# STANDARDIZED RETURN LOSS MEASUREMENT OF CABLE TELEVISION DISTRIBUTION CONNECTORS

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## ABSTRACT

Return loss is a key parameter describing the electrical performance of cable television coaxial connectors. It is currently measured in a variety of different ways, making it difficult to compare manufacturer's specifications. This paper provides a standard approach which can consistently yield meaningful data.

The method is applied to measure the return loss of feed through connectors used for half inch distribution cable. This technique measures the effect of variations in center conductor and outer conductor diameters, connector length, and dielectric supports.

The measurement range is from 0dB to 50dB return loss. Experimental results, error analysis and fully dimensioned drawings of the special hardware are included. Transmission loss measurement and measurement of other connector types is described.

## INTRODUCTION

As cable TV systems and local area networks using 75 ohm coaxial hardware extend to higher frequencies, problems with unwanted reflection of signals become more severe. System designers must rely on manufacturer's specifications to ensure adequate design margins, but in some cases these specs are based on measurements made with systems that contribute a high degree of uncertainty to the measurement. Worse yet, measurements made with "tuned" systems may make a product look better than it actually is. This paper will cover the theory of transmission line reflections, their measurement, uncertainty analysis, design of a fixture for connector reflection measurement and experimental results.

## TRANSMISSION LINE THEORY

The chacteristic impedance $Z_o$ of any lossless transmission line is given by

$$Z_o = \sqrt{\frac{L}{C}} \tag{1}$$

where L is the inductance in henrys per unit length and C is the capacitance in farads per unit length. In a coaxial transmission line,

$$L = \frac{\mu\mu_o}{2\pi} \cdot \ln\left(\frac{b}{a}\right) \tag{2}$$

and

$$C = \frac{2\pi\varepsilon\varepsilon_o}{\ln\left(\frac{b}{a}\right)} \tag{3}$$

where $\varepsilon$ = Relative Permitivity of the Dielectric
$\varepsilon_o$ = Permitivity Constant = $8.85 \times 10^{-12}$ farad/meter
$\mu$ = Relative Permeability of the Dielectric
$\mu_o$ = Permeability Constant $1.26 \times 10^{-6}$ henry/meter
a = Diameter of Center Conductor
b = Inner Diameter of Outer Conductor

Incorporating equations (2) and (3) into equation (1) gives

$$Z_o = \sqrt{\frac{\mu\mu_o}{4\pi\varepsilon\varepsilon_o}} \cdot \ln\left(\frac{b}{a}\right) \tag{4}$$

Since the dielectric usually has relative permeability = 1 (non-magnetic), we may write

$$Z_o = \frac{59.96}{\sqrt{\varepsilon}} \cdot \ln\left(\frac{b}{a}\right) \tag{5}$$

Equation (5) is extremely useful in the design of coaxial connectors and transmission lines. It has been used extensively for the design of the standardized return loss fixture.

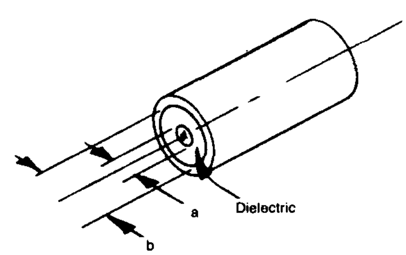



**Figure 1**
**Coaxial Transmission Line**

Cable TV systems have a characteristic impedance $Z_0$ of 75 ohms, partly because this gives a convenient ratio of center conductor to outer conductor size, and partly because this is close to the optimum impedance for minimum signal attenuation. If a, b, or ε in Equation (5) are suddenly changed so that the impedance is no longer 75 ohms, a discontinuity is created which affects the performance of the transmission system.

## Discontinuities

Any discontinuity in impedance along a transmission line causes power to be reflected back from the discontinuity.

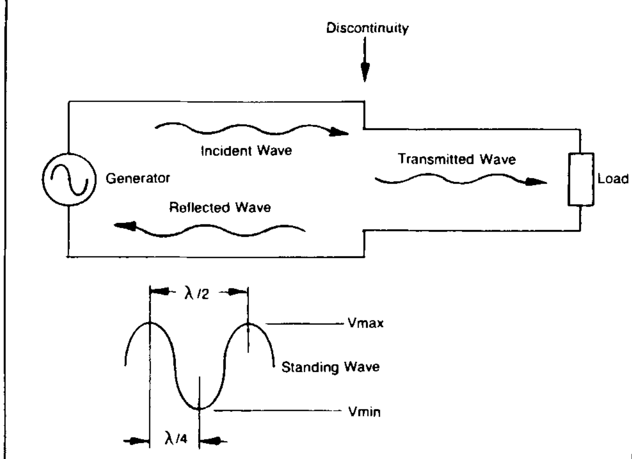



**Figure 2**
**Effect of an Impedance Discontinuity**

The magnitude of the reflected wave is expressed by the reflection coefficient ρ:

$$\text{Reflected Wave Voltage} = \rho \cdot \text{Incident Wave Voltage} \quad (6)$$

where

$$\rho = \frac{Z_2 - Z_1}{Z_2 + Z_2} \quad (7)$$

If $Z_2 = Z_1$, then $\rho=0$ and no wave is reflected. If $Z_2$ is an open circuit (impedance = infinite), then $\rho=1$ and the incident wave is totally reflected. Similarly, if $Z_2$ is a short circuit (impedance = 0), then $\rho=-1$ and the incident wave is again totally reflected but 180 degrees out of phase with the open circuit reflection. The logarithmic expression of ρ is known as return loss, defined as

$$\text{Return Loss} = -20 \cdot \text{LOG}_{10}|\rho| \quad (8)$$

Return loss varies from 0dB (100 percent reflection to infinity (zero reflection), so the higher the return loss, the better the impedance match at the discontinuity.

The combination of incident wave traveling to the left and reflected wave traveling to the right forms a standing wave on the line. The amplitude of the alternating voltage varies with position along the line as shown in Figure 2, and the ratio of $V_{max}$ to $V_{min}$ is called the standing wave ratio, or SWR.

$$SWR = \frac{|V_{max}|}{|V_{min}|} \quad (9)$$

The relationship between SWR and ρ is

$$SWR = \frac{1 + |\rho|}{1 - |\rho|} \quad (10)$$

The impedance seen looking into a mismatched line varies with position as the SWR so that

$$Z_{max} = Z_1 \cdot SWR \quad (11)$$

and

$$Z_{min} = Z_1 \div SWR \quad (12)$$

If a cable TV system has poor SWR, the signal level will vary unpredictably along the line and the impedance that an amplifier sees on its output may vary substantially from the load it was designed to drive. Good system design practice, therefore, dictates low SWR connections.

## Multiple Reflections

Systems with multiple reflections can be analyzed by representing each reflection as a polar quantity with magnitude ρ and phase shift θ. The magnitude of the overall reflection is the magnitude of the phasor sum of the individual reflections. A simple example is worked out in Figure 3, which illustrates the effect of a mismatched connector section inserted in a 75 ohm line at 250 MHz. As the frequency increases, the phase shift between $\rho_1$ and $\rho_2$ increases, increasing the overall reflection from this section. High frequency operation places more stringent requirements on connector design. (Incidently, computers are invaluable for keeping track of modelled systems with many reflections, and "sweeping" the model by varying λ to predict braodband performance.)

In reflection measurement set-ups, the effect of multiple reflections is to increase the uncertainty of the measurement. For example, if a device with $\rho_1$ = .05 is connected through an adapter with $\rho_2$ = .02, the measured reflection coefficient could vary between .03 and .07 since the phase difference between the two reflections is unknown (Figure 4). This is the principal problem with measurements where the connector being measured is seen through adapters and cable lengths which have reflections of their own that can exceed the reflection from the connector under test.

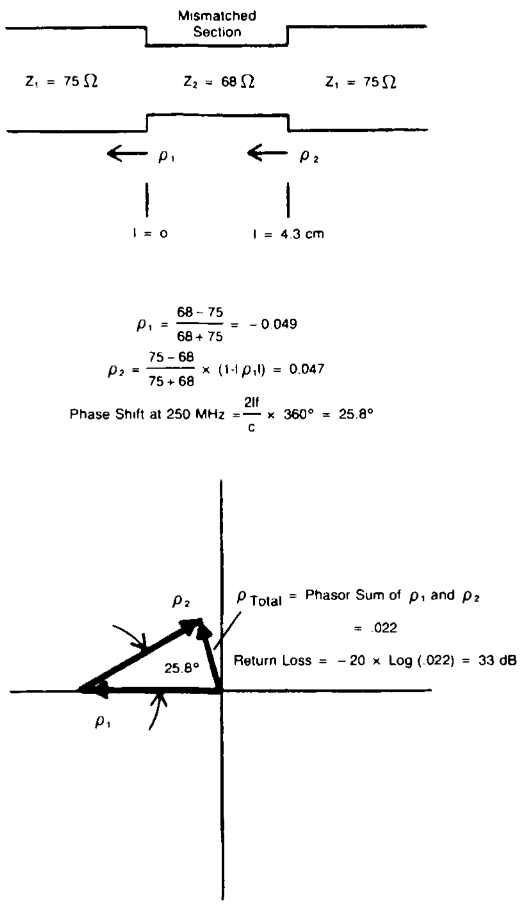



**Figure 3**
**Mismatched Connector Example**

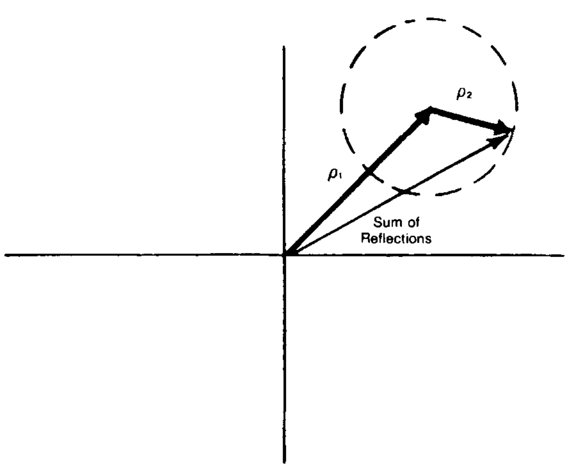



**Figure 4**
**Uncertainty Due to Multiple Reflections**

## REFLECTION MEASUREMENT TECHNIQUES

All reflection measurement techniques require a means of producing test signals and measuring their amplitude accurately. We selected a Hewlett Packard 8754A Network Analyzer for this task. It includes a sweep generator to produce 4 MHz to 1300 MHz signals, two calibrated receiver channels and a logarithmic CRT display of signal amplitude. Several other manufacturers produce similar instruments. In addition to the Network Analyzer, some means of monitoring the reflections is needed.

### Slotted Line

A slotted line is a transmission line section that has a narrow slot or groove running its length. A probe can be inserted in the slot and slid up and down the line until $V_{max}$ and $V_{min}$ (Figure 2) are found. Thus, SWR is measured directly, and $\rho$ and return loss can be computed.

Slotted lines are very accurate, but they must be longer than a quarter wave length to ensure finding the peak and trough of the standing wave. At 50 MHz, the length must be greater than 1.5 meters, making precision fabrication difficult. That is why they are generally reserved for use above 500 MHz.

### Directional Coupler

The directional coupler provides a means of separating the forward-traveling and backward-traveling waves through controlled interaction of parallel transmission lines (Figure 5a). Modern coaxial directional couplers are small and cover a broad frequency range, making them widely used. The signal labelled "R" is the coupled wave, which is proportional to the reflected wave. In use, a short circuit is placed on the test port (100 percent reflection = 0dB return loss) and "R" is measured. Then the short is removed and the device under test is connected. The drop in reflected signal expressed in dB's is the device's return loss. Since most network analyzers have a log display, return loss can be read directly.

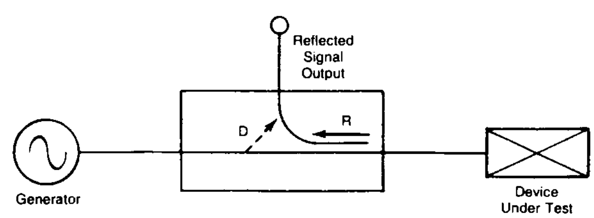



**Figure 5a**
**Directional Coupler**

The range and accuracy of small reflection measurements made with directional couplers is limited by the directivity of the coupler. The signal labelled "D" in Figure 5a is the unwanted leakage of the incident wave into the coupled line. This combines as phasor with "R" and directly affects measurement uncertainty, just as the adapter did in Figure 4. Most precision directional couplers have a directivity of 40dB, which is adequate for many applications. But if the return loss of the device under test has a return loss of 40dB, the measured return loss could vary between 34dB (both signals add) and infinity (both signals exactly cancel). Techniques such as short circuit/open circuit averaging can improve the accuracy, but generally require extra computation on a frequency-by-frequency basis.

## VSWR Bridge

The VSWR bridge schematic is shown in Figure 5b.

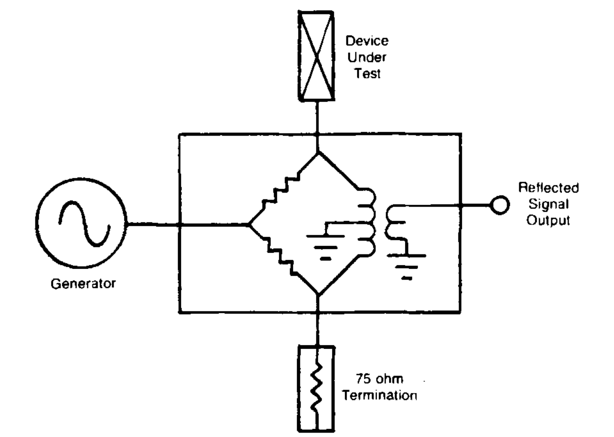



**Figure 5b**
**VSWR Bridge**

Through precision transformer winding, higher directivity than a directional coupler can be achieved. The Anzac model RB-3-75 is specified to have 48dB minimum directivity from 3 to 1,000 MHz. Since the higher directivity directly improves the measurement accuracy, this model was used for our tests.

The complete measurement set-up is shown in Figure 6. The HP 8502B Test Set is used to supply a reference leveling signal to the network analyzer. The HP 8750A Storage Normalizer provides a means of "remembering" the short circuit reflection calibration so that plotted calibration traces are unnecessary. The HP 11852A 75/50 Pad provides a means of adapting the 75 ohm bridge to the 50 ohm network analyzer input. Finally, there is the test fixture, the subject of the rest of this paper.

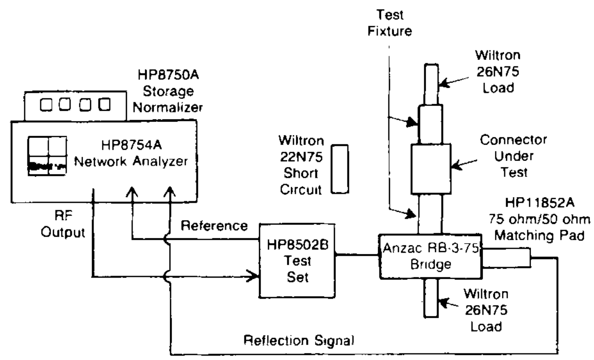



**Figure 6**
**Test Equipment Setup**

## CABLE TV FEEDTHROUGH CONNECTOR MEASUREMENT

### Problems

There are three major problems hindering accurate feedthrough connector measurement:

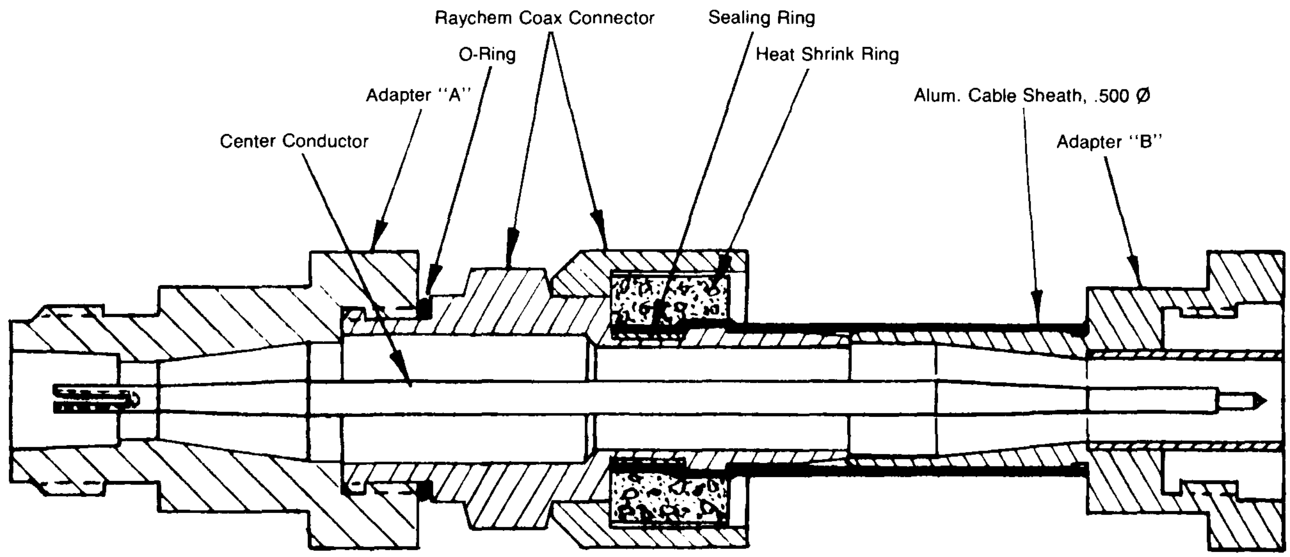
1. Connector reflection measurement assumes that no reflections come from beyond the connector (i.e., the load). "Homebrew" loads may have their own reflections which contribute uncertainty to the measurement. Furthermore, designs for these loads are not widely avaliable and have not been standardized by the industry.

2. Feedthrough connectors are designed to work with cable, but the introduction of cable into the measurement loop contributes uncertainty and non-repeatability to the measurement.

3. Precision lab test equipment usually uses Type N connectors. The adapters available to go from Type N to cable have refections of their own similar in magnitude to those from feedthrough connectors, making accurate measurement impossible.

### Solutions

To solve the load problem, we decided to use a commercially available 75 ohm termination, the Wiltron 26N75. It has a specified return loss of >52dB to 1,000 MHz, and a male Type N connector. We then designed a fixture that (a) mates with the 75 ohm Type N connectors on the test port of the VSWR bridge and the load, (b) tapers to the dimensions of half inch cable TV coax with a .111 inch center conductor, (c) allows for mounting the feedthrough connector on the transmission line, and (d) maintains 75 ohm impedance throughout, per Equation 5. The center conductor is suspended only by its ends so that the impedance is not disturbed by supports or "beads". Figure 7 shows the fixture assembled with a Raychem feedthrough connector.

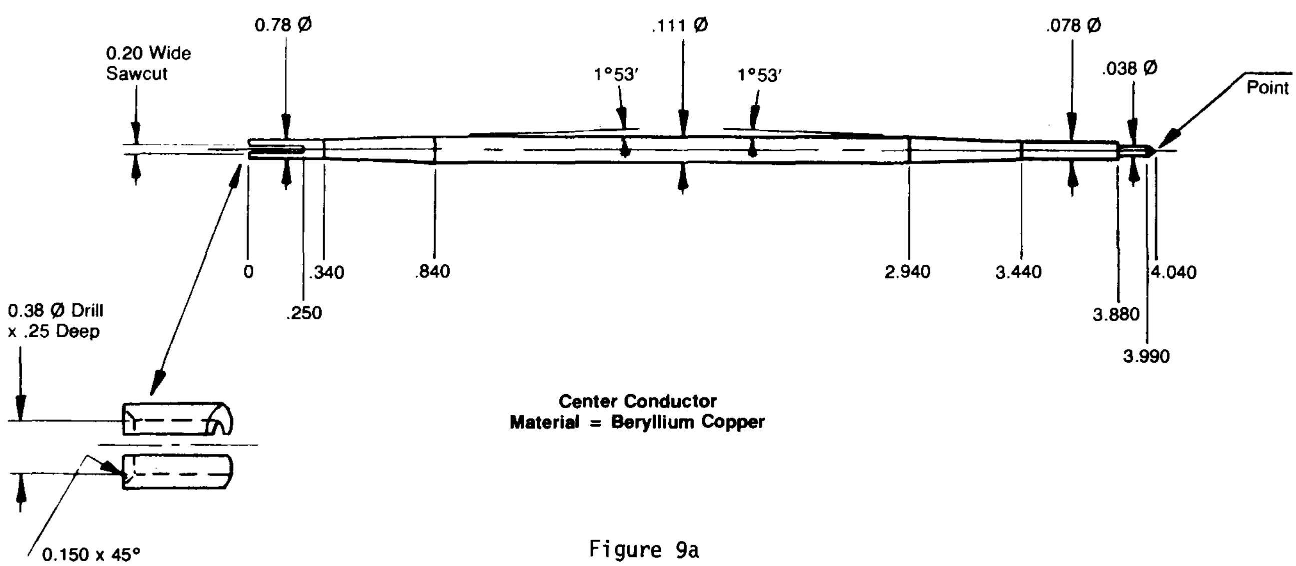



**Assembly of Coaxial Connector Test Fixture**

Figure 7

The center conductor must be held to tight tolerances for good performance. In particular, the line's impedance is sensitive to the center conductor's diameter, and the taper sections must begin and end on the same plane for center and outer conductor sections. Type N connectors have a specified "pin depth", that is distance between the shoulder or end of the center conductor and the reference plane in the outer conductor section. Therefore, the overall length of the fixture and center conductor must be accurately controlled.

Detailed drawings for the fixture are shown in Figure 9. The center conductor is made from beryllium copper so that the female pin fingers will be springy; the outer sections are brass. The connector is aligned with adapter "B" by a section of aluminum CATV outer conductor, which has been straightened to keep the components on axis. There is nothing tricky about this approach to connector measurement. It relies only on well known standards, formulas and commercially available products.




**Center Conductor**
**Material = Beryllium Copper**

Figure 9a

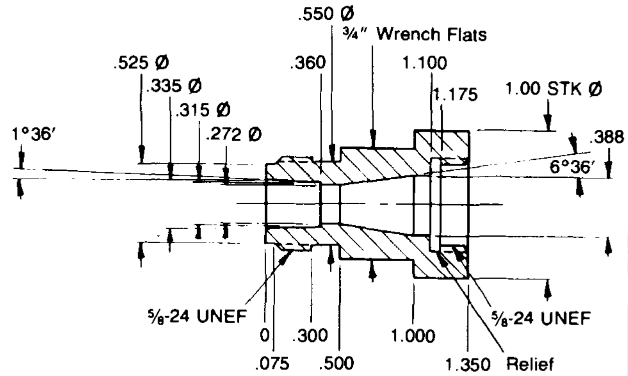



Figure 9b

**Adapter "A"**
**Material = Brass**

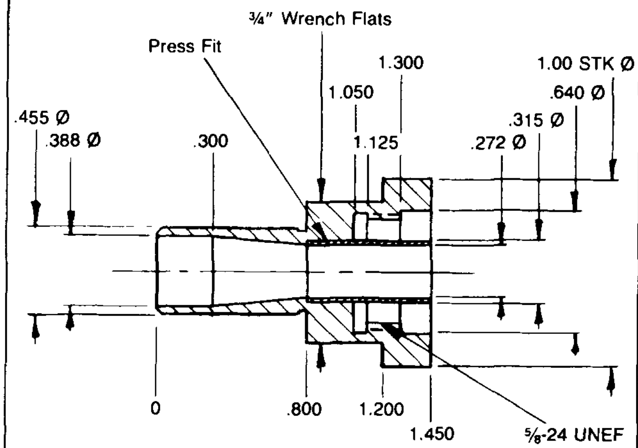
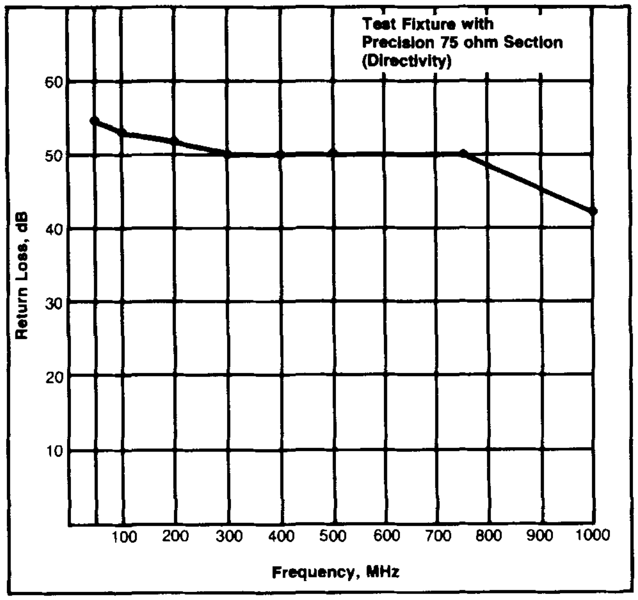



Figure 9c

**Adapter "B"**
**Material = Brass**

Evaluation of the test fixture was done with a dummy connector section designed to maintain exactly 75 ohm impedance. The return loss of the fixture is plotted in Figure 10 (<50dB to 750 MHz, 42dB @ 1,000 MHz). This is actually the combination of reflections from the fixture, the load and the directivity error signal, and comprises the effective directivity of the set-up. Since this effective directivity signal combines with the reflections from the connector under test with an unknown phase shift, it is the major contributor to the uncertainty of the measurement (Figure 4). Other lesser sources of error include the network analyzer's detector linearity ($\pm$0.5dB) and the repeatability of the connections.

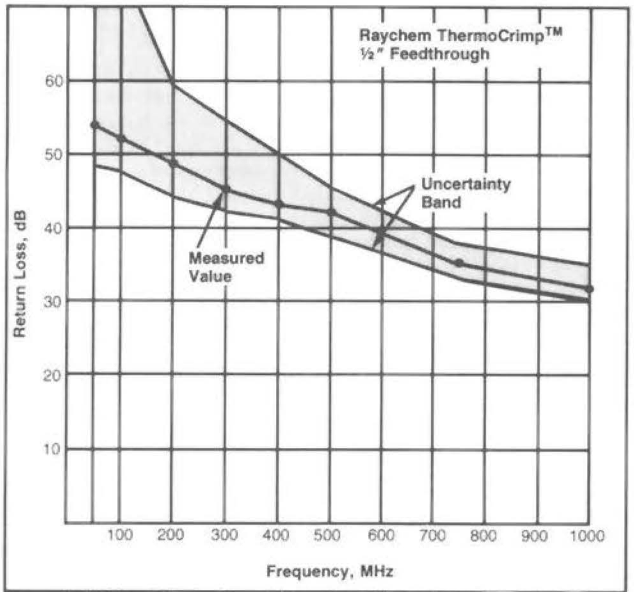


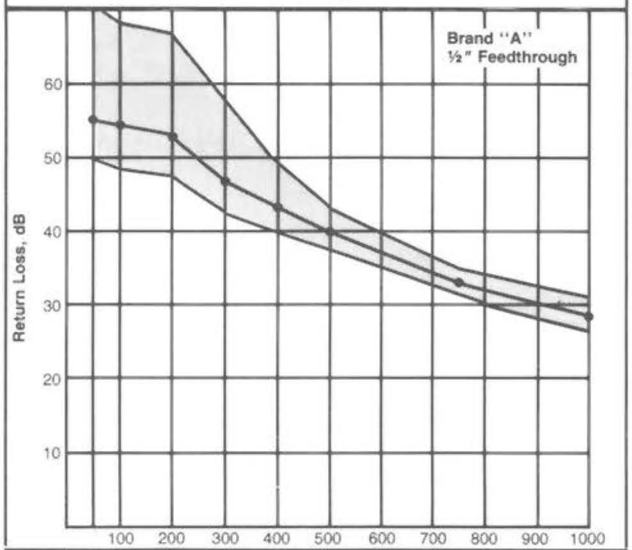

RESULTS

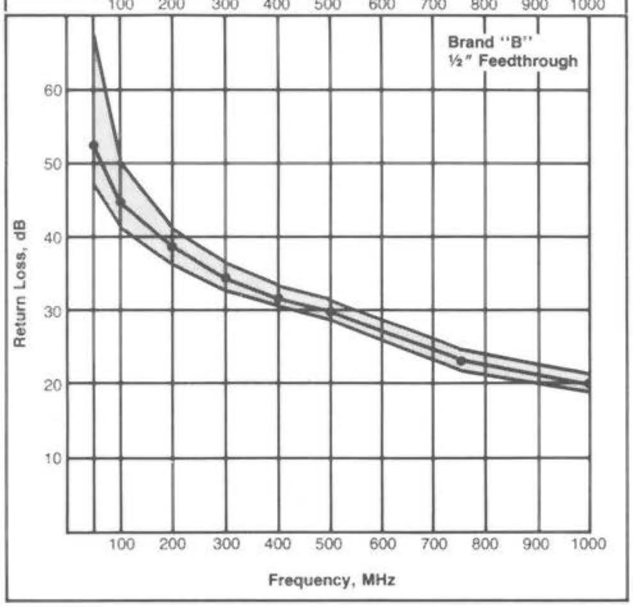
Eight samples each of the Raychem Thermo-Crimp connector, Brand "A" connector and Brand "B" connector were tested. The averages are plotted in figures 11, 12 and 13. The standard deviations were generally about 1.5dB, indicating fairly good repeatability. Brand "B", one of the most widely used connectors in the industry, clearly has inferior electrical performance compared to Raychem and Brand "A".

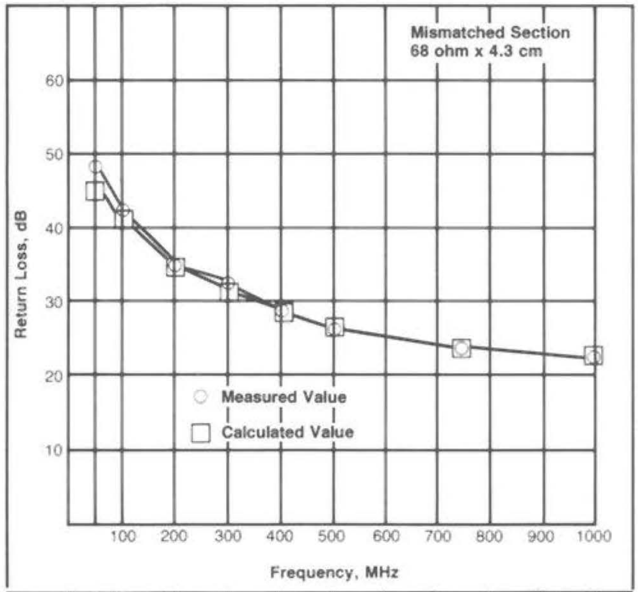
To illustrate the utility of the fixture, a mismatched connector with a uniform impedance of 68 ohms and length of 4.3cm was produced and measured. Figure 14 shows the predicted return loss based on a computer model and the measured return loss. The agreement between predicted and actual results indicates a reliable test.

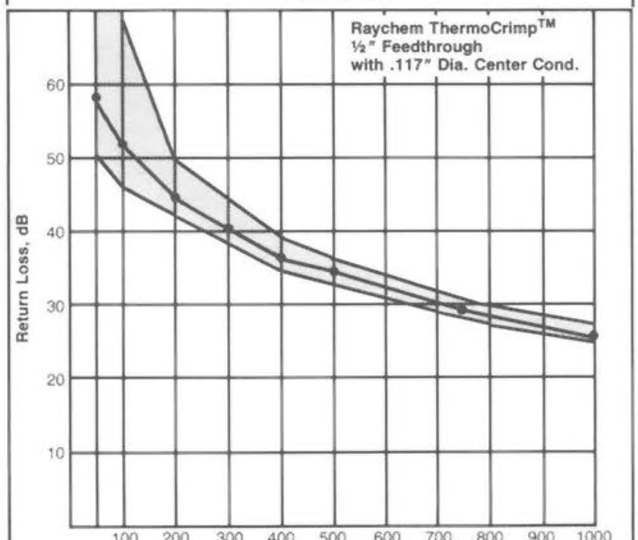
Not all half inch cable TV coax has the same diameter center conductor. The most commonly used cable has a center conductor diamter of .111 inches, but some older cables have a .099 inch center conductor and some recently introduced cable (Comm/Scope QR-500) has a .117 inch center conductor. Since the impedance of a coaxial line is sensitive to center conductor diamter, special center conductor sections of .099 inch and .117 inch diamter were designed for the test fixture. The measurement data for the Raychem connector with these sections, and for an alternate Raychem connector designed for a .099 inch center conductor, is shown in Figure 15. (A slight impedance mismatch is present because the tapered outer conductor sections were designed for a .111 inch center conductor and new sections were not made for this test.)

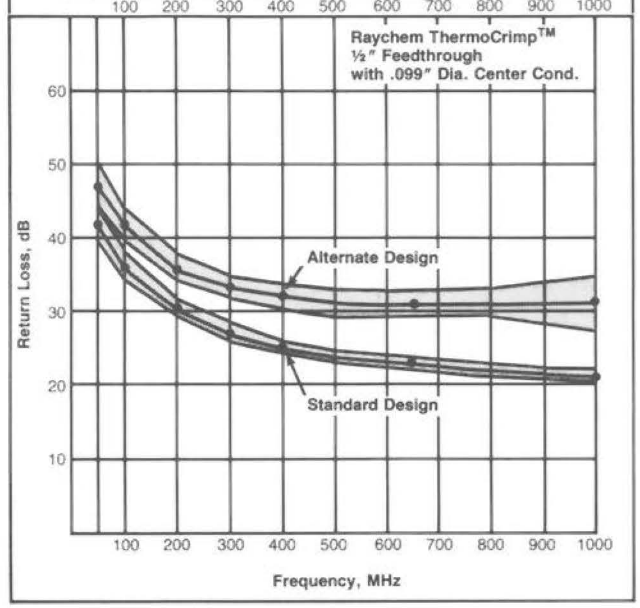

Raychem ThermoCrimp™
½" Feedthrough
Uncertainty Band
Measured Value
Return Loss, dB
Frequency, MHz


Brand "A"
½" Feedthrough
Return Loss, dB


Brand "B"
½" Feedthrough
Return Loss, dB
Frequency, MHz


Mismatched Section
68 ohm x 4.3 cm
Measured Value
Calculated Value
Return Loss, dB
Frequency, MHz


Raychem ThermoCrimp™
½" Feedthrough
with .117" Dia. Center Cond.
Return Loss, dB


Raychem ThermoCrimp™
½" Feedthrough
with .099" Dia. Center Cond.
Alternate Design
Standard Design
Return Loss, dB
Frequency, MHz

## OTHER TESTS

### Insertion Loss

Loss of signal in connectors can be due to lossy dielectrics, resistive connections, or signal egress. It can be easily and accurately measured using the fixture by feeding the transmitted signal back to the network analyzer rather than terminating it in the load (Figure 16). None of the connectors measured exhibited insertion loss greater than .05dB, indicating that this is not a serious connector performance issue.

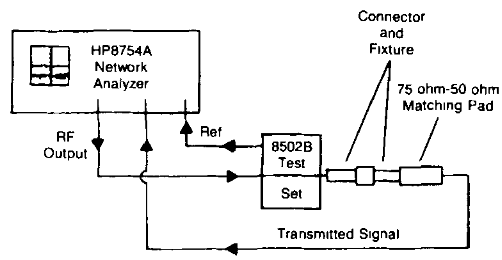



**Figure 16**
**Insertion Loss Test Setup**

### Dielectrics

Most connectors use an insulating "bead" to center the center conductor. The effect of variations in raw material, molding processes, dimensions, etc., can be accurately assessed using the fixture described. Quality control of finished parts is also simplified.

### Different Sizes and Types

The fixture design can be modified to allow testing of connectors for the different cable sizes. The tapers should remain gradual, pin depth controlled, and the fixture's performance verified using dummy sections.

Pin-type connectors and in-line splices can also be tested by this method. The center conductor will be split and it is suggested that the connector's pin be cut short and totally engulfed by the fixture's center conductor so that uniform impedance can be maintained. Again, fixture performance verification must be done to ensure accurate results.

## CONCLUSIONS

A technique has been described which allows accurate and reproducible return loss measurement of cable TV connectors. The method is based on existing standards and as such, is available for all to use. It is useful for connector development and test, quality control, and evaluation of existing products on the market. Standardized test methods should help component manufacturers and system designers improve overall system performance, maintaining a healthy growth in the industry.

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