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OFS

INTRODUCTION

The rapidly increasing utilization of wavelength-division multiplexing has generated a significant growth in demand for attenuators in singlemode fiber-optic networks. Usually these attenuators are employed with single-fiber interconnections, for which the prevalent connectors are presently the FC, SC and ST. These differ only as to attachment hardware and share a 2.5mm-diameter cylindrical ferrule in which the optical fiber is embedded centrally. Driven by a need for higher interconnection densities, a new generation of connectors has appeared. Relevant to the subject at hand are the LC and the MU, each of which is based on a 1.25mm-diameter ferrule. In this paper we describe an attenuation scheme appropriate to either of the connector sizes.

Fixed, as opposed to variable, attenuators have been classified by Telcordia as "connector receptacle, optical pad, and patch-cord attenuators"[1]. The focus here is a form of receptacle (or adapter) attenuator; and it, like an optical pad, is applied at a connection point such as on an interconnection panel or on the exterior of optoelectronic equipment. Because of this functional similarity and because optical pads (called buildouts by some manufacturers) are widely used, it is useful to review the construction and use of an optical pad.

An optical pad, such as shown in Figure 1 along with two connector plugs and an adapter, has male and female ends, the former having the structure of a connector plug and the latter behaving as one half of an adapter. Attenuation is achieved through special treatment of fiber embedded in a ferrule inside the optical-pad housing. Often this is done by using a section of absorbing fiber there. Manufacturing processes are similar to those of assembling and mounting connector plugs, so optical pads generally are robust. A key attribute is that, with access available to only one side of an optical interface, the level of attenuation can be changed easily by unplugging one optical pad and plugging in another.

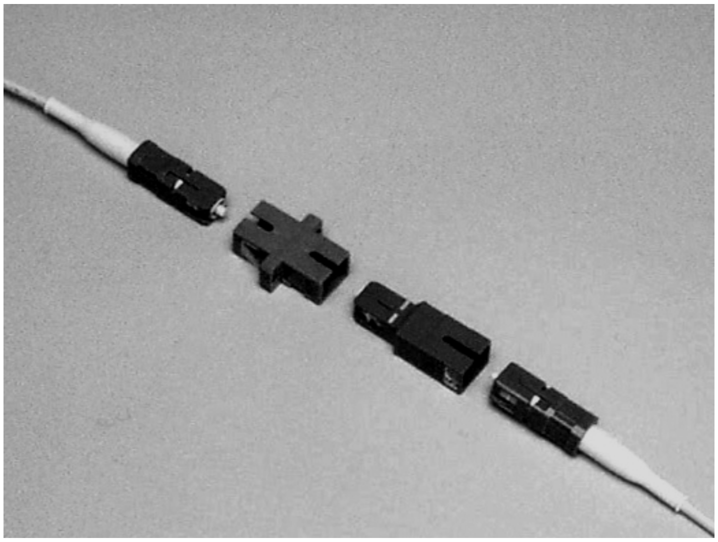

Figure 1 Optical Pad
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An adapter-attenuator as the name implies, is one in which some sort of element is mounted in the alignment sleeve of the adapter. This form of attenuator requires no additional space and is relatively inexpensive to manufacture. However, a significant drawback is that often one cannot change attenuators while having access to only one side of an interface. To correct this deficiency, a split-adapter system has been developed by letting an adapter comprise two distinct parts: a "base", which is permanently mounted in a panel and serves as the connector port on one side of an interface; and a "cap", which contains the alignment sleeve and serves as the other connector port. An adapter is formed when a cap is attached to a base through a mechanical latching arrangement. One family of components comprises ST and SC bases along with ST, SC and FC caps. A second family comprises LC bases and caps. Attenuator elements can be housed in the caps, so each type of cap has associated with it a family of attenuators. Attenuation is easily changed because a cap can be removed and replaced without special tools.

After describing the two families of split adapters, we discuss the characteristics of a relatively new form (plastic spacer) of attenuator element.

SPLIT ADAPTER FOR 2.5mm-FERRULE CONNECTORS

For singlemode single-fiber connections, the FC, SC and ST connectors are currently the most popular. They are all based on 2.5mm, usually ceramic, alignment ferrules; and this commonality, along with that of corresponding alignment sleeves, facilitates the mating of these otherwise dissimilar connectors. Figure 2 depicts the components of a modular system that permits mix-or-match interconnections; SC and ST bases are in the background, and SC, FC and ST caps are in the foreground.

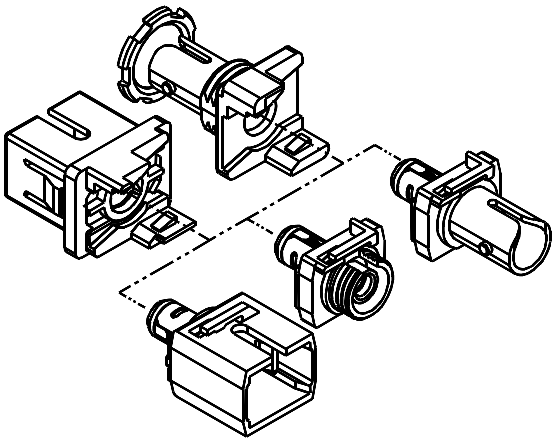

Figure 2 SC/FC/ST Split Adapters

As any one of the caps is being attached to one of the bases, the cylindrical portion, containing the alignment sleeve and visible at the rear of each cap in Figure 2, is inserted into the corresponding circular hole in the base. Behind that hole is the ferrule of the base-side connector, and thus the sleeve accepts the ferrule as the cap is advanced into place. An important feature of the design is the means of retention of a cap in a base. Retention is accomplished by the mating of wedge-like stops on the parallel walls of a base with corresponding cavities in a cap. Thus once final engagement is effected, the stops prevent axial motion of the cap relative to the base.

Attachment of a cap to a base is achieved in two steps: first the cap, with orientation about 15 degrees counterclockwise of final position, is advanced into flush contact with the base; second the cap is rotated into final position where its orientation is maintained by a locking beam. Disengagement is effected by depressing the locking beam and reversing the steps. The kinematics are illustrated in Figure 3.

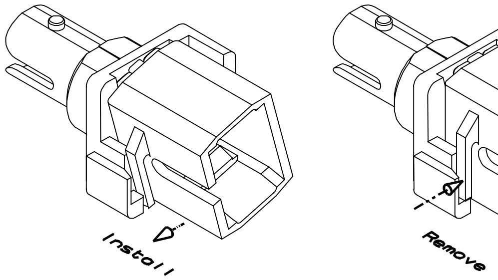

Figure 3 Kinematics of Attachment and Detachment

Need for the configuration, ST base and SC cap, shown in Figure 3 was the initial stimulus for the design, and the rotation associated with the attachment process was deemed the best way to conform to the very limited space available on certain important circuit-pack faceplates. A drawback, however, is the possibility of fiber damage should *both* connectors be engaged prior to attachment of cap to base.

Applications to panels with SC bases are shown in Figure 4. Two of the ports have the caps removed so one can see the ends of connector ferrules, and one can imagine the ease of cleaning. In one base an SC cap has been installed so that functionally one has an ordinary adapter (whether or not attenuated). An FC cap is shown installed in one of the bases so as to illustrate a hybrid connection.

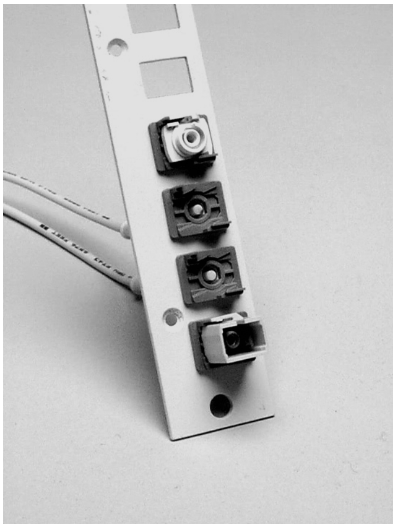

Figure 4 Implementation in an SC Panel

Performance standards for adapters necessarily pertain to an optical connection – that is two connectors and an adapter. For the most part, the split adapters have been found to be indistinguishable from unitized adapters when mated to the same quality connectors. This should not be at all surprising since the key element is the common ceramic alignment sleeve, presuming of course that one hasn't missed the mark on connector-retention geometry. Nonetheless, the fact that a split adapter comprises two plastic assemblies, only "loosely" joined, stimulates concern about environmental behavior and about mechanical strength. These concerns have been addressed by testing [2] that has confirmed robustness satisfying Telcordia standards [3].

Assembly of an SC cap is illustrated in Figure 5. Without the attenuator element, this would be one of the sides of a split adapter, but with the element it becomes one side of an adapter-attenuator. The attenuator element is a plastic disk attached to a hanger which is free to slide along the slot in the ceramic alignment sleeve [4]. This provides a natural accommodation to slightly different connector-plug-spring stiffnesses when, in operation, the disk is pinched between the mating connector ferrules. After assembly the attenuator element is permanently trapped within the cap. A cap then is associated with a certain level of attenuation, and so a change of attenuation at a connection is accomplished by changing the cap part of the split adapter-attenuator.

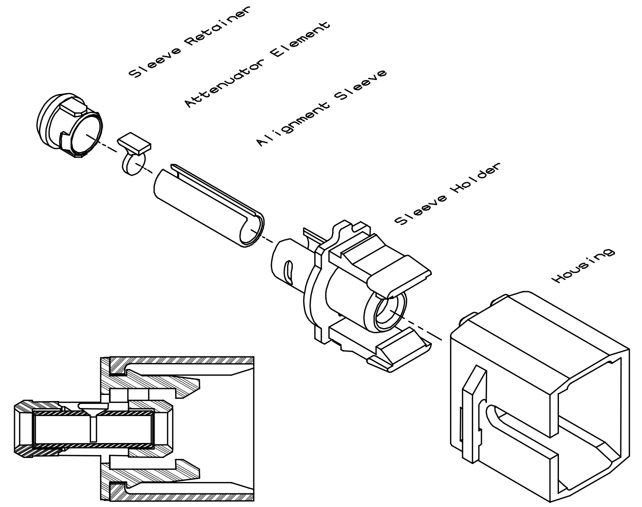

Figure 5 SC Cap Assembly

SPLIT ADAPTER FOR THE LC CONNECTOR

The LC is a compact (small-form-factor) connector for which the cylindrical alignment ferrule has a diameter of 1.25mm, as does the MU. While the MU is basically a one-half-size SC, the LC uses the plug-to-adapter latching structure of an RJ-45 plug and jack. An LC split adapter (base and cap separated) is shown in Figure 6. The base is one injection-molded part, and it snaps into a panel by way of integrally molded latches. The RJ-45 arrangement has been implemented twice to effect attachment of the cap to the base.

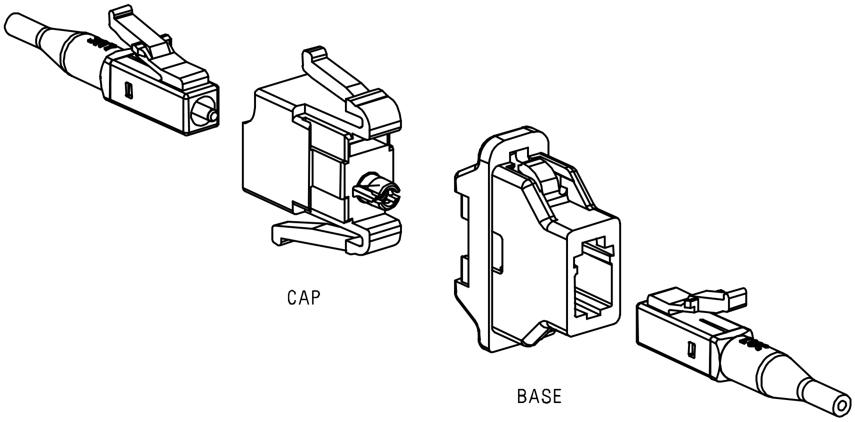

Figure 6 LC Split Adapter

Assembly of a cap, including an attenuator element, is illustrated in Figure 7. In contrast to the SC assembly shown in Figure 5, here there is not a separate sleeve retainer. This is because of the difficulties associated with one-half size scaling from the larger connector system. With the LC cap, the sleeve is retained by a clamshell structure integral to the cap; deformable segments are opened at assembly to allow the sleeve to be inserted.

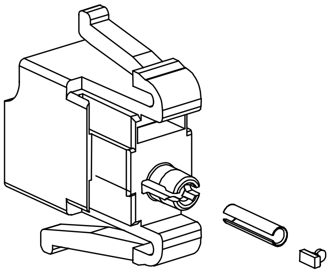

Figure 7 LC Cap Assembly

Environmental and mechanical testing have confirmed that Telcordia standards [3] for small-form-factor connectors are satisfied by LC connectors using this split adapter.

ATTENUATOR ELEMENTS

For a singlemode connection, the attenuator element is a “clear” molded-plastic spacer (see Figures 5 and 7). When pinched between the ends of two connector-plug ferrules, the element enforces a gap in the waveguide structure of the optical fibers [4]. Attenuation is achieved by failure of the receiving fiber to capture all of the optical beam spreading in the gap. Additionally, if the plastic spacer can be made to have intimate contact with each of the connecting fibers, then reflections will be dictated by the difference between indices of refraction of the fiber and the polymer spacer. For this consideration the closer the index of refraction of the element is to 1.46 the better.

The underlying theory of operation for "plastic-gap" attenuators may be found in the literature of singlemode splice-loss theory [5, 6, 7]. Suffice it to say that the attenuation depends upon indices of refraction, gap size, wavelength of the light, and the mode-field diameters of transmitting and receiving fibers. Of particular significance is the fact that the gap width δ is combined with the index of refraction, n, of the material in the gap as δ/n in the formula for attenuation [7]. Therefore, for a given level of attenuation, the higher is the index of refraction the greater is the required element thickness. So, plastic-gap attenuators exhibit less sensitivity to thickness than air gaps, and this facilitates practical control of attenuation tolerances.

Theory [7] and practice reveal that a range of attenuator-element thicknesses from 0.05mm to 2mm will produce attenuations in the range 1dB to 20dB when used with standard telecommunications fibers and wavelengths, provided the index of refraction of the element material is about 1.5. Furthermore, attenuation is predicted to be smoothly varying with wavelength; and values at 1300nm and 1550nm should differ by less than $0.10A$, where A is the nominal attenuation (in dB) set at an appropriate wavelength, say 1550nm. Thickness tolerances of 0.01mm correspond to attenuation tolerances of less than 0.3dB. Consequently, it has been found feasible, using specially designed tools for injection molding, to produce families of attenuators where nominal values are spaced at 0.5dB.

A number of thermoplastic polymers have been investigated as potential materials for attenuator elements. Aside from necessary and/or desirable optical and thermomechanical properties, ease of molding is obviously of great importance. Likewise is the availability of material from suppliers; one is compelled to try to use off-the-shelf polymers because one element is so small that huge volumes of attenuators would be needed to fuel demand for any significant quantity of the polymer. Technical requirements are: clarity (low transmittance); index of refraction near enough that of the fiber; a glass-transition temperature well above the maximum intended temperature of operation; and a sufficiently high modulus of elasticity that gap changes brought on by the pinching fibers will not significantly alter attenuation.

A fundamental difficulty of material selection is that it seems that the closer the index of refraction comes to that of the fiber (1.46), the worse are the thermomechanical properties. Several acrylics have been used to produce elements. One, exhibiting reflectances around -30dB ($n = 1.53$) has a glass-transition temperature of about 140°C, and it is quite resistant to creep even at an elevated operating or storage temperature such as 85°C. A second acrylic ($n = 1.49$), exhibiting the more desirable reflectance of about -38dB, has a glass-transition temperature around 100°C; and thus we recommend that its applications be in controlled environments. Polymethylpentene has a nominal index of refraction of 1.46, so reflections from attenuators using such elements should be anticipated to be quite small. Because it is less robust thermomechanically than the acrylics, recommended applications are limited to those where low reflection is imperative, the environment is controlled, and where few matings and rematings are expected.

ATTENUATOR PERFORMANCE

Typical insertion-loss performances for LC plastic-gap attenuators are shown in Table 1. The attenuator elements were acrylic and jumpers were constructed of depressed-clad singlemode fiber manufactured by OFS. Measured values in Table 1 are ten-sample averages. Of particular note here are the differences in attenuations at 1550nm and 1300nm.

This is consistent with theory [7], which also predicts a smooth variation in attenuation with wavelength. However, at the present time spectral-loss testing for the full 1300-1500nm window has not been carried out.

Table 1 Typical Performance

Attenuation (dB)		
Nominal at 1550nm	Measured at 1550nm	Measured at 1300nm
3	3.1	3.3
6	5.9	6.3
9	9.0	9.7
12	11.7	12.9
15	14.8	15.8
18	17.8	18.7
20	20.1	20.3

For a wavelength window appropriate to some DWDM applications, spectral loss is shown in Figure 8 for four different attenuation levels. Over this interval the attenuations are essentially flat with wavelength, and this supports the utility of plastic-gap attenuators in such applications.

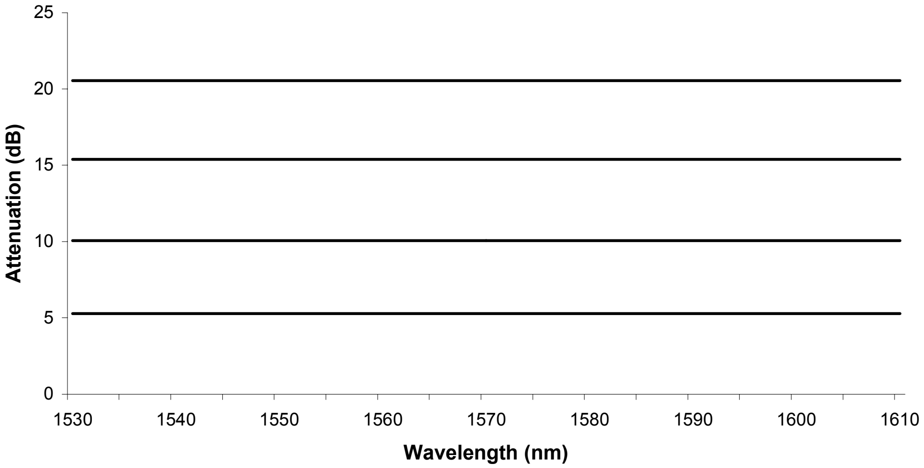

Figure 8 Spectral Attenuation (Incident Power 0dBm)

Because the attenuator elements are only weakly absorptive, there is an expectation that high optical powers can be tolerated. That in fact has been validated by experiment for incident power up to 23dBm. However, at incident power above 10dBm, attenuation has been found noticeably higher than at lower power. At 23dBm the increase is about ten percent (in dB), but wavelength insensitivity (in 1530-1610) is preserved. Moreover, whatever the phenomenon, it appears to be reversible, and extended exposures have exhibited no apparent damage to the material nor compromise of function.

In operation, an attenuator element is pinched between two ferrules, with about 2lb of thrust for a 2.5mm ferrule and about 1lb for a 1.25mm ferrule. Consequently, creep of the polymer element is of concern, particularly at elevated temperatures. There are two risks; the first is that with time the gap will be sufficiently reduced that the attenuation is significantly changed. Active monitoring of attenuators for five weeks at 90°C has demonstrated that this is not an issue for any acrylic considered nor for polymethylpentene. The second risk is that, upon uncoupling a connector plug, a residual dent is left in the element, and remating may lead to a small air gap at the fiber-element interface. This will be indicated by occurrence of a relatively large reflection. Table 2 conveys the results of mating durability tests carried out after two weeks of aging at 85°C. The consistently appropriate reflectances indicate that this material (glass-transition temperature about 130°C) is sufficiently resistant to creep.

Table 2 LC Mating Durability (Attenuation and Return Loss)

Sample (atten.)	Pretest	After 25	After 50	After 75	After 100	After 125	After 150	After 175	After 200
1 (0 dB)	.12/56	.16/53	.15/54	.12/53	.13/57	.12/54	.22/56	.14/55	.20/54
2 (6 dB)	6.15/34	6.17/33	6.15/36	6.18/35	6.17/32	6.21/34	6.23/36	6.17/36	6.18/36
3 (6 dB)	6.07/33	6.2/34	6.18/34	6.17/34	6.12/35	6.11/35	6.18/34	6.16/35	6.15/35
4 (6 dB)	6.09/34	6.09/35	6.14/34	6.15/33	6.14/34	6.16/33	6.15/35	6.18/33	6.22/36
5 (12 dB)	12.18/34	12.08/31	12.11/35	12.11/37	12.13/36	12.16/36	12.23/36	12.13/36	12.21/36
6 (12 dB)	12.2/35	12.17/35	12.13/35	12.14/35	12.14/35	12.21/35	12.14/36	12.12/35	12.17/35
7 (12 dB)	12.11/36	12.13/34	12.17/34	12.11/36	12.19/34	12.2/35	12.13/36	12.17/34	12.13/36
8 (20 dB)	20.12/34	20.13/34	20.1/35	20.17/36	20.11/35	20.08/35	20.13/35	20.17/35	20.13/36
9 (20 dB)	20.13/33	20.15/34	20.05/36	20.12/36	20.13/34	20.2/33	20.14/36	20.14/34	20.11/35
10 (20 dB)	20.22/35	20.13/36	20.23/36	20.21/34	20.22/34	20.16/34	20.12/33	20.16/35	20.13/34

Polymers generally have indices of refraction much more sensitive to temperature than that of the glass fiber. Consequently, there should be a temperature dependence of the reflection at a fiber-element interface. Since the polymer's index will decrease with increasing temperature, reflections correspondingly decrease (increase) where the polymer's index is greater (less) than that of the glass. Examples are shown in Figures 9 and 10. Each of the acrylics, for which behavior is depicted in Figure 9, has an index greater than that of the fiber even at 90°C, so reflections increase monotonically with reductions of temperature from there. On the other hand, Figure 10 illustrates a situation where the index of refraction of the polymer is close to that of the fiber at about 40°C. Thus, as temperature is increased or decreased from that point, reflection levels increase.

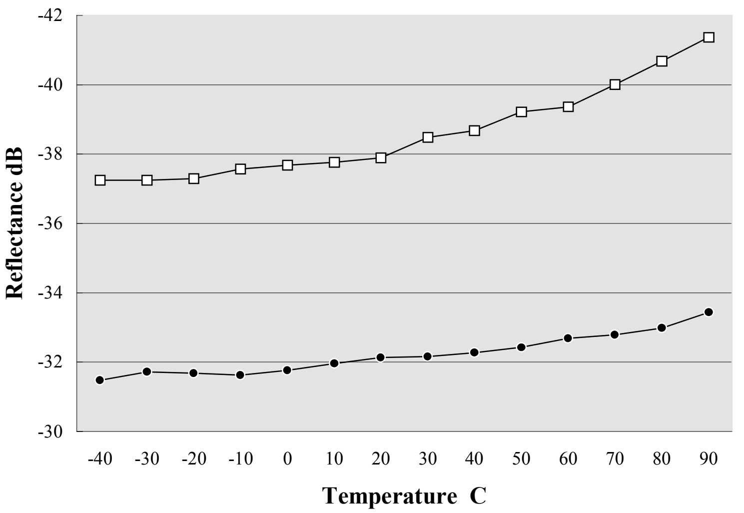

Figure 9 Reflections from 10dB SC Attenuators; Acrylic Elements

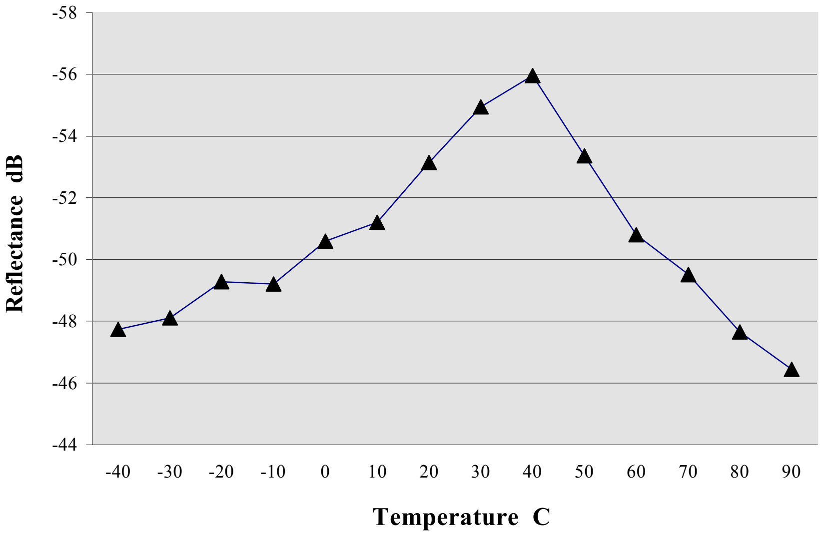

Figure 10 Reflections from 10dB SC Attenuator; Polymethylpentene Element

CONCLUSION

A modular adapter-attenuator system for singlemode-to-singlemode connections has been developed. Fixed levels of attenuation can be changed easily from one side of an interface, yet no more space is required than that for an ordinary adapter. Attenuation is accomplished by clear plastic spacers which can be made with sufficient precision to tightly control attenuation. Acrylics have been identified as attenuator-element materials that have adequate optical and thermomechanical properties, and reflections have been confirmed to be lower than generally needed for digital systems. Experiments confirm theoretical predictions that wavelength dependence is smooth and relatively small.

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