FIBEROPTIC TRUNKING
THE REALITIES OF ACTIVATION, OPERATION, AND MAINTENANCE

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ABSTRACT

Lightwave transmission has been touted as a ready-made solution to many of the characteristic shortcomings of traditional RF networks. Immunity from EMI and RFI, signal theft resistance, extended bandwidths, high transmission quality, and lower active parts counts are among the virtues of fiberoptic systems.

This paper will show that through an understanding of fiberoptic's concomitant "unknowns" this type of system is no more difficult to operate and maintain. Actual operating data will be used to substantiate conclusions.

I. THE SELECTION PROCESS

Fiberoptics has been heralded as the answer to the future demands of broadband distribution. Few are unfamiliar with the advantages of lightwave transmission, but they bear repeating to persuade the remaining non-believers.

The most popular quality among interference-weary operators is fiber's inherent RFI , EMI and crosstalk immunity. It's totally dielectric (with the exception of metallic strength members, if any), thereby eliminating ground loops and various electrical code problems. Fiber lists tremendous bandwidth, low loss, easy upgradabilty and small physical size and weight among its attributes. It's impervious to corrosion and oxidation, doesn't require pressurization, needs fewer splices and active electronics. Needless to say, it's giving competing technologies a run for the money.

Obtaining frequency and path authorizations for a microwave link is becoming increasingly difficult, particularly in urban areas. Competition for spectrum in the previously exclusive CARS band has eliminated microwave as an option in many cases. FCC interaction is required, often delaying installation and activation of a microwave hop even if path coordination is achieved. Zoning, FAA, and building code restrictions may preclude placement of towers or antennas. If approvals are obtained, towers and leased antenna space are expensive and will involve other factors such as lighting, painting and accessibility problems.

CAFM is the other option available to the interconnect designer. Over short runs, involving few channels, conventional FM coaxial systems are very cost effective. However, a longer cascade may destroy the original logic. With an amplifier spacing of 2200 feet (2.4 amps/mile or 1.4 amps/km), 72 amps would be required to span 30 miles (50 km). Conversely, an equivalent fiberoptic system with "amplifiers" required only every 19,000 feet (0.28 "amps"/mile or 0.17 "amps"/km) would yield an 800% reduction in active line electronics; 9 "amplifiers" would do the job. The proportional increase in reliability brought about by reducing the number of potential failure points is a key argument. Additionally, conventional cascaded amplifier calculations can be applied to quantify the improved performance.

Granted, one coaxial cable could accomadate 10 CAFM channels, whereas 3 optical fibers are necessary to achieve the same capacity. But not all signals in the optical system would pass through the same amplifier as they would in the CAFM link; separate repeater modules are required for each fiber. This in itself also adds to the system's reliability; a failure of one repeater would not affect all the channels on the interconnect.

With all of these qualities and more, why has the CATV industry not totally embraced fiber? To be sure, lightwave transmission is an emerging "sci-art". There are many revolutions yet to occur in laser, detector, and fiber technology.

There are many lessons yet to be learned at the School of Hard Knocks by suppliers and appliers alike.

Designing and purchasing the optical system are only a few of the engineering manager's concerns. He's obligated to make it work day after day, beginning the day after the stuff is installed! And besides, they're ONLY a cable company, not a bunch of scientists. Where are they going to find the talent to maintain the system? Who can afford to hire MIT graduates for technicians?

In reality, optical transmission is no different from RF transmission. Most of the animosity towards fiber stems from "fear of flying"! The majority of the industry's technical cadre has not been exposed to optical technology--thereby breeding a dread of the unknown.

Many fiberoptics systems have frequency-division multiplexed RF as their input to the laser transmitter. Once modulated onto the light carrier, the signal is simply another form of electromagnetic energy and behaves similarly to RF. Light power loss and repeater spacing are still quoted in dB; carrier frequency and bandwidth in Mhz. It is well within the ability of most CATV operators to operate and maintain an optical system utilizing existing technical personnel. A well thought-out training program, good system documentation, and a minimum of additional test equipment complete the requirements.

II. BACKGROUND INFORMATION

Caltec Cablevision of Baltimore County, Maryland has, for the past eighteen months, been operating a fifty-kilometer optical trunking system. Over that period, a realistic approach to the operation and maintenance of the optical link has evolved. Designed in concert with Times Fiber Communications, the lightwave network links together four equipment sites. Figure 1 illustrates the routing and present channel loading of the system. An eighteen-channel FM microwave system provides the overwater tie-in between the West and East portions of Caltec's network.

Referring to figure 2, four wideband FM video carriers with subcarriers are frequency-multiplexed and applied to each fiber's optical transmitter. The transmitter intensity (amplitude) modulates a laser diode, its output being light in the near-infrared region, with a wavelength of 820 nanometers (nm) and a power level of no less than 100 mW (20 dBm). This energy is coupled into a 125 micron O.D. graded-index fiber with a

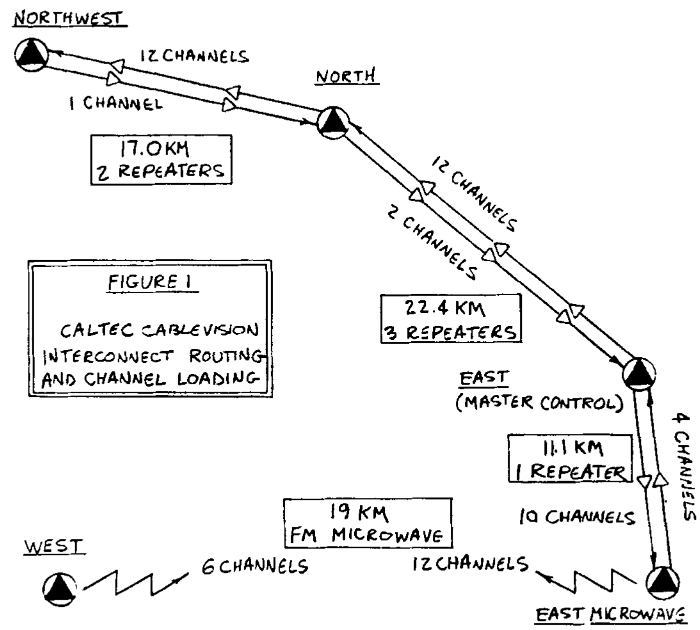

FIGURE 1
CALTEC CABLEVISION INTERCONNECT ROUTING AND CHANNEL LOADING

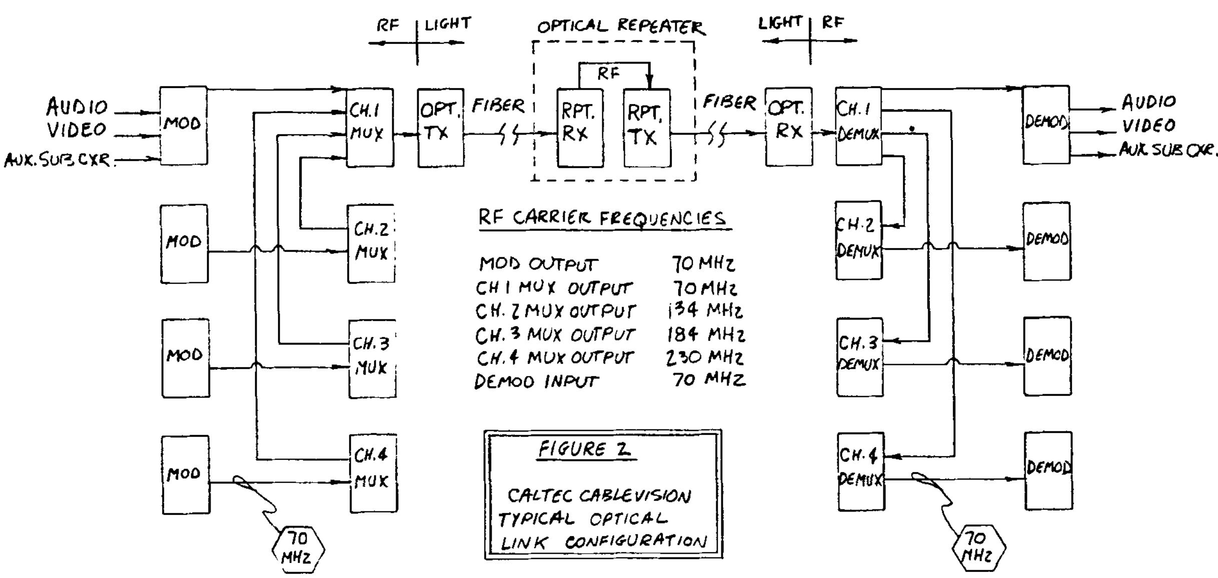

FIGURE 2
CALTEC CABLEVISION TYPICAL OPTICAL LINK CONFIGURATION

characteristic loss of 2.5 dB/kilometer (about 0.8 dB/1000 ft.). As in a traditional RF system "line amplifiers" or repeaters are required approximately every 22 dB of fiber (with allowances for splice losses and system margin), yielding a repeater every 6 kilometers.

Repeaters are essentially demod-remod stations; the light energy is brought back down to its original FDM-FM form, amplified, and reapplied to the input of another optical transmitter. This process continues until a terminal point of the system is reached. Here the signals are again "bumped down" to RF, demultiplexed and demodulated. Signals continuing on to the next site undergo the process again.

III. DESIGN CONSIDERATIONS

For the purposes of this discussion we will assume that the egg preceded the chicken. As such, no system should be specified until the requirements of that system have been determined.

A key parameter of any transmission link is it's insertion distortion. By what factor will a transported signal be degraded? What is the tolerable limit? For example, if the CATV system has a minimum video signal to noise spec at the end of it's longest cascade, what is the minimum required S/N at the input of the system (or the output of the interconnect)? Quality of transmission does not come without accompanying expense; it may be wise not to over-specify the system.

Cost tradeoffs can be made in the original design by including FM mods/demods that provide only the required improvement factors. Each channel's transmission bandwidth can be tailored to meet the target performance. Narrowband FM mods/demods could also be used for non-entertainment channels such as teleconferencing and monitoring.

The second consideration is channel capacity, both at present and in the forseeable future. No one has the foresight to predict channel demands with total precision. Fiber's relative ease of expansion can help soften the expense later. Initial installation of a spare fiber or two may be a prudent decision. Upstream channel requirements must be determined also. Provisions for additional remote feeds, monitoring channels and return data paths should be made.

Most optical fibers have two operational "windows" available. While present technology favors the shorter 850 nm components, cost-reducing developments in 1300 nm lasers, detectors and passives are occurring. Wavelength division multiplexing could be accomplished on existing systems using optical diplexors and two "colors" of laser light. The longer wavelength laser energy experiences a lower loss through the same fiber, thereby necessitating even fewer repeaters than the 850 nm links. The controlling factor at 1300 nm becomes one of available bandwidth; as wavelength increases, bandwidth decreases.

The fiber supplied by Times has a loss of 2.5 dB/km and 1.5 dB/km at 850 nm and 1300 nm respectively, while the passband narrows from roughly 800 Mhz/km to 500 Mhz/km. To determine the actual available bandwidth for a given length of fiber, apply this formula:

$$F_t = F_1 \ / \ 1+(N-1)^{0.5}$$

Where F_t = Total system bandwidth
F_1 = Bandwidth of 1 km of fiber
N = Fiber length (km)

The important concept to keep in mind is that the optical system possesses inherent expandability by virtue of its physical characteristics.

A package of spare equipment is part of any complex system. Each major component should have its counterpart held in reserve to permit rapid service restoration in event of a failure. Minimizing downtime of the network is paramount, particularly where revenue generating services are concerned. Determining quantities of spare equipment requires a careful analysis of the proposed system. Common elements in a link (those that effect all services on a particular fiber--laser transmitters, optical receivers, power supplies) should be stocked on-site in sufficient numbers.

Ask for the manufacturer's calculated reliability of the various components. Better yet, request factory service histories for actual in-service failure rates. Inquire about the turnaround time for such repairs, and other warranty information. Don't cut corners on spares! Their availability (or lack thereof) when needed will separate success from failure.

One proposed method of applying spare equipment involves installation of a spare fiber and "hot standby" optical components (laser, repeaters, receiver) on critical sections of an interconnect. This may seem frivolous, but service restoration after an optical failure becomes a matter of simply re-patching inputs and outputs at the terminal ends of a fiber hop. This may save time when compared to poleline troubleshooting.

IV. CONSTRUCTION AND ACTIVATION

One of the greatest areas for potential error is the physical construction of the system. While the techniques involved are straightforward and traditional, hanging and/or burying the optical waveguide and turning up the electronics involves careful planning.

Before the first centimeter of fiber is ordered, a diligent walkoff of the proposed route is mandatory. Hopefully, the manufacturer will have specified the number and spacing of repeater stations. Make every effort to situate repeaters in accessible locations! Just as trunk amplifiers are spared residence in backyard easements or on "suicide" poles that attract more vehicles than most, a repeater must be protected and reachable. If possible, avoid routing along roads that may preclude maintenance during specific hours. State and local authorities frown on a string of cones occupying a lane of roadway in the thick of rush hour. At the very least, insure that service vehicles can be positioned sufficiently out of traffic (perhaps on the shoulder or sidewalk) to guarantee the safety of service personnel.

Positioning of splice points is also very important. The splicing procedure is relatively time consuming and demands conditions other than mid-span over a busy intersection. If the system is to be installed in telco-type ducts with manhole access, and fusion (electric arc melting) splicing is employed, leave sufficient excess fiber to permit splicing above ground. Safety dictates that electric arcs are not discharged in potentially explosive environments! Once fused, the fiber can be coiled and placed in the manhole.

To allow optimum placement of repeaters and splices, varying continuous fiber lengths are assigned unique places in the link so their ends fall at predetermined locations. Taking the time to judiciously lay out the system will provide for easier installation and future servicing.

Actual installation of the fiber does not require special crews, and is within the ability of any conscientious crew using due care. The longer length of many pulls (averaging about 1 km each) is perhaps the largest difference. Fiber is not practically limited by the number of 90° turns in any given pull. Due to its integral strength members, fiber is resistant to deformation by reasonable pulling forces. Its flexibility far exceeds that of any mainline coaxial cable. Aerial runs can be overlashed to existing lines; direct burial fiber is also available.

One form of insurance during the construction phase involves obtaining pre and post-installation optical TDR (OTDR) signatures. Similar to coaxial fault location, any initially defective fiber will be discovered. After installation, the absence of damage can be verified to everyone's satisfaction. System management should insist that manufacturer's representatives perform these tests.

Once on the poles or in the ground, splicing and connectorization can occur. The optical TDR is usually employed again to give a real-time indication of splice quality. Figure 3, a photo of an OTDR display, shows the signature of a typical 3700 meter section of fiber, after splicing. The "steps" on the trace indicate the loss of each fusion splice. There are four splices on this segment, with losses of 1.0, 0.3, 0.3 and 0.4 dB respectively. Design allowances for splice losses should not be exceeded. Fusion splices attenuate light energy an average of 0.5 dB per junction. The 1.0 dB splice in this fiber segment could be improved.

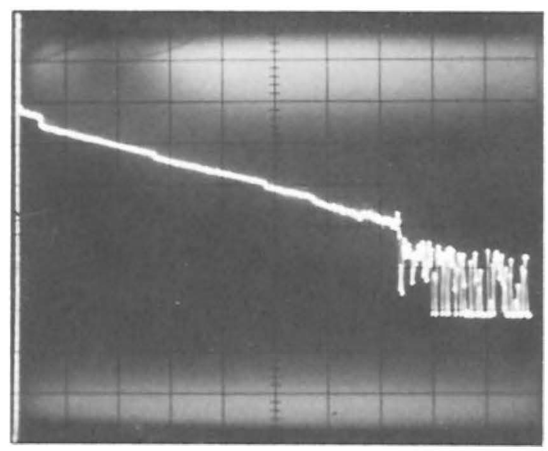

Figure 3

Figures 4 and 5 show two parallel fibers over a 2800 meter span. In figure 4, note the splice at 750 meters; it exhibits a 0.8 dB loss. The pip on the trace at 2550 meters indicates the presence of an air bubble created during splicing. In contrast, figure 5's splices at 750 and 2550 meters are practically invisible.

Splice points , once completed, are generally trouble-free and require no maintenance. Photos of each fiber's loss signature should be obtained and held on file for future reference. Connectors at fiber-to-equipment interfaces require special tooling to install; the skills are

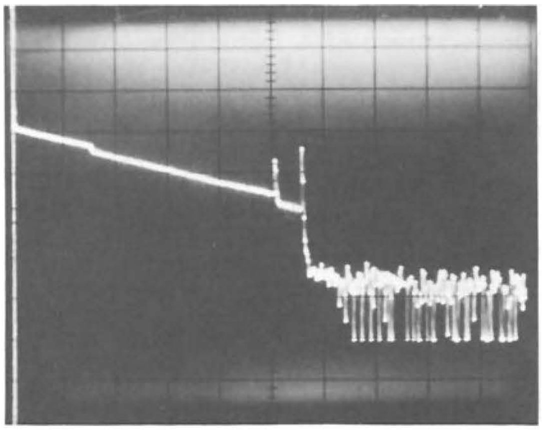

Figure 4

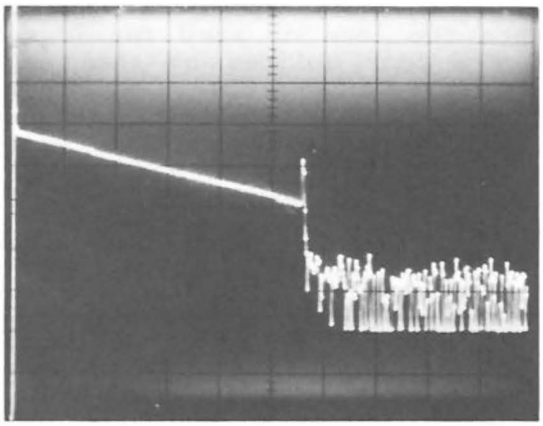

Figure 5

easily learned. System technicians should develop facility in connector attachment.

Once the fiber is spliced, the next step is the installation and activation of the system's electronics. Prior to placing any active component in the field, it is strongly suggested that each module be thoroughly bench-tested. Back-to-back tests of all components under laboratory conditions will save many an hour later. Aside from weeding out the few units that won't work, subtle departures from factory specs can be more accurately detected. Parameters such as optical, RF, and baseband level capabilities should be examined.

Another advantage of this pre-installation shakedown is that it allows most key operating adjustments to be made in advance. Prime examples of this are a modulator's deviation setting and demodulator output levels. Of course, thorough documentation of all tests is strongly advised.

In a large system, turn-up of the link's electronics will be largely the equipment manufacturer's responsibility. In theory, lighting up each link should be a matter of applying predetermined methods and getting predetermined results. Hopefully the vendor's field personnel will have the benefit of experience in dealing with the many unforseen problems that crop up in any technical undertaking. However, this is also the ideal time for the system's owner to get his technicians involved; the best lessons are learned through observation. Throughout the entire activation procedure, complete records should be maintained. This would include in-service spectral photographs of the various RF portions of a link as well as outgoing and incoming optical power levels.

Once in place and operating, each link should be proof-tested to verify compliance with manufacturer's and accepted industry specifications. Of primary concern are the link's video and audio transmission quality. Standard tests for gain vs. frequency, signal-to-noise, chrominance-to-luminance gain/delay inequalities, differential phase and gain, line and field rate anomalies, and general subjective quality should be conducted and documented. This information will prove invaluable as an index of system performance over an extended period. To reiterate, document the entire installation process from start to finish. Include summaries of various problems encountered, delays (if any), time and man-hours expended on each portion of the project (including fiber placement), and notes on procedures employed. After all, history is being made!

V. EQUIPMENT AND PERSONNEL

One statement from the outset--it's not necessary for optical technicians to have a degree in electro-optics. That would be helpful, and maybe with time key personnel will obtain such accolades. The technical manager will have to educate himself in the salient points of the system. But again, the optical trunk is nothing more than a souped-up RF system; many of the same principles are applied.

In all likelihood maintenance of the network will occur utilizing existing technicians. Usually, these people will have line or headend upkeep experience and will suffice quite nicely. What is required of these techs is an ability to grasp new concepts and master the use of a few new pieces of test equipment. Fundamental qualities should also include a good attitude and perseverance. Being assigned to work on a lightwave link should, and will be, viewed as a promotion and a new challenge.

So--what about training? There will be some new concepts involved. The laser transmitters, receivers and optical connectors will be the most notable items. It's incumbent on the technical manager to be familiar with these devices. By doing so, he can teach by example and anticipate the anxieties and questions of his staff. Proper instruction must be given in the fundamentals. Demonstrate how to attach fiber connectors, handle optical fibers, and set-up the various components. Develop their familiarity with the system's channelization and routing.

To assist these ends, it's recommended that either the vendor or technical manager prepare a Field Operations Manual that pertains specifically to the system as installed. Topics might include:

1. A system overview.
2. Safety considerations.
3. Step-by-step setup procedures.
4. Summaries of key specifications.
5. Reference charts and block diagrams.
6. A system map showing repeater locations.
7. A link summary listing pole numbers and locations of splice points and repeaters.
8. Emergency and preventive maintenance procedures.
9. The system's initial performance documentation.
10. Examples of any forms used for maintenance.

This type of document is infinitely more valuable to the field tech than the often highly technical manufacturer's equipment manuals. True, they will be a main source of information during compilation of the Field Operations Manual. Their relevance to the particulars of the system as it exists in operation are questionable. Each equipment manual usually covers a discrete component's circuit specifics and is of little value to the technician with system-oriented concerns.

Uppermost in management's mind should be the safety of its personnel. Low power solid-state lasers as used in communications systems are not inherently dangerous. The Times Fiber laser transmitters have all optical sources enclosed under normal operating conditions; no laser energy will escape with a fiber connected to the output.

As mentioned earlier, these devices are not necessarily harmful to humans. They won't burn through plate steel, much less skin. One should not tempt fate, however. The eye is not the proper test instrument to determine the presence or absence of laser light. The near-infrared energy will be visible as a reddish glow, and could potentially cause damage to the retina of the eye with prolonged or focused exposure.

No optical instrument (magnifying glass or microscope) should ever be used to view the laser in operation or the end of a laser-active fiber. Infrared viewers are available that convert the IR radiation to eyesafe visible light. These devices are relatively inexpensive (less than $1000) but not absolutely essential for maintenance.

To protect both the company and its lightwave technicians it is advised that all personnel directly connected with the operation or maintenance of the system have a complete eye checkup. This would include an ocular history, a visual acuity test, and an ocular fundus examination. The ocular fundus portion should record the specific qualities and pre-existing condition of the interior and light-sensitive tissues of the eye.

These tests should be conducted upon initial assignment, immediately after any suspected eye damage, and again after transfer to other duties. Records should be maintained for an extended period, possibly no less than 20 years.

Many states have laser safety regulations either on the books or under legislation. State occupational safety agencies will be able to "shed light" on the pertinent rules. Stress to each person associated with the system that all the rules in the world don't automatically create safe conditions. The employee must accept as much, if not most of, the responsibility for his on-the-job safety. It is management's role to educate their people about potential occupational hazards. It is the employee's duty to observe safety practices and report all injuries, actual or suspected.

Fiberoptic links require some additional tools and equipment to permit proper maintenance. They can generally be divided into two categories: the "would like to have" and the "must have".

The former classification would include the high-dollar instruments--fusion splicers and optical TDR's. Depending on the size of the network, it may be beneficial to have a splicer and OTDR handy for rapid restoration after a fiber break. However, this usually happens when motor vehicle and fiber-bearing pole or pedestal meet by accident! These types of fiber faults are easy to localize and can be restored more rapidly by installing mechanical connectors and a fiber "patch" until conditions are conducive to permanent splicing. Fusion splicing is an art and proficiency is rapidly lost if not done regularly.

In the event that the fiber does have to be fault-localized and/or re-fused, short term rental of the required instruments will be a more cost-effective solution. The system supplier should also have the resources to locate and repair fiber discontinuities available on an emergency basis. Charges covering per diem fees and expenses will no doubt be levied. Still, this beats tying up capital with purchases of seldom-used equipment.

Equipment in the "must have" category will be an RF spectrum analyzer, optical power meter, digital voltmeter, and connector installation tool(s). Remember, the lightwave system is fundamentally an RF system. A good spectrum analyzer will be the primary test instrument. There are several units available in the $7K to $10K range that will suffice. Most CATV systems have already found them to be invaluable for maintenance of existing plant and probably already own one.

Without an optical power meter all the tech can do is guess what his light levels are. True, some laser transmitters and companion receivers may contain built-in test points that provide a DC voltage indication of light power levels. These are prone to potential error, and do not necessarily guarantee that all the energy being developed by a laser is leaving the output port or reaching the receiver.

The optical revolution has spawned the appearance of many low-cost and easy to use instruments. A good optical power meter with input adapters and jumpers can be obtained for about $500. These usually provide indications in microwatts or dBu and may be ordered with detectors tailored to the wavelength of the system's lasers.

A digital voltmeter will be necessary to accurately measure various test point voltages, including power supplies. This meter should also preferably have dBm readout capabilities, which will facilitate setting baseband audio levels. Several manufacturers offer instruments with this feature.

Lastly, providing the necessary tooling to attach the optical connectors will complete the hardware requisites. Today's connector is distant from those of yesterday that demanded precision polishing and epoxy to affix. The connector selected by Times requires only a single tool to cleave the fiber end at the proper length. It may be prudent to purchase a spare tool in the event that one is misplaced or damaged. The optical connector is perhaps one of the most frequently replaced items in a system; to be tool-less is to be vulnerable!

VI. OPERATIONAL PROCEDURES AND DATA

After the system is installed, activated and tooled, emphasis shifts to the long-term concerns of maintenance, both routine and emergency. Routine service is comprised of equipment set-up and preventive maintenance procedures. Emergency or outage restoration techniques must also be addressed.

The Field Operations Manual will be where these procedures are detailed. The manufacturer's equipment manuals will be a good reference here, but the accent is on short, clear, concise no-frills directions. During compilation of the manual, include only the information necessary to perform each operation. Define nominal test point values, alarm light indications and operation of controls.

The value of preventive maintenance has long been recognized in CATV. It certainly applies to a complex interconnect network, regardless of the mode of transmission--but it especially applies to the optical system. Conducting routine PM checks is one of the best ways to guarantee the longevity of the system's performance as well as educate technical personnel in its care and feeding.

Determine what parameters should be checked on a cyclic basis. RF and light levels, test point voltages and dynamic standby power tests (if any) should be logged on prepared forms. Data from each set of tests must be compared to help detect any changes in performance. An initial test interval of every two weeks is suggested until familiar with the system's idiosyncrasies. After that, dropping back to every three or four weeks will probably be acceptable.

Service restoration after an outage is largely a matter of common sense and traditional troubleshooting techniques. The technician must be aware of the system's channelization and routing so as to be able to interpret the clues of a system failure. If status monitoring is part of the network, fault location is made even more clear-cut. Procedures to be followed during an outage should be included as part of the Field Operations Manual. A periodic review of all procedures, both routine and emergency, will keep them relevant as more experience is gained.

The question on everyone's mind is one of reliability. It's evident that over longer distances fiberoptic systems require fewer active components. But does this translate into a higher level of dependability? Unfortunately, it's difficult to make an apples-to-apples comparison between a true RF supertrunk and its hybrid RF-optical counterpart. There are many differences, not only in the total number of electronics "on the pole", but in the number of channels affected by each failure of the system.

Caltec has tracked system outages informally since the network was activated. In October 1983 a formal procedure was initiated whereby a System Failure Report (SFR) is generated whenever an outage occurs. Using these SFR's for a representative 160 day period, the following analysis was made regarding the fiberoptic trunk.

There were a total of 17 failures summing 40.5 hours during this 3840 hour span. This yielded a total system availability factor (when the optical interconnect was functioning 100%) of 98.95%. The mean time before failure (MTBF) of any component was 225.9 hours. The mean time to repair (MTTR) any outage was 2.4 hours. Outage duration ranged from 15 minutes to 8.5 hours, depending on the time of day and severity of the failure. The tech's location on the "learning curve" also influenced this statistic.

The optical components (laser transmitters, repeaters, optical receivers) failed twice, for a total of 9.5 hours. This resulted in an optical availability factor of 99.75%, an MTBF of 1920 hours, and an MTTR of 4.8 hours. Again, the average duration of each of these outages can be attributed to time of day, location of failure, and technician's skill. Considering that these two failures represent the total of all outside plant problems, this is an acceptable figure.

Surprisingly, the so-called tried and true RF components turned in the lowest availability factor; 99.47%. These devices, however, are the most numerous in the system. A total of 9 RF outages (20.3 hours) produced a 426.7 hour MTBF and a 2.3 hour MTTR.

The other major category of equipment is power supplies and connectors. Here, 6 failures totalling 9.1 hours gave an availability factor of 99.72%. The MTBF and MTTR were 640 hours and 1.5 hours respectively.

A total of 41 channels are carried between the four sites served by the optical trunk. Figure 6 shows the distribution of the number of channels affected by each outage. Outages disabling 1 and 2 channels were the most numerous; 6 each. Failures affecting 4, 6, or 8 channels numbered 1 each. Finally, 9-channel outages were 2 in number. A typical outage on the fiber will affect fewer channels; not all channels pass through the same active device as they would in an RF trunk.

Across the extensive nine-site Caltec headend complex, the fiberoptic system accounted for 13.9% of the total outages. Total preventive maintenance time on the light-net during the 160 day period was 128 hours. This, added to the 40.5 hours that the system was "outage-afflicted" resulted in a total manpower commitment of 168.5 hours, or a little over 1 hour per day.

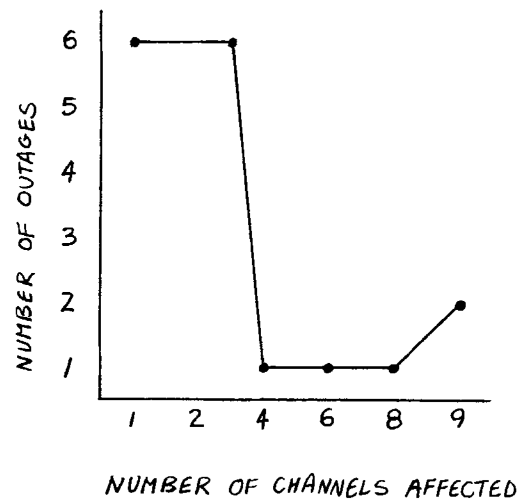

Figure 6

VII. SUMMARY

The fiberoptic system is not an unmanageable entity. It is not bred of strange and exotic stock. Any CATV operator able to make the commitment to personnel development, test equipment, and assiduous maintenance techniques will be successful with fiberoptics.

The future is here now! Gain experience with optical systems. Read up on advances in technology and applications. Light is indeed communication's "new wave".