To: Del Hanson, David Cunningham, Mark Nowell

From: Lew Aronson

Date: November 20, 1997

Subject: Field setup for ROFL MMF bandwidth measurements

CC: Dave Dolfi

I. Introduction

Per your request, we have been working on a measurement system which will allow us to do radially over-filled launch (ROFL) and possibly standard over-filled launch (OFL) modal bandwidth measurements of fibers in actual cable plant settings. This memo describes the measurements we are trying to do, the special considerations for doing these measurements in the field and our proposed implementation, particularly the equipment we will plan to use and the capabilities we expect it to have.

The immediate need for this equipment is to measure the worst case modal bandwidth of the fibers in an actual fiber installation. This data will be used for various purposes including:

1) Developing a statistical base for understanding the distribution of fiber bandwidth

2) Measuring the details of the differential mode delay in these fibers

3) Identifying particularly poor fibers on which to test conditioned launch solutions to the differential mode delay problem.

The fiber installations that will be measured are at Lawrence Berkeley National Labs and Lawrence Livermore National Labs. These sites have large numbers of multimode fibers (MMF) of both basic types (50 and 62 μm) and of various lengths ranging from 80 – 1300 m of which we will be primarily concerned with links of 200 – 600 m. The links are typically between buildings (as opposed to building backbones) and are terminated in typical patchpanels and with ST style connectors. A base of information does exist on previous OFL measurements by the LBL/LLNL using a Tektronix instrument, but apparently there is some suspicion that these measurements may be inaccurate as some are significantly outside the usual fiber specifications.

While recent measurements have been done on various fibers using the classical OFL method as well as the newly defined ROFL method (see below) by your group and others, these measurements have typically been laboratory based and would be very difficult to replicate in a field environment.

II. General Technique for ROFL and OFL Bandwidth Measurements

In general, there are two types of MMF modal bandwidth measurements. These are time domain and frequency domain measurements. In the time domain measurement, a very short optical pulse is launched into the fiber and the pulse shape is measured at the output of the fiber. The Fourier transform of the output gives the frequency response when normalized by the corresponding transform of the input pulse. In addition, the pulse measurement gives more information about the modal properties of the fiber than the single bandwidth number.

The frequency domain measurement consists of launching light with a small signal modulation at a given frequency. The transmission of the fiber is measured as a function of the frequency of modulation. This result, when normalized by the frequency response of the measurement system with no fiber, is the fiber's modal bandwidth. In the description of both of these methods we have ignored any bandwidth reduction due to chromatic dispersion. This can be handled either by using a suitably narrow-band source or by normalizing the result using the source linewidth and known chromatic dispersion.

Of course, any measurement of modal bandwidth will depend on the modal distribution which is launched into the fiber. To date, the only standard test of fiber bandwidth uses what is known as over-filled launch (OFL) which basically attempts to launch equal power into all modes. While this measurement is valid for LED based links, it has proven insufficient for laser based links such as those used for Gigabit Ethernet. Recently, the PMD group of the IEEE802.3 has defined a new bandwidth known as worst case modal bandwidth (WCMB) which is supposed to represent the worst modal bandwidth which will be experienced for all reasonable launch conditions. WCMB is defined as the lesser of the bandwidths measured by OFL and ROFL. ROFL, or radially over-filled launch is a set of launch conditions which can be generated by launching light from a single mode fiber (SMF) into the MMF of interest with a gap between these fibers. The gap between the fibers is defined such that the coupling loss between the fibers is 0.5, 1.0 or 2.0 dB (±0.2 dB). Other than controlling the launch conditions, the ROFL bandwidth measurement is the same as the standard OFL technique.

III. Special considerations for bandwidth measurements in the field.

Applying the measurements described above presents a number of difficulties when they must be done outside the laboratory. The most immediate difference between the field and the lab is that we do not have direct access to both ends of the fiber from the same location. While an eventual commercial test instrument for this application would probably be designed to do a single ended measurement, much in the way an optical time domain reflectometer (OTDR) works, this is too difficult to build on our limited time scale. Thus, we will have to design our experiment to work with equipment to launch the light at one end and another set of equipment to analyze the signal at the opposite end. Moreover, it would be difficult to transmit any other timing or frequency information to the receiving end other than the test signal itself. It is our decision that a time domain measurement will be easier to implement with separate transmit and receive equipment sets.

A second key difference between a lab implementation and one for the field is that a field instrument can't rely on delicate adjustments such as typically done with alignment stages. Thus, all sources and detectors must be reliably pigtailed or connectorized. Normally this does not present a problem, except that in this case we will need devices which are not widely commercially available yet. Additionally, we must come up with a method of reliably setting up the ROFL. One method for accomplishing this launch would be to permanently join two fibers with a suitable spacing. A more flexible technique, and one which would allow us to eliminate an extra patchcord which would complicate the measurement, would be to build a bulkhead coupler which keep the single mode and multimode fibers at a fixed, reproducible spacing, such that the ROFL launch can be accomplished directly into the cable of interest and then repeated on another fiber.

IV. Proposed HP Labs Implementation

As mentioned above, we propose to do time domain measurements of the ROFL and OFL bandwidth of the fibers at the test site. Our equipment will consist of two short equipment carts, one for each end of the fiber to transmit and receive. Figure 1 shows a preliminary illustration of the transmitting cart.

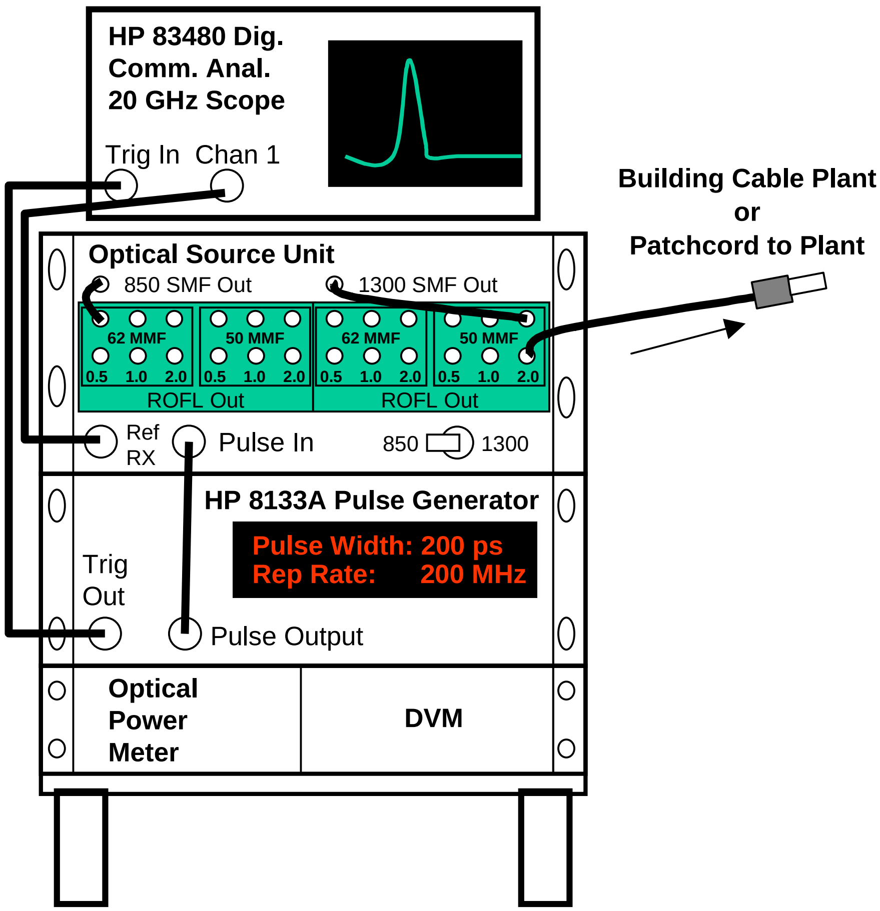

Figure 1. Proposed transmitter equipment cart.

The basic function of this cart is to inject short optical pulses into the optical fiber under test. These pulses should be as short as possible in order to measure a wide range of bandwidths over a variety of fiber lengths. In particularly, measuring large bandwidths over relatively short fiber lengths requires the shortest pulses. For this application, the optical pulses should be at least below 100 ps. This is best accomplished by gain switching a laser diode, which in turn requires a relatively fast electrical drive (although not as fast as the required optical output). Lab experiments have indicated that for our short wavelength source, electrical pulses as long as 200 ps can be used to generate optical pulses of less than 35 ps. The electrical source we have chosen is an HP8133 pulse/data generator. In addition to generating electrical pulses down to 150ps or less, this instrument has the advantage of high repetition rate pulses as well as very low pulse to pulse jitter which is critical since the receiving system must trigger off the previous pulse.

In general, we must do 8 tests on each optical fiber. First, we must test the fibers at both short wavelengths (~850 nm) and long (~1300 nm). Secondly, for each wavelength, there are three types of ROFL launch as well as OFL launch. In addition, there are two types of multimode fiber which results in 16 possible launch conditions.

The optical source unit shown in Figure 1 and in partial detail in Figure 2 is the key unit and include many functions (some not shown). This unit takes the electrical pulses from the 8133A and switches them either to an 850 nm or 1300 nm single mode source. Each source has its own bias control which may be adjusted in the field to maintain short pulse operation. The 850 nm source will be a single mode VCSEL which, in addition to offering stable efficient coupling to the short wavelength single mode fiber, will output a very narrow linewidth signal and make the effect of chromatic dispersion negligible. Chromatic dispersion at 1300 nm is so small that the Fabry-Perot laser we will use should also not lead to signficant chromatic dispersion.

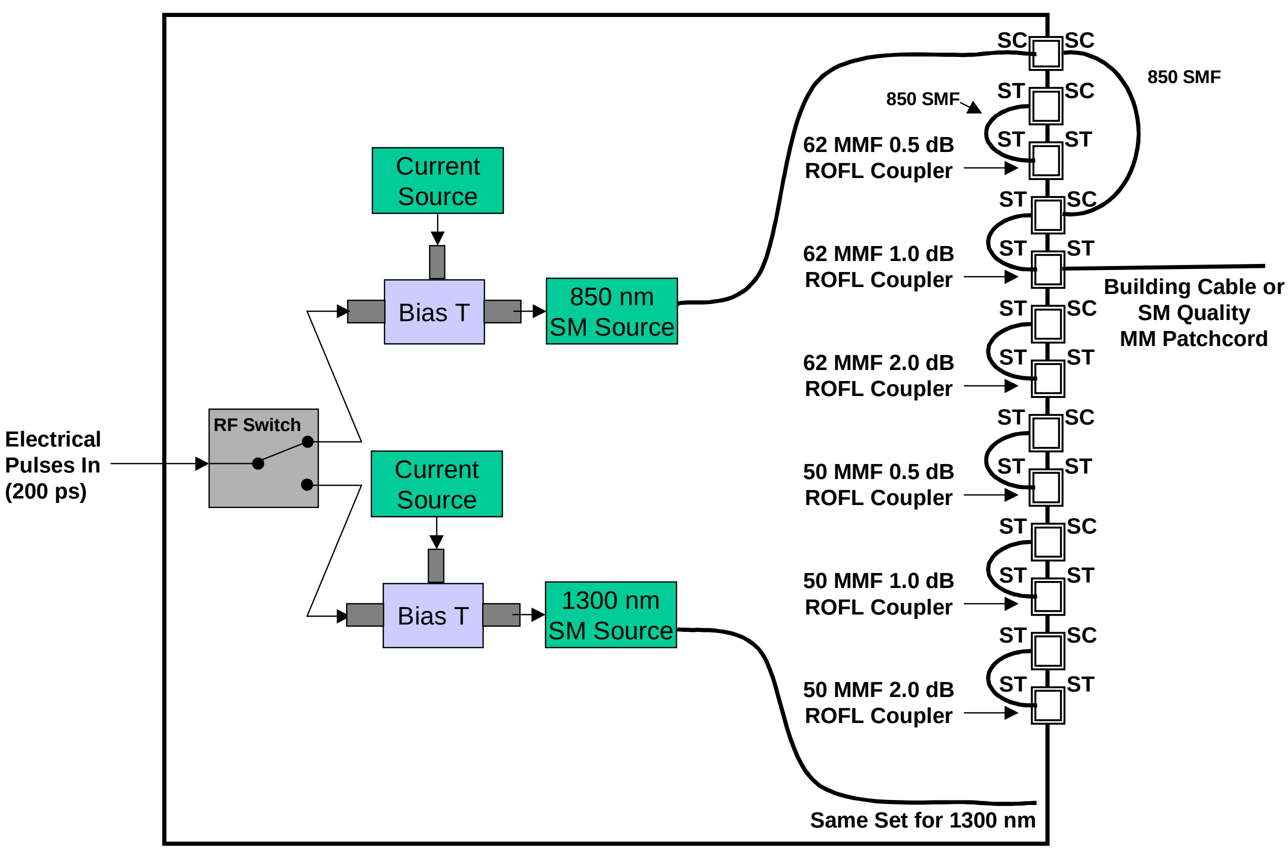

Figure 2. Partial detail of the optical source unit.

In addition to the optical sources, there is also a good deal of fiber plumbing to allow convenient switching between the different launch conditions. Figure 2 illustrates the fiber circuits for the 850 nm ROFL case. The 1300 nm section is not shown but is similar.

The light from the 850 nm source is routed to the front panel by a patchcord using Corning FlexCore 780 which is single mode over the 1000-SX wavelength range. This output may be patched back into any of six coupling sleeve bulkheads which route the signal (still through single mode fiber) to special ROFL bulkheads. These bulkheads will contain precision spacers which will form the proper spacing between the internal singlemode fiber and the external MMF to be tested (or a multimode patchcord with singlemode quality connectors if the fiber to be tested will not reach the unit). While ROFL launch is defined by the loss, we can translate this into a physical air gap with a fair degree of certainty. Figure 3 shows recent measurements of the transmission loss from SMF to MMF as a function of the air gap distance. We note gaps which range from about 150 to 450 µm for the various ROFL cases of interest. If precision spacers are built with a thickness accuracy of ± 10 µm, we will get ROFL losses of ±0.1 dB which is within spec.

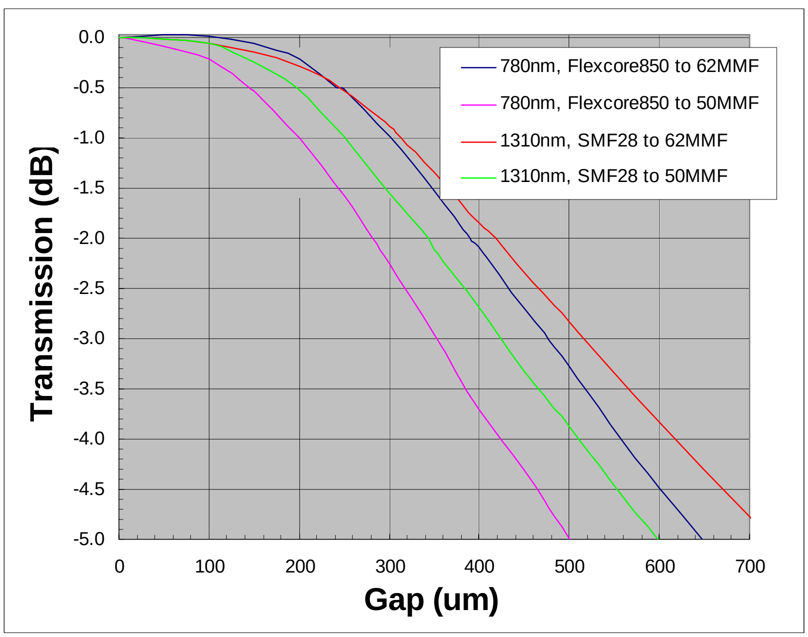

Figure 3. Measured SMF to MMF loss versus gap.

If we want to have a standard OFL capability, we will also need a mode mixer option on the front panel which will consist of a step index fiber wrapped around a mandrel.

In addition to the transmission part of this setup, this unit will also have a reference receiver similar to the one described in the receiver cart. This receiver, as well as the scope shown in Figure 1, is to be used periodically to take reference measurements of the transmitted pulse and if necessary to adjust the source operating conditions (bias). The cart will also contain an optical multimeter to measure output power as well as various patchcords and adapters to measure fibers with different connector types.

The receiver cart unit for the other end of the fiber link is shown in Figure 4 below. It consists primarily of optical receivers for the two wavelengths as well as a high speed sampling scope (20 GHz) for displaying and recording the optical pulses generated by the various launch conditions.

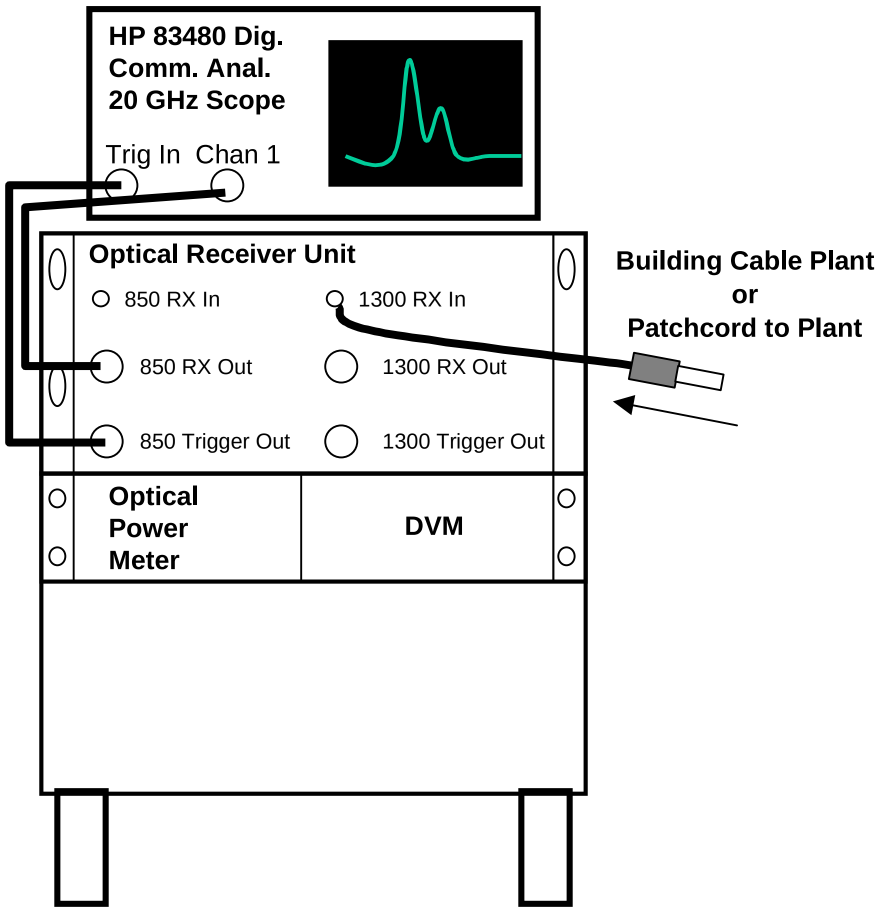

Figure 4. Proposed receiver equipment cart.

Figure 5 below shows some of the details of the optical receiver unit. The optical input to this unit is in 62 MMF with high quality connectors which will accept all of the light from either fiber type. The packaged detectors in each unit need to be quite fast (ideally with <= 50 ps pulse response) and with good responsivity at the wavelengths of interest. Another important point is that the detector will need to accept all of the light from 62 MMF. This is critical because if the receiver has mode selective loss, we are not measuring the true modal bandwidth, and the true result could be better *or* worse.

One complication at the receiving end is triggering the scope. The method we will attempt to use is to split the received signal and use one half for the trigger input to the scope. We will have to use the previous pulse to trigger the measurement of the pulse of interest because the scope requires about 25 ns to setup for a measurement after reception of the trigger. Because of various factors, it also may be necessary to have a suitably fast amplifier to provide enough signal for triggering and scope measurement.

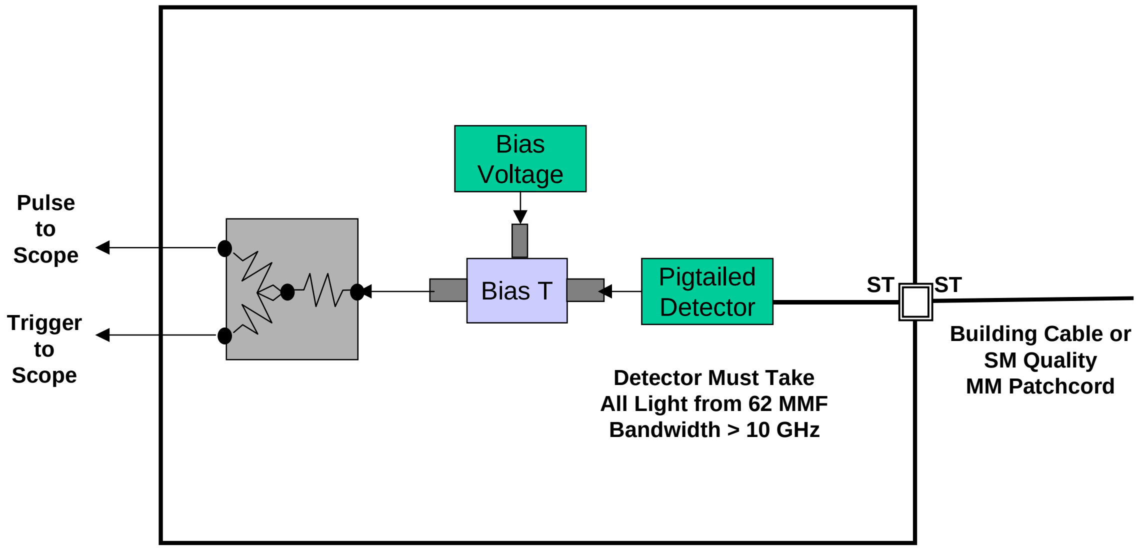

Figure 5. Detail of a measurement channel in the receiving unit.

V. Status and Conclusions

If we are able to construct the equipment described above, a full set of fiber modal bandwidth measurements can be made the field by simply switching the front panel patchcords and recording the various received pulses on the scope for later data reduction. At this moment, we are still accumulating and building the various components needed for the test. After the parts are gathered and the units constructed we will still have to validate the system in the lab on various lengths of test fiber. We hope to accomplish all of this in the next two weeks barring any significant roadblocks.