accurate measurements are desired. When measurements are made utilizing a jumper cable, an inline attenuator, or the meter switchable attenuator should be used to properly terminate the jumper cable. This is extremely important when measuring amplifier test points, since most test points present a high source impedance and thus the jumper cable, if not properly terminated, can have multiple reflections, with the indicated level dependent on the length of the jumper.

The problem of calibration of the field strength meter has been lessened with the commercial availability of accurate RF thermocouple transfer standards, such as the Model 440 Selby Micropotentiometer offered by Ballantine Laboratories. These units are inexpensive and can be calibrated by either the manufacturer or can be calibrated by the Bureau of Standards Calibration Labs to an accuracy of better than + 1 db over the VHF range.

To summarize, the requirements to measure the performance of modern CATV equipment requires accurate and stable test equipment. Furthermore, test methods and actual laboratory setups should be reviewed to insure that problems or improper techniques do not exist, whereby the equipment to be evaluated is not measured properly.

CHAIRMAN TAYLOR: Thank you very much Mr. MacMillan. We have just a few minutes to ask questions on test equipment to Mr. MacMillan. (No questions)

It is of particular pleasure to introduce our next speaker, Mr. I. Switzer from Lethbridge, Alberta. We always enjoy having our Canadian friends and counterparts attending our convention. Mr. Switzer's subject this afternoon will be time domain reflectometry. Mr. Switzer.

MR. I. SWITZER (LETHBRIDGE, ALBERTA, CANADA): The RF transmission lines used in CATV system are important and critical parts of the system. Emphasis in CATV marketing techniques on quality in pictures delivered to the subscriber makes it increasingly important that our coaxial cables have the best possible transmission characteristics when installed and that these characteristics should be maintained to a very high standard during the useful life of the cable.

Common CATV system practice for cable testing has progressed from simple transmission sweep testing, through "frequency domain reflectometry" to the present well accepted practice of use of the Swept RF Impedance Bridge for cable testing. The RF bridge provides a very sensitive test, in the frequency domain, for cable imperfections and flaws.

Recent developments in the precision oscilloscope field now make time domain reflectometry a practical and useful tool for CATV system application.

Reflectometry I shall refer to as the measurement of system characteristics by measuring reflections caused by imperfections. Measuring reflections as a function of frequency is reflectometry in the frequency domain; measuring reflections as a function of time is reflectometry in the time domain.

In general the frequency and time domains are related mathematically by the Fourier transform, and a description in either domain is a complete and sufficient description of the system; which representation is most useful depends on the application of the information. One might say that frequency domain information about a cable is most useful for considerations of frequency response and envelope delay. Time domain information is most useful for considerations of "ghosts". Strictly speaking, frequency domain implies measurement of both amplitude and phase. Because of instrumentation problems, phase is very rarely measured directly and for this reason most frequency domain measurements and techniques are, strictly speaking, deficient because of lack of phase information. Time domain measurements, are on the other hand, complete since only a plot of waveform versus time is required.

By way of example of the correspondence between time and frequency domain, the following example may be cited: The transmission characteristics of a television system can be determined in the time domain by recording the response of the system to a standard pulse of some kind. The output pulse may be compared to the input pulse and the characteristics of the system determined. Since television pictures consist of a complex pulse train, such a description is a very good test of a television system. However, if something is wrong with the system, it may be difficult to determine what and where the trouble is. The transmission characteristics of the system may also be determined by frequency domain testing. The response of the system may be plotted as plots of both amplitude and phase as a function of time. The amplitude response is the familiar frequency response curve. The phase plot is not so frequently seen but is an important part of the system test. It is not usually drawn because of uncommonness of phase instrumentation. Nevertheless, phase information is important, particularly for color transmission systems. Frequency domain description of the transmission system may in some circumstances be a very valuable guide to finding system troubles. Strictly speaking, the two tests are completely interchangeable, and the one used depends on the nature of the problems to which it is being applied.

In the field of transmission line testing there has been widespread application of TDR testing for many years. The transmission lines, however, were large power transmission lines, and the equipment used was not applicable to our coaxial cables. TDR testing is a kind of radar in which a pulse is sent down the line and reflections from imperfections are received and timed to give information on the location of the fault. The resolving power and accuracy of TDR systems depends on the "rise time" of the system. Pulses must have fast rise times and the oscilloscope systems for viewing the reflections must have sufficient response to display the rise times of reflections. The development of fast rise time pulse generators and "sampling mode" oscilloscopes has made application of TDR techniques practical for CATV system use. A typical modern TDR instrument has a system rise time of about 150 picoseconds, corresponding to a frequency response of 0-2, 300 MC.

The Hewlett-Packard Company introduced a TDR system as a plug in for their 140A oscilloscope system in 1964. We felt that this would be a very suitable instrument for CATV application and we introduced the use of this instrument into some of our systems in the summer of 1965, being possibly the first CATV systems to make practical study of cable and connector systems. A number of cable manufacturing companies also took up use of the instrument soon after its introduction.

High resolution TDR techniques had been used on a laboratory basis since sampling mode oscilloscopes were introduced a few years ago, but the H-P instrument made available a simple "black box" at a moderate price.

The TDR puts out a unit step function with a system rise time of 150 picoseconds and at a 1 volt level. The sampling system is capable of displaying reflections which are 60 db down (0.1%) from the incident pulse without overloading the system. When used for tests on short lengths of cable, the system is capable of very high resolution. We often use the TDR system for evaluating competing connector systems and fittings and we have been able to distinguish the rear part of an AF-201 type connector from an F-81 and terminating resistor at the other end of the connector, i.e. we can distinguish the front and back parts of a connector about $1\frac{1}{2}$ inches long.

We use a special version of the H-P instrument called the HO-5 modification which has an extra position on the range scale extending the calibrated range to about 2,500 feet.

Since the resolving power, and hence the ability of instrument to accurately determine the position of a fult depends on cable rise time or frequency response, there is a considerable loss in resolution in longer cable lengths because of the rapid loss of high frequency components implied by fast rise times. The frequency domain spectrum associated with the unit step function shape of the TDR pulse has high frequency components which go down at a 6 db per octave rate. If the dynamic range of the instrument is considered to be 60 db, and since pulses have to go both ways through the cable before they are observed as reflections, a 1,000 foot piece of cable may be considered to have a cut off at the frequency at which its two way attenuation is 60 db. For .412 aluminum cable this is about 500 Mc. This same 1,000' piece of cable has a DC loss (two way) of only 0 5 db.

Since time and distance in the cable are related by propagation velocity, we can use the TDR to determine the nature of a fault and its position. Frequency domain techniques will tell us that there is a problem at a certain frequency or band of frequencies, but they will not tell us where the problem is. The TDR shows us where the fault is and tells us something about the nature of it. The precision of fault location depends on the accuracy of time scale calibration of the instrument and the echo rise time which depends on cable length and high frequency attenuation. The basis time scale accuracy on the instrument is 5%, but translation to distance requires accurate information on propagation velocity. We have noticed some variance in cables from published specifications and wherever possible we calibrate the instrument on the actual piece or type of cable being checked by measuring time to a known termination or discontinuity. This improves accuracy considerably.

In terms of practical application, we have found the TDR most useful in checking new cable during construction. The TDR detects any construction flaws, such as kinks, cracks, dents, and also checks quality of connections and terminations. We are even able to detect connectors that have been out on by running and tubing cutter right through the sheath instead of cracking the sheath through in the approved manner. Use of the instrument has a powerful psychological effect on construction crews since they know that every part of the cable is being "radar monitored" for quality. The instrument should be used in conjunction with a return loss bridge since it is possible to have small periodic defects which an operator might pass by TDR as acceptable without realizing that their periodic spacing is adding up to a serious frequency domain effect.

In operating systems we use the TDR for cable troubleshooting. It rapidly spots bad taps, connectors and terminations. An accurate tape measure is an essential accessory. We have found that when the TDR points out a bad tap 183 feet down the line, that is exactly where it is and we have been mislead several times by eyeballing distances indicated by the TDR or by pacing them out instead of measuring them.

Wet cables, connectors and splices are easily detected. The moisture alters the dielectric constant of the dielectric which changes the characteristic impedance of the cable and hence causes reflections which the TDR displays. Wet sections are pinpointed for drying out or replacement. One of our systems more than paid for the cost of its TDR on this one application by using it to examine all the cable in a system that was considered due for replacement in an all-band conversion program. Certain cable sections were found still quite serviceable and were left in place.

Another application is evaluation of connectors. We evaluate connectors which vendors offer us and have found for example that there are significant differences in the match of different manufacturers versions of the same connector, for example the common F-81 connector. When we first got our TDR we layed out some scrap cable sections with different connectors and examined them with the TDR so as to train our technicians to recognize the characteristic display from different fittings. We then started to kink the cable and pound in dents with a hammer. We found that the return from a very serious dent (which we would have rejected by visual inspection) was no worse than the return from the splice connector which we would have used to repair it!

Since the TDR principle is directly related to the situations that cause ghosts in our system, it is a powerful instrument for tracking down ghost sources and correcting them. One must take care not to over use the instrument in this kind of application. The TDR output pulse has frequency components to 2,300 Mc and the oscilloscope system is capable of displaying these frequencies. Normally the instrument should be restricted to broad band systems where a fault will cause "broad band reflections" which are valid reflections at virtually all frequencies. In complete CATV systems we have components which are good impedance matches in only a comparatively narrow band of frequencies. For example amplifiers are usually adjusted to present a good termination to an input line at only the frequencies normally used, typically 54-200 Mc. A perfectly good amplifier could reflect energy in the TDR pulse outside these frequencies and show up as a bad match on the TDR display, which indeed it is at frequencies outside its working band. In such cases the TDR frequency response, rise time, should be restricted by filters. We are experimenting with low pass coaxial filters for this application. Reflections still apparent in this frequency limited system are of concern. Their position cannot be accurately determined because of the restricted rise time of the filtered system, but the filter can be removed for more accurate determination of location of the fault.

We are beginning to believe that we may be over emphasizing the importance of some of the cable flaws that we have been detecting and rejecting with the TDR because of the great resolving power of the instrument. Corrugated sheath cables and disc insulated cables are very commonly used in CATV systems. We know these to be good cables in our frequency range because although the corrugations and discs are strictly speaking impedance discontinuities, their dimensions are so small compared to the wave lengths we use that they have negligible effect on transmission at our frequencies. If we had TDR with even greater resolving power than our present instruments, we would be able to distinguish the discontinuities caused by corrugated sheath and disc insulators. If we extend this principle to wave lengths closer to those we use, we realize that the TDR system has frequency components ten times greater than our highest frequency of interest, and these high frequency components are showing us flaws that are really quite small compared to our wave lengths and which do not materially contribute to transmission degradation. We are experimentally applying our low pass filters to such situations to see whether we are indeed being too fussy about cable flaws now that we have such a powerful cable examination tool. The TDR is capable of extreme precision in determining impedance of cables. For ordinary cables it is capable of comparing their impedance within 0.1 ohms. I have said "comparing impedance". Actual impedance cannot be determined with a standard to compare to. Unfortunately there do not appear to be any 75 ohm standard transmission lines available. Standard 50 ohm sections are available with calibration traceable direct to NBS. Comparison of 75 ohm cables to 50 ohm standards would reduce accuracy to about + - 2 ohms. Resistances are difficult to measure at VHF and a 75 ohm termination may be considered to be that termination that perfectly terminates a 75 ohm transmission line. A 75 ohm transmission line can be defined in terms of dimensions of inner and outer conductors and characteristic of dielectric but so far we have been unable to obtain accurately constructed 75 ohm line sections to use as an absolute standard with our TDR systems.

We buy equipment items with specified VSWR or return loss or characteristic impedance without too much concern about the accuracy of the specification checks. We may run into some problems if we are building systems with tight impedance match requirements or specifications in putting together items from different sources which have been checked for impedance match against questionable standards. The situation becomes apparent in considering specification of cable. A typical aluminum-sheathed cable spec calls for impedance of 75 ohms + - 2 ohms. This is measured usually by a method that gives the average impedance for a piece of cable. Additional specs on frequence domain measurements specify return loss at minimum 25 db. Again this is an average for the whole length of cable. The TDR permits checking the impedance profile along the whole length of cable. The impedance at the end of the cable when it is cut at any particular point may vary from 73 to 77 ohms. It is quite possible that a 73 ohm end may be spliced to a 77 ohm end. This would give a reflection coefficient of 0.0267 or return loss of 31.5 db. Systems requiring better match would have to check such splices and select cable reels to give ends that match. The TDR when used with a suitable 75 ohm impedance standard can check cable impedance profiles with great accuracy.

Several problems have been encountered in application of the H-P instrument to CATV. The H-P TDR was designed for 50 ohm systems and has a source impedance of 50 ohms. When used in a 75 ohm system, there is a mismatch which causes some difficulty due to multiple reflections caused by reflection at the mismatch between TDR and 75 ohm cable. H-P have an adapter available which consists of a 25 ohm resistor in series with the cable. This back matches the cable since the reflected pulse sees the 25 ohms in series with the 50 ohm impedance of the TDR. This introduces a 6 db loss in sensitivity due to voltage divider action on both the incident and reflected pulses. A resistive minimum loss matching pad can be used with somewhat higher loss of sensitivity. For precise quantitative measurements, the instrument can be easily recalibrated to compensate for either adapter. I personally prefer to use the MLP or no adapter at all, making corrections for multiple reflections according to the formulas in H-P's application manual.

Some problem has been experienced with 60 cycle AC pickup particularly on cables on joint use poles. This is usally noticed on lines with low impedance shunts such as resistive terminations. The pickup seems to disappear when the line is completely opened. H-P is developing a unit called a "humdinger" to alleviate this problem.

We have found the TDR, particularly the version by H-P, to be a reliable, very useful instrument for routine use by CATV systems, large and small. In the words of one of our system managers - "I don't know how we ever got along without it".

CHAIRMAN TAYLOR: Thank you very much and I want to apologize first off for eliminating the punch line at my introduction. Mr. Switzer is a CATV consulting engineer in Lethbridge and also has been associated considerably with the famous players in their CATV systems throughout Canada.

Our next speaker, Mr. Isaac S. Blonder, Chairman of the Board of Blonder-Tongue Laboratories, Inc., will speak to us on the importance of technical training. Mr. Blonder.

MR. ISAAC S. BLONDER (BLONDER-TONGUE LABORATORIES, INC.): At the back of the room there is a table containing my speech and also another paper on CATV technical training that was prepared by Fred Schulz who is in charge of our sales training. I was delighted at the opportunity to be able to talk about technical training. I've done nothing else all my life.

Technical knowledge may be categorized as having four general divisions: scientist, engineer, technician, craftsman. Technical training is accomplished in these approximate areas: university, technical institute, high school, military, apprentice, self-study.

Measurement standards for the level of technical knowledge achieved are virtually non-existent. The CATV operator, and indeed every other employer