May 2003

ANUE SYSTEMS, INC

# White Paper:
# Performing Next Generation SONET Testing using a Delay Generator


**Abstract:**

New Technologies like Generic Framing Procedure (GFP), Virtual Concatenation (VC) and Link Control Access System (LCAS) are enhancing the capabilities of SONET, bringing about a convergence of SONET and Ethernet. This enhanced, or “Next Generation,” SONET can efficiently transmit gigabit rate Ethernet data and can dynamically scale SONET connections sizes up or down to meet bandwidth demands.

Next Generation SONET ICs, software and equipment are currently being developed. Due to their complexity and unique requirements, however, testing and validating these Next Generation solutions present significant challenges to manufacturers of communications products and providers of network services. Fortunately, these challenges have been met with the Anue Systems’ line of SONET Delay Generators. Anue’s Testers emulate signal delays, path level delays, bit errors and signal loss in a precise, programmable manner. These functions are essential for testing GFP, VC and LCAS solutions.

## I. Introduction

In the world of data communications, high speed networking over large distances is the wave of the future. Everywhere, information is moving faster. Data rates are rapidly increasing from 100 megabits per second (Mbps) to 1 gigabit per second (Gbps) to 10 Gbps. At the same time, the world is shrinking. Sending digital information around the globe will soon become as easy as sending it across the office.

Communications technology companies have made great strides in their networking products, which is accelerating the move to higher speed communications. In addition, service providers have laid enormous amounts of high-speed fiber optic cable to transmit data over long distances. However, these efforts have been limited by a significant gap between two well-established but separate methods for transmitting data:

1) Ethernet, the dominant method for sending data over short distances, such as local area networks (LANs), and
2) SONET[1], traditionally used to carry voice traffic over long distances (i.e., thousands of miles) of optical fiber.

SONET is circuit based; Ethernet is packet based. SONET is continuous; Ethernet is "bursty." SONET bandwidth is defined by OC rates (see Table 1) that do not match the 10/100/1G/10G Ethernet rates. Nonetheless, both SONET and Ethernet are pervasive and here to stay. There are hundreds of SONET Rings in operation today, and in 2002, 450,000 OC-48 SONET ports were added worldwide.[2] The Ethernet market is even larger. Already a multi-billion dollar market, Gigabit Ethernet (GigE) equipment revenue could reach $44 billion by 2005.[3]

Though developed to carry voice traffic, SONET is now being adapted to carry data. Promising new technologies have been developed to send packetized data over the huge installed base of SONET rings around the world. In addition to Ethernet, other protocols -- such as IP, ATM, SDL, HDLC, Fibre Channel, etc. -- can be transmitted over long distances via SONET using these new technologies. In particular, Generic Framing Procedure (GFP), Virtual Concatenation (VC) and its associated Link Control Access System (LCAS)[4] are open standards that have been dubbed "The Holy Grail of SONET" by industry experts. These open standards enable the sending of high-speed data (like Ethernet) over SONET.

[1] Stands for "Synchronous Optical Network." SONET networks are typically referred to as "SONET rings."
[2] IDC, Oct 2002.
[3] Pioneer Consulting, Nov 2001.
[4] These "Next Gen SONET" standards emerged from ITU-T and American National Standards Institute (ANSI).

The beauty of these new standards is that they do not require changes to the fiber optic "core" lines that carry the data. However, these new technologies are technically complex. They slice data traffic into several parts, send the parts along different paths, and then recombine them at the receiving end. This process requires new equipment and software at the network endpoints, such as chips, routers/switches, multiplexers, and security devices. The new infrastructure that brings together SONET and GigE is now being developed in the R&D labs of networking and communications companies.

| Optical Carrier (OC) Level | Electrical (STS) Level | Line Rate (Mbps) |
|---|---|---|
| OC-1 | STS-1 | 51.84 |
| OC-3 | STS-3 | 155.52 |
| OC-12 | STS-12 | 622.08 |
| OC-48 | STS-48 | 2488.32 |
| OC-192 | STS-192 | 9953.28 |

**Table 1: SONET Line Rates**

## II. SONET Overview

SONET is a layer one protocol (see Table 2), and carries higher layer payloads in Synchronous Payload Envelopes (SPEs). In addition to the SPE, each SONET frame consists of Section Overhead (SOH), Line Overhead (LOH) and Path Overhead (POH) data. Figure 1 diagrams a SONET frame. Each SONET frame contains 90 columns and 9 rows. Each column includes N bytes, where N indicates the OC level. Therefore, an OC-12 frame contains 9 x 90 x 12 = 9720 Bytes.

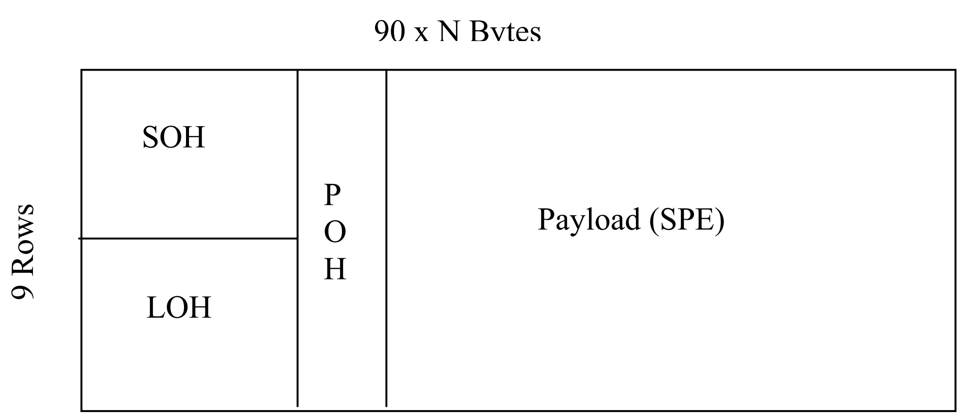


**Figure 1: SONET Frame**

 

| | | |
|---|---|---|
| 7 | Application | Telnet, FTP |
| 6 | Presentation | Encryption |
| 5 | Session | RPC, NetBios |
| 4 | Transport | TCP, ATP |
| 3 | Network | IP |
| 2 | Data Link | Ethernet, GFP |
| 1 | Physical | SONET, ATM, DSL |

**Table 2: OSI Layers with Examples**

A key characteristic of SONET is data "concatenation," or "joining together." SONET concatenates data in a very specific manner as it is framed and transmitted.

Let's take a common example of the way this "contiguous concatenation" works within SONET. In this example, four consecutive OC-3 data streams are concatenated into a single OC-12 "pipe." In this case each OC-3 signal is referred to as an OC-3c. The data in each OC-3c is interleaved together with the date of the other OC-3c's. The interleaving format is rigid; every fourth channel in the OC-12c pipe must belong to the same OC-3c. This format leaves little flexibility for expansion and can lead to severe inefficiencies.

In our example above, we were fortunate. Four OC-3's fit nicely into an OC-12 signal. What if instead of OC-3 (155 Mbps) a particular customer required 200 Mbps? Today, this customer would be allocated an OC-6 (310 Mbps) amount of bandwidth because this is the next highest level of granularity able to be allocated on a SONET OC-12 or higher network. Furthermore, what if this customer's bandwidth needs increase or decrease, maybe even on a daily basis? Wouldn't it be nice if the SONET service provider could dynamically "right-size" the portion of the pipe it provides to such a customer, and interleave this customer's data into a high capacity link? Next generation SONET, comprising VC, LCAS and GFP, enables such capability.

## III. Virtual Concatenation/LCAS/GFP

Virtual Concatenation (VC) is a method of creating a single SONET payload out of two or more associated payloads that are transported through a network completely independently. VC has the ability to maximize bandwidth utilization of SONET payloads with its flexibility to "right size" existing channels. Payloads can be dynamically combined and resized to match the optical carrier path size.

This is a tremendous benefit! Today "utilization" is a major disadvantage of SONET. Without VC, at gigabit data rates, at best two gigabit Ethernet streams can be combined onto one OC-48 SONET network. This results in a utilization rate of 80%. Sending 100 Mbps Ethernet through SONET results in an even lower utilization rate of 67%, since an 155 Mbps OC-3 pipe is next highest non-VC level of granularity that can be allocated. In reality, the difficulty associated with allocating circuit-based bandwidth to particular packet-based users results in much lower SONET utilization rates.

 

High Order VC (HOVC) breaks payloads into individual OC-1 (52 Mbps) or higher levels of granularity. Low Order VC (LOVC) has the ability to concatenate data as low as VT-1.5 (1.5 Mbps) bandwidth granularity.

As an example, consider what occurs when a standard OC-12 signal is virtually concatenated. VC breaks the OC-12 frames into 12 separate OC-1 signals, and transports them individually through a network. Since each OC-1 contains its own path overhead data, the position/sequence of each data path is tracked, as well as the original group each OC-1 signal belongs to. These OC-1 signals can be transported via OC-1 bandwidth pipes, or, more likely, combined with other data on OC-12 or OC48 SONET lines. At the termination end point of the SONET Ring, VC recombines the original OC12 signal. The VC algorithm is able to buffer individual payloads until they all arrive at the destination. All of this occurs on existing SONET Rings, using existing, unmodified network equipment!

As you can see from this example, "differential delays" -- that is, the time differences between the arrivals of different OC-1 paths of the concatenated group at the receiving end of the network -- are necessary attributes of VC. In addition to delay resulting from diversely routed paths through a SONET network, there are other causes of differential delay in a VC system:

- chromatic dispersion caused when VC signals are transmitted on several different wavelengths,
- protection switches due to faults on different parts of the network, and
- diversely routed path protection schemes.

While delays occurred with earlier technologies, they were much shorter than VC induced delays (particularly at high speed data rates: OC-12, OC-48 and OC-192). For example, TADM allows only a 13 microsecond delay between two parts of a data signal. Such a small delay can be emulated with a spool of optical fiber – in this case, a 4000 meter long spool. With the much longer delays imposed by VC, this is not the case.

With VC, differential propagation delays of up to 25ms (representing 7500 km of differential distance traveled) are easily possible within an OC12 signal, while protection switch delays of up to 50 ms are possible.

LCAS, the Link Capacity Adjustment Scheme, allows the dynamic provisioning of bandwidth using VC. This ability to increase and decrease channel capacity without impacting the data further contributes to the ability to maximize utilization of a SONET network. With LCAS, the network does not need to be shut down and data is not lost during the re-provisioning of bandwidth.

Generic Framing Procedure (GFP), another ITU-T standard, is a key enabler for VC and LCAS. The Generic Framing Procedure is a substitute for High Level Data Link Control (HDLC), and maps higher order protocols onto SONET. GFP provides rules for payload specific mapping on various network topologies. GFP comes in two forms: GFP-F (frame mapped) and GFP-T (transparent mapped). GFP-F encapsulates higher layer protocol frames (such as Ethernet and IP) in which the signal frame is mapped in its entirety onto one GFP frame, while GFP-T provides block level encapsulation of bit streams whereby block-coded characters are decoded and then mapped into a fixed-length GFP frame and may be transmitted immediately without waiting for the receipt of an entire client data frame. GFT-T works with ESCON, Fibre Channel, etc.

## IV. Delay Generation

*Signal Delay*

In the last section, we described the significance of delay in a VC SONET system. It is critical for developers of VC semiconductors, network equipment (routers, switches, multiplexers, etc.) and software solutions to be able to effectively generate specific, pre-programmed amounts of delay in laboratory environments to effectively test their solutions.

One possible solution is to use optical fiber spools to "generate" this required signal delay. Unclad 25 km spools, which can be connected in series, are available at a cost of approximately $0.10 per meter. Many labs already possess such fiber spools in multiple lengths. However, to achieve the signal delays required for VC testing, fiber quickly becomes unfeasible. Generating 25 ms of delay would require 300 – 25 km spools as well as amplification equipment to propagate the signal over such a large distance!

Fiber spools present other difficulties as well.

- Repeatedly plugging in and yanking out cable connectors causes them to break.
- Cable lengths, and therefore delay times, are limited to specific sizes available requiring interpolation in lab testing.
- Test setup is cumbersome as fiber spools need to be moved around the lab.

The programmable SONET Delay Generators from Anue Systems[5], Inc. are far superior options for testing VC induced delays in an optical network. Without any modification to the signal, Anue's Delay Generators emulate various signal delays that occur over different lengths of fiber optic cable. Using multiple generators, with each generator delaying a signal by a different amount, the user can simulate the transmission delays that will be encountered by diversely routed members of a VC group.

As an example, Figure 2 shows how four separate OC-12 Delay Generators can be used to test a virtually concatenated SONET OC-48 data stream. Here, the OC-48 stream is multiplexed into four OC-12 paths, each of which is then delayed by a different amount of time. At the receiving end, the de-multiplexing equipment and VC software under test recombine the OC-48 signal to be identical to the original incoming data stream. (In actuality, only three Anue Delay Generators would be needed for this test since one line could be "undelayed" as a result of a direct fiber connection. The other three testers would inject differing amounts of delay resulting in four different delay times: zero, x, y and z).

[5] Anue Systems, Inc. Delay Generators currently shipping include: ASDG 1225 (OC12, 25 ms delay) and ASDG 3100 (OC3, 100ms). See www.anuesystems.com for details.

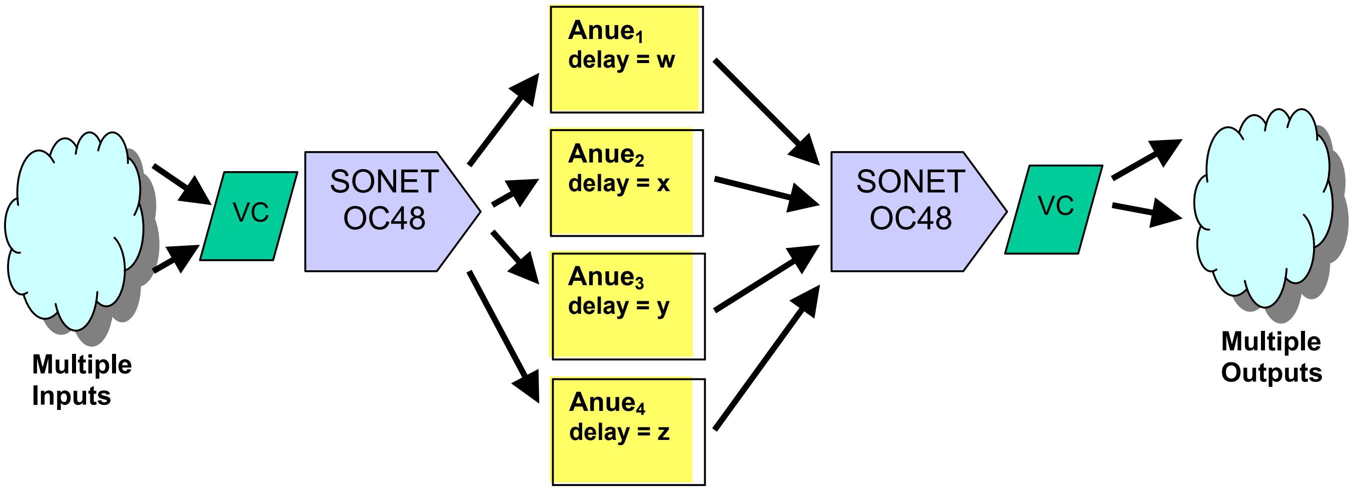


**Figure 2: Typical Virtual Concatenation testing configuration using Anue Delay Generators.**

As described previously, High Order VC concatenates signals down to the OC-1 level of granularity. How could the experiment in Figure 2 be modified to test more data path granularity? Certainly, up to16 separate OC-3 Delay Generators could be used instead of the four OC-12 Generators, but this only achieves OC-3 granularity and requires a large number of testers. For this, another solution is needed: the Path Level Delay Generator.

*Bit Level Delay*

We described earlier how each SONET frame begins with a three row by three column Section Overhead. The first two bytes in this SOH are framing bytes, in particular the F6 28 bytes. A key design consideration for SONET framing and mapping devices involves ensuring that this two byte framing pattern is maintained. All bit rotations in this framer must be tested and verified by the SONET designer.

Testing bit rotations involve repeatedly delaying in increments of one bit the F6 28 framer. A properly designed SONET framer will be able to verify all bit rotation combinations. The Anue Delay Generators are ideally suited for bit level delays of this type and ideal for a developmental test setup.

*Path Level Delay*

HOVC parses data in increments as small as OC-1, or 51.84 Mbps. Therefore, true HOVC testing requires the generation of differential delays on separate, contiguous OC-1 data streams. In fact, for other reasons, which will be described later, it is desirable to differentially delay data in increments of only one byte!

Path delay generation refers to the ability to delay individual segments of data of virtually any size -- as small as one byte to as large as several frames. Data paths are identified by a J1 byte at their starting point.  Paths may overlap more than one SONET frame, that is, starting in one frame and ending in another.

The Path Delay Generators from Anue Systems[6] delay individual paths within an OC12 or OC48 signal.  The size of each path and the amount of delay desired on each path are selected by the user.  Referring back to Figure 2, if each of the four Delay Generators shown there were OC-12 Path Delay Generators instead of OC-12 Signal Delay Generators, a total of 48 separate OC-1 data paths could be delayed by different amounts (from zero to 25 ms) before reaching the receiving equipment.  Alternatively, one OC-48 Path Delay Generator could accomplish the same task.[7]

## V. Error Generation

*Loss of Frame (LOF)*

A SONET Ring is composed of both a working fiber and a protection fiber, as shown in Figure 3.  This redundancy is a key SONET attribute.  If a failure occurs on the working line, the system automatically recovers through the use of the protection fiber.  This process of changing from the working fiber to the protection fiber is called a “protection switch.”  The SONET requirement in this area is very specific: a loss of a frame in a SONET system must force a protection switch within 50 ms.

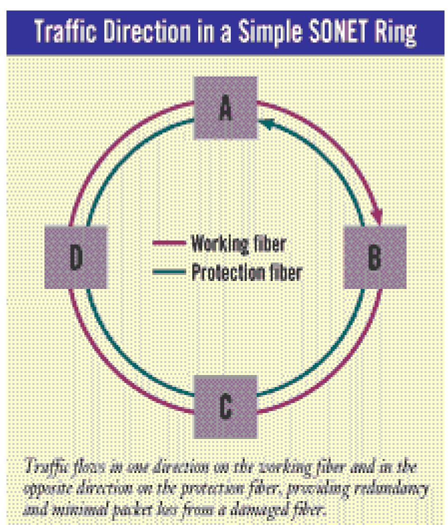


**Figure 3: SONET Ring[8]**

Anue’s Delay Generator testers are ideal for creating errors, such as LOF, under computer control.  The precise controllability of a LOF with the Anue tester means that the protection switch time can be measured accurately in a lab environment or on an actual SONET system under test.

[6] Models ASPD 1225 (OC12, 25 ms delay) and ASPD 48500 (OC48, 500 ms delay).
[7] OC-48 Path Delay Generator available in August 2003.
[8] Network Computing

The simple lab setup shown in Figure 4 using four Anue testers can simulate a SONET Ring. Here, two pieces of customer equipment (which could be ADMs, routers, etc.) represent two of the four nodes in a SONET Ring. The Anue testers generate the signal delay both on the working and protection fibers that would occur in a real world SONET Ring where these two nodes may be separated by hundreds of kilometers. Additionally, Anue testers one and two in Figure 4 provide the delay that would be experienced by a signal traveling around the rest of the Ring through additional equipment nodes.

With this setup, either of the two Anue testers on the working lines can be programmed to generate a LOF. The ability of the equipment under test to execute a protection switch, and the amount of time required for the switch can be measured.

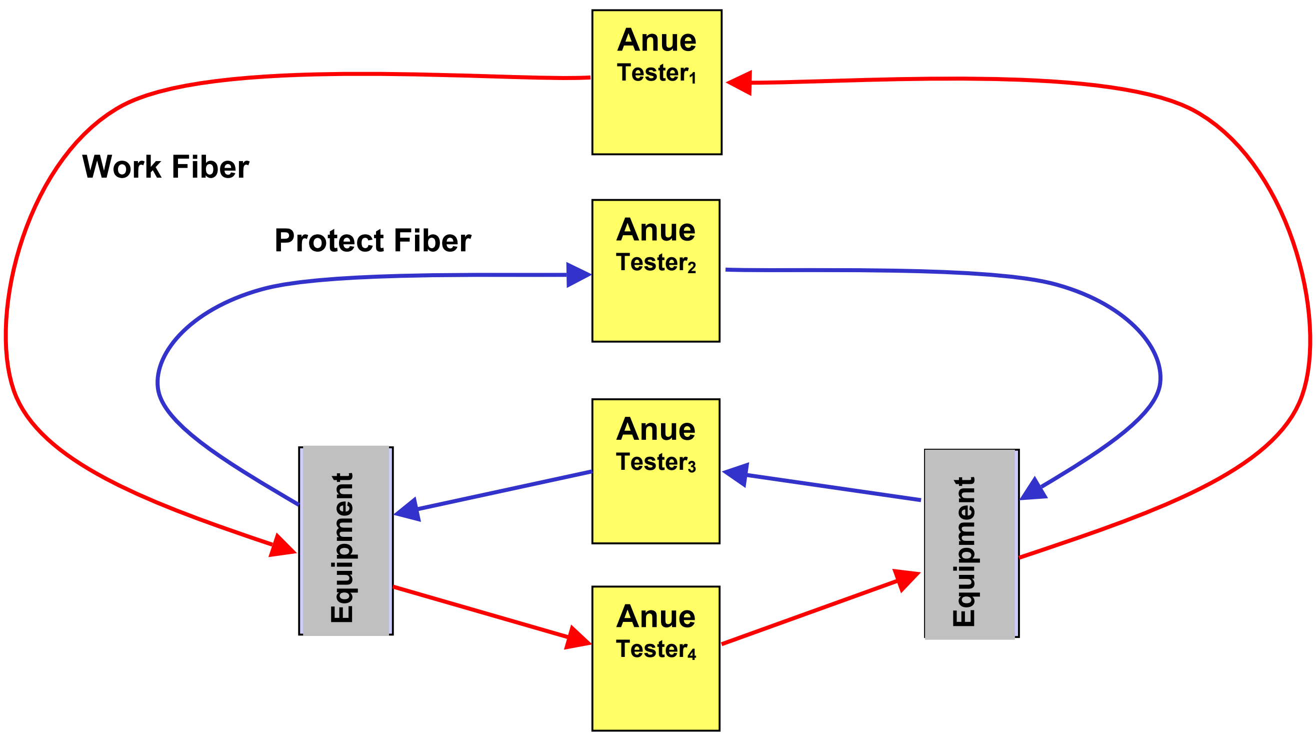


**Figure 4: Simulated SONET Ring using Anue Delay Generators. Each Anue tester can generate delays, bit errors, and/or loss of frame.**

*Bit Error Generation*

Bit Errors naturally occur on any fiber optic system. A bit error rate (BER) of approximately $10^{-9}$ is considered "normal." The "normal" BER falls to $10^{-12}$ with the use of forward error correction (FEC).

As BERs increase beyond this acceptable level, the SONET signal degrades. At a certain error level, the signal fails and a protection switch must occur. This level is programmable in a network. In a test environment, it is essential to test signal degrade conditions and protection switching, in addition to the signal failure/LOF described above.

With the Anue Delay Generator, bit error testing is precise and easy. Bit error rates from $10^{-12}$ to as high as necessary (though rates higher than $10^{-2}$ are generally irrelevant) can be programmatically injected. The Anue product is being used by customers to progressively increase injected bit errors to facilitate testing of signal degrade and signal fail algorithms. Prior to causing a protection switch, the correct number of bit errors should be reported by the equipment being tested.

## VI. Other factors: Dispertion & Attenuation

In this paper, we've discussed several attributes that need to be tested in a fiber optic network: signal delay, path delay, loss of frame, bit errors, framing errors, etc. There are two more areas that bear mention, optical dispersion and attenuation.

As a signal travels over long distances of fiber, it experiences both dispersion – the "spreading or flattening out" of the signal with respect to time – and attenuation – the decrease in amplitude of the light pulse. Earlier, we described how fixed length spools of fiber are often used in a lab setting to delay a signal. In addition to delay, the optical signal experiences dispersion and attenuation while traveling through such fiber. This is advantageous as it mirrors what occurs in a real SONET network.

Used alone, an Anue Delay Generator does not create dispersion or attenuation. However, there is a very straightforward, and inexpensive, way to generate all three attributes – delay, dispersion and attenuation – in a lab with the use of a Delay Generator. This is done with the use of a relatively small spool of fiber and an optical attenuator placed in serial with a Delay Generator as shown in Fig a below.

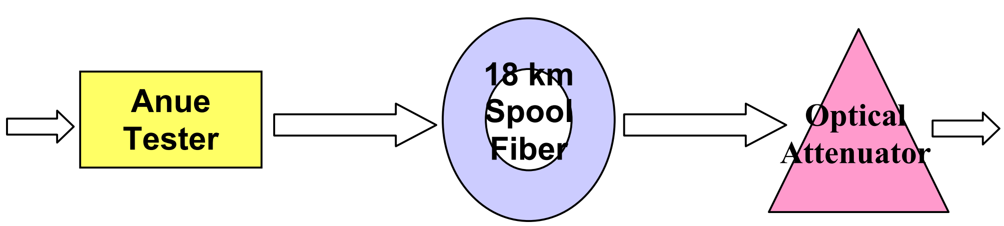


**Figure 5: Inexpensive way to generate delay, dispersion and attenuation**

 

Dispersion can be very effectively created with a fiber spool as small as 18 km. Likewise, a simple optical attenuator can provide more than sufficient attenuation, the amount of which is adjustable. Matching the capability of Figure 5 would require multiple spools of fiber (hundreds of kilometers long) as well as regenerating equipment -- a costly proposition – and still would have less flexibility.

The Anue Delay Generators provide a scalable, cost-effective solution for many of the challenges faced by today's developers of SONET IC's and network equipment. Designing, building and testing next generation SONET products, including VC/LCAS solutions, require tools such as those from Anue Systems with features and functionality that target the specific communications testing needs described in this White Paper.

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