be sufficiently low to permit the use of the same channel frequencies on different routes. In a few cases, however, it is expected that interroute interference might be severe enough to prevent using these channels on more than one route unless remedial measures are taken, such as the construction of a new route for short distances.

The results from the field tests and from experience with interstitial channels placed in service in the Chicago-Mishawaka and Indianapolis-Terre Haute and Troy Hill-Hopedale sections subsequent to the field trial indicate that both the regular and interstitial channels have transmission characteristics practically the same as those of TD-2 channels on noninterstitial routes. In view of these satisfactory results, plans are being made for the installation of interstitial channels on TD-2 routes in many portions of the United States. It appears that nearly all the main TD-2 routes will have interstitial channels added during the next few years.

REFERENCES

1. Grieser, T. J. and Peterson, A. C., A Broad-Band Transcontinental Radio Relay System, Elect. Engg., **70,** 1951, p. 810.
2. McDavitt, M. B., 6000-Megacycle-Per-Second Radio Relay System for Broad-Band Long-Haul Service in the Bell System, A.I.E.E. Trans., **76,** Pt. 1, 1958, p. 715.
3. Lince, A. H., Antennas for the TD-2. Bell Lab. Rec., **30,** 1952, p. 49.
4. Friis, R. W. and May, A. S., A New Broad-Band Microwave Antenna System, Comm. & Elect., No. 35, 1958, p. 97.
5. Roetken, A. A., Smith, K. D. and Friis, R. W., The TD-2 Microwave Radio Relay System, B.S.T.J., **30,** Pt. 2, 1951, p. 1041.
6. Medhurst, R. G., Hicks, Mrs. E. M. and Grossett, W., Distortion in Frequency Division Multiplex FM System Due to an Interfering Carrier, Proc. I.E.E., **105,** Pt. B, 1958, p. 282.
7. Welber, I., Evans, H. W. and Pullis, G. A., Protection of Service in the TD-2 Radio Relay System by Automatic Channel Switching, B.S.T.J., **34,** 1955, p. 473.
8. Harkless, E. T., A Network for Combining Radio Systems at 4, 6 and 11 KMC. B.S.T.J., **38,** 1959, p. 1253.
9. Curtis, H. E., Radio Frequency Interference Considerations in the TD-2 Radio Relay System, B.S.T.J., **39,** 1960, p. 369.