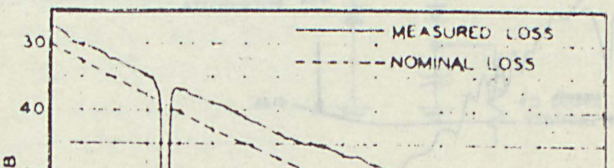
TRANSMISSION LINES
Thursday, July 22, 1965

MR. ARCHER S. TAYLOR, CHAIRMAN: Our first paper this morning is on the "Sweep Testing of Coaxial Cable" by Mr. Ken Simons of the Jerrold Corporation. Ken Simons graduated from the University of Pennsylvania in 1938. He's been in CATV since 1951. He helped design the 704-B field-strength meter, the UBC 26-B amplifier and the 900B sweep generator. He is formerly chief engineer of the Jerrold Corporation and is now Vice-President for Research and Development. Mr. Ken Simons. [Applause.]

MR. KEN SIMONS: Sweep testing is essential for coaxial cables used in ETV and CATV distribution systems. This article compares three basic methods: measurement of transmission loss, measurement of input impedance, and measurement of reflection coefficient.

The technical requirements for flexible coaxial cable were organized in Military Specification JAN-C-17, originally issued in 1944. This specification and its subsequent revisions spell out in detail the requirements for physical construction and a number of electrical parameters, including attenuation and dielectric strength of the cable. Regarding the characteristic impedance, JAN-C-17 specified the nominal impedance which was determined by a calculation involving the total measured capacitance of a reel of cable, and the delay factor measured on a short sample. For cables of relatively short lengths, this specification was adequate; but the advent of CATV systems, where TV signals are transmitted through many miles of cable, uncovered the need for an additional specification.

The problem first came to light in our organization about twelve years ago when one of our field engineers returned to the laboratory a reel of cable which, he claimed, would not pass TV channel 16.



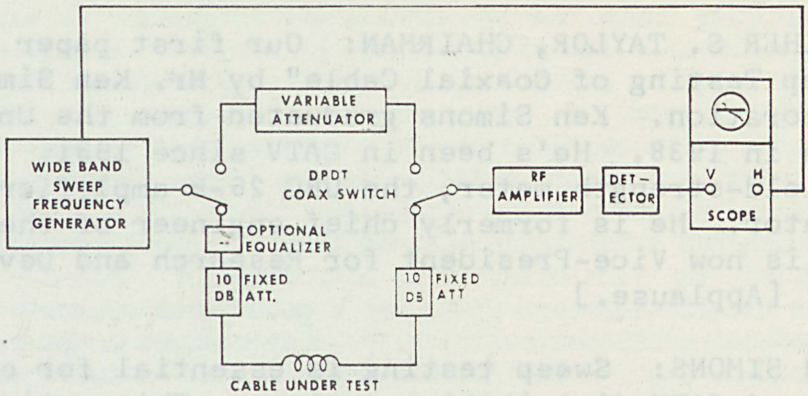
Loss versus frequency for 2,000 feet of defective RG11/U cable

FIG 1

Figure 1 shows the measured attenuation of this reel of cable, indicating an attenuation spike 50 db deep at 87 mc!

Investigation showed that this effect was due to periodic discontinuities. Something in the manufacture of the cable produced variations in characteristic impedance recurring at precisely spaced intervals throughout the length of the cable. Due to this precise spacing, many reflections, precisely phased at a certain frequency, arrived back at the input end

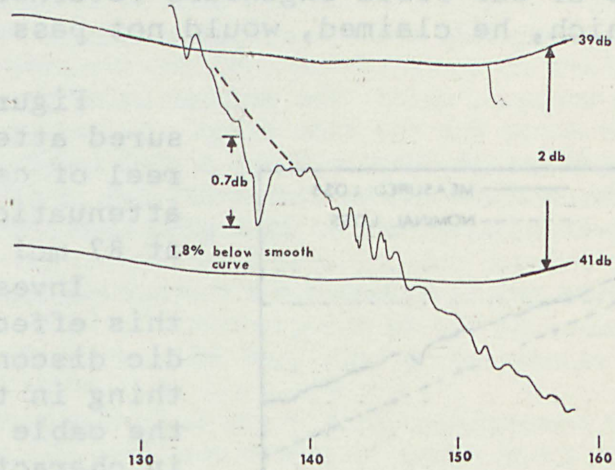
Fig. 1



Equipment Connection For Transmission Test

FIG 2

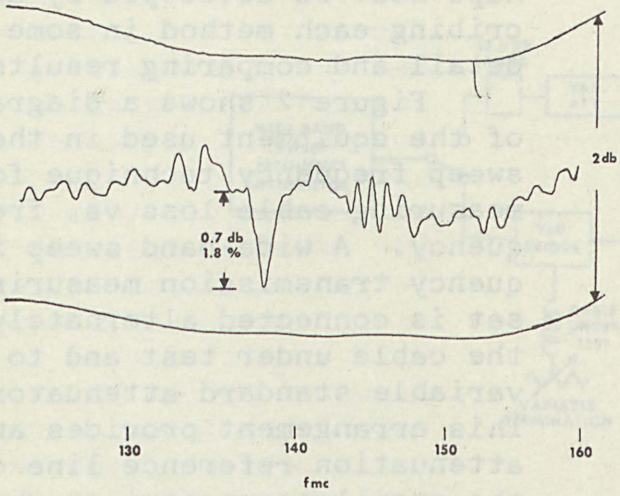
Fig. 2



Transmission Measurement, 1000' Reel Of RG59/U

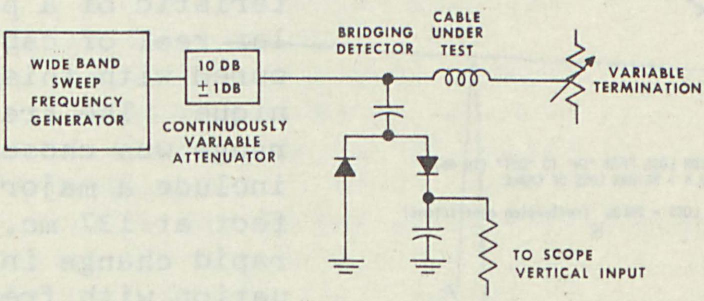
FIG 3

Fig. 3



Transmission Measurement 1000' Reel RG59/U
Equalized
FIG 4

Fig. 4



Equipment Connection For Impedance Test
FIG 5

Fig. 5

of the cable, causing this severe distortion of the transmission characteristic.

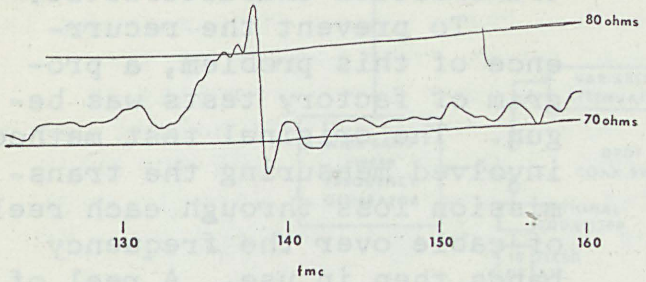
To prevent the recurrence of this problem, a program of factory tests was begun. The original test method involved measuring the transmission loss through each reel of cable over the frequency bands then in use. A reel of cable was rejected if the loss in these bands dipped more than 0.25 db below the smoothed attenuation characteristics.

After this transmission loss measurement method had been used for several years, it became evident that a more sensitive test was needed. It was found that a measurement of the input impedance at each end of a reel of cable gave a more sensitive indication of the existence of periodic reflections. Experience with the impedance measurement method showed two major defects: it was difficult to arrive at an accurate calibration, and the measured deviation was a critical function of cable length. Removing two or three feet from the end of the cable would change the entire pattern. To overcome these defects, a test method was developed employing a bridge; this method allowed observation and measurement of the reflections from the cable end, eliminating uncertainity and allowing easier calibration. This reflection measurement method has been used by a number of cable manufacturers during the past five years and has provided a satisfactory way of controlling periodic defects.

The relative merits of the three methods of sweep frequency cable testing can perhaps best be developed by describing each method in some detail and comparing results.

Figure 2 shows a diagram of the equipment used in the sweep frequency technique for measuring cable loss vs. frequency. A wide-band sweep frequency transmission measuring set is connected alternately to the cable under test and to a variable standard attenuator. This arrangement provides an attenuation reference line on the oscilloscope against which the loss of the cable can be compared. For accurate measurement, it is essential that the cable face a well matched impedance at each end. 10-db fixed attenuators are used to establish this condition.

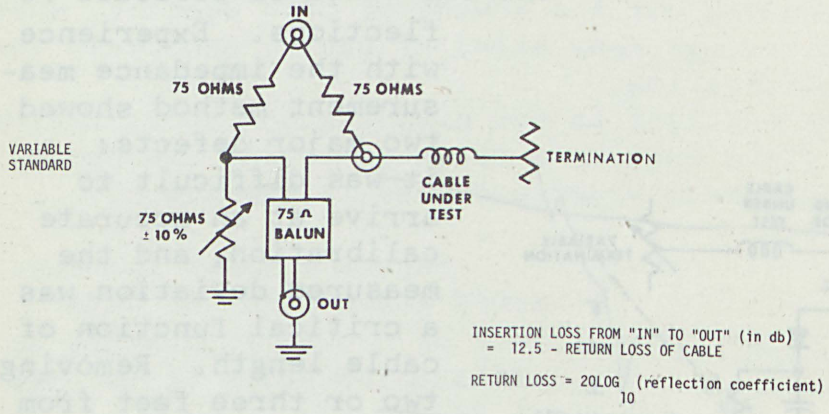
Figure 3 illustrates the loss characteristic of a particular reel of cable measured with this technique. The frequency range was chosen to include a major defect at 137 mc. The rapid change in attenuation with frequency makes accurate measurement of the dip at 137 mc difficult. The measurement is easier by inserting an equalizer in series with the cable so that the average loss is flat and the irregularity is more clearly displayed and measured, as shown in Figure 4. One of the defects of the transmission loss measurement method appears on this plot. With the high end-to-end attenuation present on this reel, the single shield allowed sufficient coupling to produce ripples in the frequency characteristic.



Impedance Test On 1000' Sample Of RG59/U

FIG 6

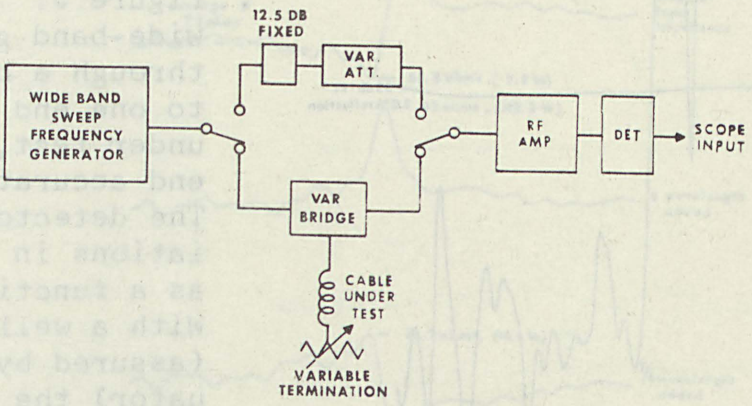
Fig. 6



Variable Bridge For Cable Reflection Testing

FIG 7

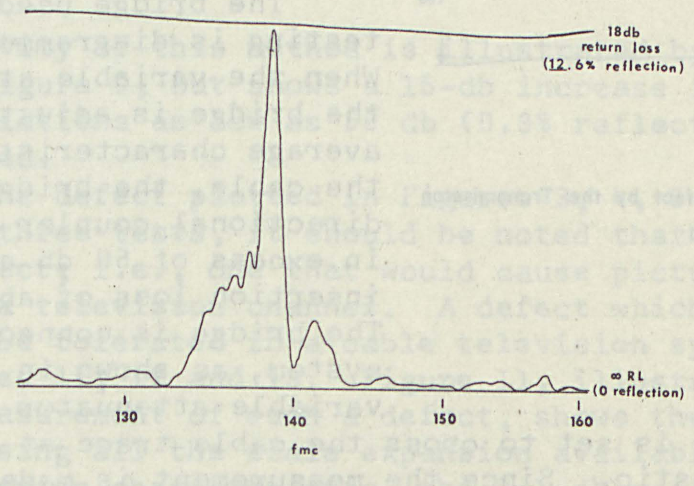
Fig. 7



Equipment Connection For Reflection Test

FIG 8

Fig. 8

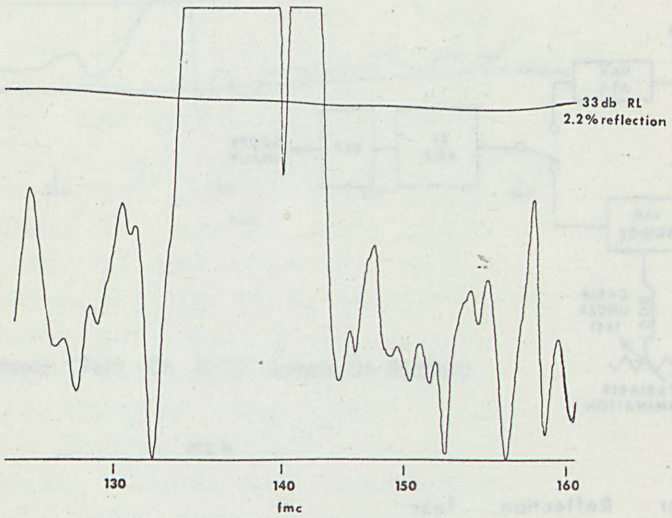


Reflection Test On RG59/U Sample

FIG 9

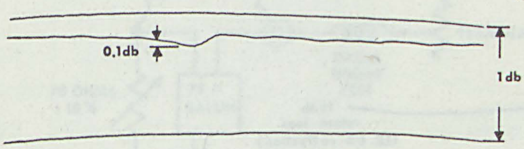
Fig. 9

A more sensitive test, free from this coupling problem, is obtained by using the technique diagrammed in Figure 5. The output of a wide-band generator is fed through a bridging detector to one end of the cable under test, with the other end accurately terminated. The detector measures variations in input voltage as a function of frequency. With a well-matched source (assured by the 10-db attenuator) the input voltage varies almost directly with the magnitude of the cable's input impedance. And impedance plot made by this technique for the same reel of cable is illustrated in Figure 6 (compare with Figure 4). Calibration was obtained by substituting a precise 75-ohm terminator for the cable end and varying the attenuator above and below 10 db by an amount corresponding to the indicated inpedance levels.



Same as Fig. 9 with gain increased and reference changed.
FIG 10.

Fig. 10

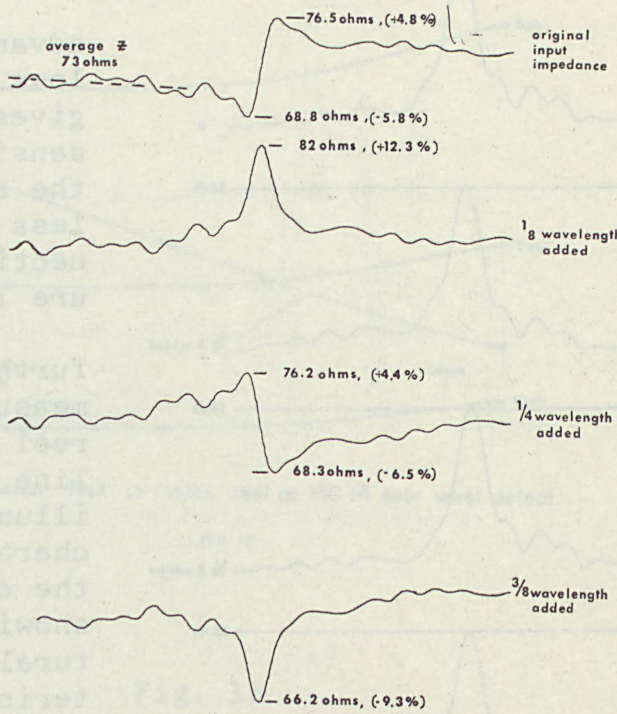


Measurement of a cable defect by the Transmission Method
FIG 11

Fig. 11

The bridge used for reflection testing is diagrammed in Figure 7. When the variable standard arm of the bridge is adjusted to equal the average characteristic impedance of the cable, the bridge acts as a directional coupler with directivity in excess of 50 db and a constant insertion loss of about 12.5 db. The bridge is connected into a test system, as shown in Figure 8. The variable attenuator generates a reference trace which is set to cross the cable trace at peaks of the reflection characteristic. Since the measurement is made in dbs, the results are most conveniently expressed in these terms. The reflection coefficient expressed in db is the "return loss", and the return loss characteristic of cable, due to periodic variations in its structure, has become known as the "structural return loss".

Figure 9 illustrates a structural return loss plot with the characteristic of the same cable defect as shown on the curves in Figures 4 and



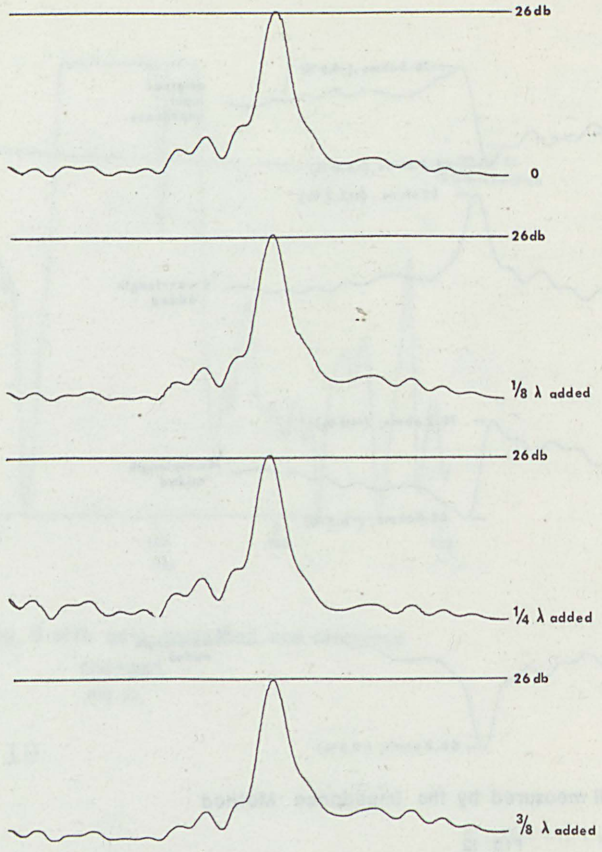
Same defect as FIG. II measured by the Impedance Method

FIG 12

Fig. 12

6. The sensitivity of this method is illustrated by Figure 10, which is similar to Figure 9, but shows a 15-db increase in sensitivity. Return loss variations as low as 50 db (0.3% reflection) can be clearly displayed.

Although the defect plotted in Figures 3, 4, 6 and 9 showed up clearly in all three tests, it should be noted that it was a particularly bad defect; i.e., one that would cause picture distortion if it fell within a television channel. A defect which is about the worst that can be tolerated in a cable television system is illustrated in Figures 11, 12 and 13. Figure 11, illustrating the transmission loss measurement of such a defect, shows the difficulty of this method: using all the scale expansion available, and equalizing the transmission characteristic, the 0.1-db variation is difficult to discern and impossible to measure accurately. Figure 12 shows a great improvement in sensitivity obtained by impedance measurement, but also illustrates the weakness of this method in that four different measurements were obtained, depending critically on small variations in the point at which the cable was connected to the detector. The reading on this particular defect varied from



Same defect as FIGS 11 & 12 measured by the Reflection Method

FIG. 13

Fig. 13

4.4% to 12.3%, depending on the length of the connection.

Figure 13 shows the advantage of the return loss bridge method, which gives a high degree of sensitivity with essentially the same reading, regardless of the point of connection (compare with Figure 12).

This comparison is further illustrated by measurements made on a reel of good CATV trunk line cable. Figure 14 illustrates the return loss characteristic taken over the entire TV spectrum, showing excellent structural return loss characteristics. Figures 15 and 16 show transmission loss measurements near the worst defect. Note that the transmission loss variation, at this point, can hardly be seen or measured by this method. Figure 17 illustrates an impedance test of this worst defect, and figures 18 and 19 show return loss tests in this same frequency range.

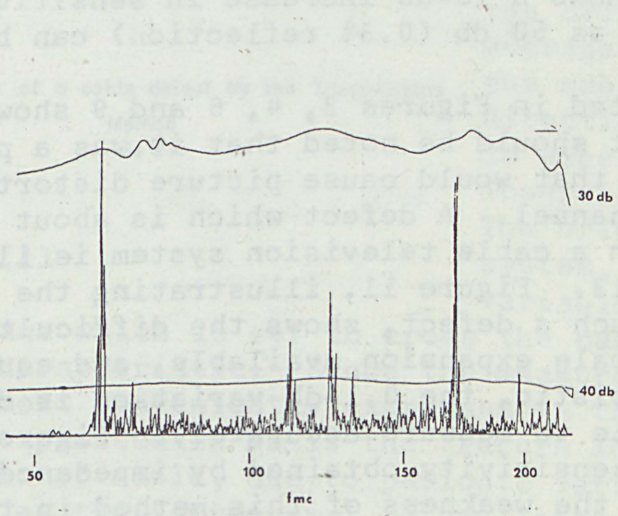
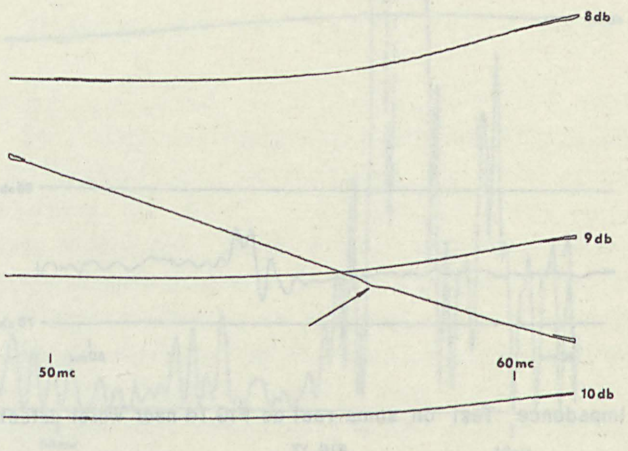


Fig. 14

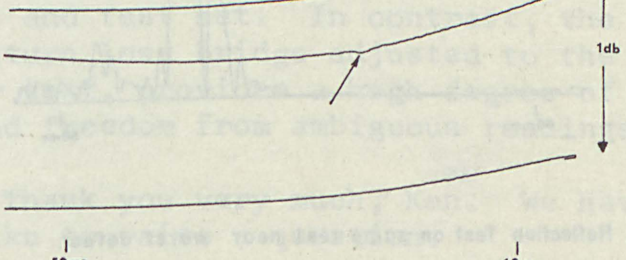
Reflection Test On Sample Reel Of CATV Trunk Line Cable

FIG 14



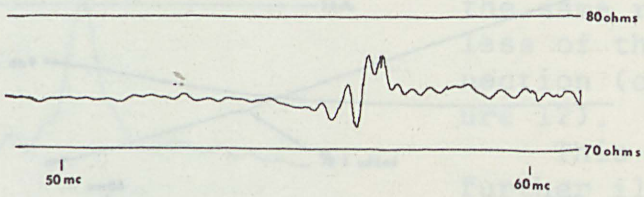
Transmission Test on same reel as FIG. 14 near worst defect.
FIG 15

Fig. 15



Same as FIG. 15 except Transmission equalized.
FIG 16

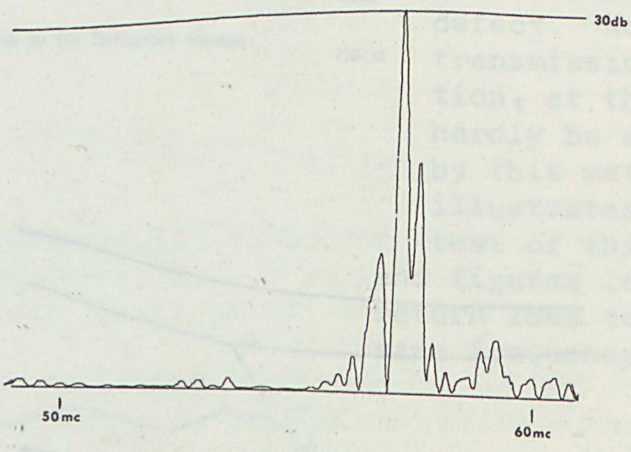
Fig. 16



Impedance Test on same reel as FIG 14 near worst defect.

FIG 17

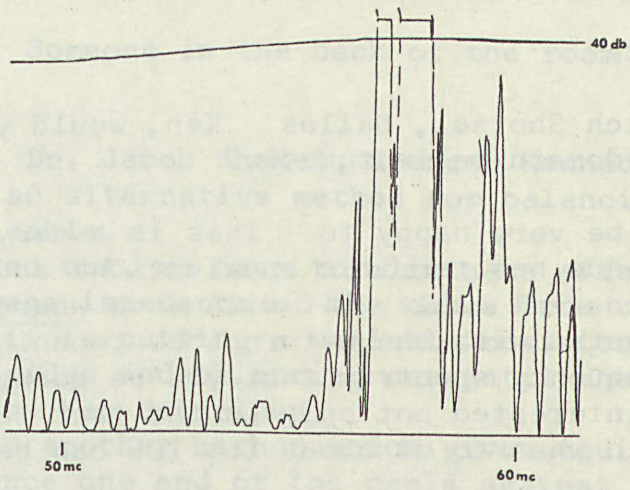
Fig. 17



Reflection Test on same reel near worst defect.

FIG. 18

Fig. 18



Same as FIG.18 except gain increased, reference shifted.

FIG.19

Fig. 19

In summary, three methods that have been used to determine the existence of electrical problems due to periodic discontinuities in cable have been described. The transmission measurement method suffers from low sensitivity and the need for equalization. The impedance measurement method presents difficulties in calibration and is ambiguous because of variations peculiar to the point of connection between cable and test set. In contrast, the reflection test method, using a return loss bridge adjusted to the average impedance of the cable under test, provides a high degree of sensitivity, ease of calibration, and freedom from ambiguous readings.

MR. TAYLOR: Thank you very much, Ken. We have a few minutes, if anyone would like to raise a question.

MR. EARL QUARR: Mr. Earl Quarr, Long Island Cable Division. Did I understand you correctly? Should you measure return loss from both ends of the cable?

MR. SIMONS: Very definitely, and I would say it's an encouraging sign if you measure the same from both ends. This says that particular reel probably has a uniform characteristic throughout. Generally, you should measure a reel from both ends and the characteristic should be good from both ends.

MR. QUARR: Thank you.

MR. TAYLOR: Dutch?

MR. SHOTSEL: Dutch Shotsel, Dallas. Ken, would you comment on the possibilities of time-domain reflectometry?

MR. SIMONS: I'd be very happy to. This is a very active subject. The time domain technique has terrific applications and is most helpful in the production of coaxial cable. It will show where the discontinuity occurs, as contrasted with the return loss technique which shows how it affects the frequency spectrum that you're going to use. Since a manufacturer is most interested not only in the fact that a given reel of cable is bad, but in what to do about it, TDR can be a terrifically useful tool.

There is one minor difficulty in the fact that the available TDR (and I may be doing somebody an injustice, but the only one I know about is the Hewlett-Packard) has a 50 ohm source impedance. You can work with this, but it introduces a small problem in the fact that you get multiple reflections. If there is an echo from the cable, it goes back to the 50 ohm source and is re-reflected. Since most of the discontinuities are small, this doesn't give much trouble. The Hewlett Packard engineers have told me they have a technique that they believe will be satisfactory in giving a matched 75 ohm source and with or without this improvement I believe the TDR is a tremendously useful tool.

MR. KUSHNER: Mr. Al Kushner, Times Wire. Ken, we've used your bridge, of course, in the factory, quite a bit and there's one thing we've noticed. If we first display on the scope 50 to 220 megacycles and measure a 30 db spike, and then reduce the sweep width so we're only looking at plus or minus ten mc, the reading will increase sometimes by as 2 db. Does this correspond with your results?

MR. SIMONS: It certainly does. The difficulty here is a simple one, and we do have a fairly effective correction for it. If you look at the RF signal that comes out of the bridge as an amplitude modulated one, the amplitude modulation has a very high percentage and the detector tends to exhibit peak clipping. In addition there is a problem with envelope frequency response. If you sweep past a ripple too fast, it is not displayed accurately and the correction which we found quite effective is to put a little high frequency boost in the audio output. It is adjusted by first spreading the pattern way out, getting a reading, then sweep maximum bandwidth and adjust the "boost" for the same reading.

MR. KUSHNER: There is one other thing. Since we've been working with 30 db cables we found that, when we get above 30 db return loss the TDR shows reflections of 60 to 70db down.

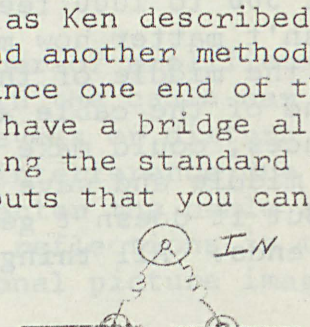
MR. SIMONS: TDR is most useful for isolated problems - lump discontinuities or for analyzing the nature of the periodicity as to whether it is a sinusoidal variation in diameter or whatever it may be.

MR. TAYLOR: Someone in the back of the room had his hand up. Dr. Shekel?

DR. SHEKEL: Dr. Jacob Shekel, Spencer Kennedy Labs. I just want to describe an alternative method for balancing out the average impedance of the cable.

As Ken pointed out, we have to eliminate effects due to variations in the average impedance of the cable from reel to reel. Now, one way of doing it is putting a variable resistor and capacitor on one side of the bridge and balancing out until the minima come down to the baseline, as Ken described.

We have found another method which gives equivalent results. In effect we balance one end of the cable against the other. For this you have to have a bridge allowing access to both connectors. Instead of building the standard impedance as part of the bridge, you have two outputs that you can balance against each other.



CABLE UNDER TEST

Now, this is the same basic bridge that Ken's been describing except that I have now two openings for two things to balance against each other. What we do in this case is to connect both ends of the cable to both ends of the bridge. The average impedance of the cable is likely to be the same at both ends since the cable was not especially made to taper from one end to the other. But the manufacturer tried to make it uniform, so the average impedance would balance out and wouldn't show on the output. If there is any mismatch in the connectors, there is one on each side of the bridge and their mismatches would balance out.

Now, if there is any chance that the attenuation is not enough and the signal may go in on one side and come out through the other side, and look as if it were a reflection, there is also a similar signal going the other way. And again, they will balance out. The only thing which is left is the random reflections which come from each end and because they are random, they are incoherent and they will not balance out. Moreover, each of them has the wave form of a noise. Thus we have, in effect, two noise wave forms that add up to give another noise wave form 3 db higher than each of them by itself. So when we make a measurement this way, all we have to do is subtract 3 db from the results and then we get the cable perfectly balanced against the best thing it could be balanced against, which is itself.

MR. TAYLOR: Did anybody have another question they would like to ask?

MR. SHIELD: Don Shield, Vancouver. Ken, I was wondering if you have come up with a practical limit to the length of cable for which your testing technique is useable? I know that 2000 feet is a typical length for a reel, but it seems to me that the length of the cable or the attenuation will have an effect on your results as well. Am I clear on that, or is that a confusing thing?

MR. SIMONS: The answer to that question is that the return loss method gives you a view into the first 500 to 1000 feet, depending on the loss of the cable. Of course, it doesn't matter how much longer than that it is, but you're not looking at the middle of the cable. You get a decidedly prejudiced view of each end of the cable and if the manufacturer, under the present circumstances, could make cable that was very good at both ends and bad in the middle and save money that way, I suppose you could get away with it. But it doesn't generally happen, if you have a cable that is good at both ends. All things being equal, it's apt to be good in the middle.

MR. TAYLOR: Thank you very much, again, Ken. We'll proceed onto the next paper by Mr. Allen Kushner of Times Wire and Cable, who is going to continue the discussion of cable by talking about, "Coaxial Cable Performance for CATV". This is a substitute for Dave Karrmann who was listed on the program. I introduce Mr. Kushner. [Applause]

MR. ALLEN M. KUSHNER (Times Wire & Cable, Division of The International Silver Company): Dave Karrmann was originally scheduled to write this paper. However, since the time we submitted his name he was taken off this particular project. I was assigned the job of writing the paper.

I watched with great interest Ken's paper because since I came with the Company my primary responsibility has been really to watch over the testing of cable. So I have seen some 300,000,000 feet of test reports reflecting basically what Ken has had on the board and it was quite interesting.

PURPOSE

The purpose of this paper is to discuss the characteristics of coaxial cable which are of major importance in CATV system performance. We shall attempt to accomplish this by showing how the cable affects system design and customer pciture quality. We also shall attempt to show the substantial improvements which have been made in cable design and manufacture in the past 15 years, and to discuss what remains to achieve the optimum cable design of the future. As a result of this