1 GHZ FIBER-TO-THE-PEDESTAL SYSTEM FOR CATV

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Abstract

The design of a one gigahertz fiber-to-the-pedestal CATV system is described and discussed. The system consists of numerous unrepeatered fiberoptic links from the headend to receiver-amplifier units in pedestals. There is no cascading of amplifiers. The two types of amplifier units for this system are described and the system performance is discussed. Typical equipment costs for the deployment and design trade-offs are outlined. Other operational features and efficiencies are also described.

At the present time the architecture of this fiber-to-the-pedestal system is particularly well-suited for dense concentrations of dwelling units. However, the paper will indicate the likely path of progression from today's fiber-to-the-feeder systems to this fiber-to-the-pedestal architecture for more moderate subscriber densities.

BACKGROUND

During the past 18 months the cable television industry has made a dramatic move toward fiber-to-the-feeder (FTF) system architectures. In a paper[1] at last year's NCTA national meeting we analyzed the reasons for this shift in detail, but the key advantages of FTF can be summarized as:

- High signal quality
- Cost-effectiveness
- Reduced outage rates
- Subscriber-base segmentation

The one new feature underlying FTF that has made it such a successful architecture for cable TV, however, is its use of laser transmitters and optical fiber to free the system design from the requirement for a long amplifier cascade with low distortions. The fiber link takes the signal all the way into a neighborhood with reasonable fidelity. The concomitant high cost of the optoelectronics, however, is offset by lengthening the distribution strings from the conventional 2-3 amplifiers up to 4-6 amplifiers, thus serving greater numbers of subscribers from each fiber node. Additional reach is achieved by allowing operating levels to increase -- at the expense of distortions. The higher level of distortions is not a problem in FTF because there are so few amplifiers in the cascade.

We report here on a system under design that takes this distortion-vs-reach trade-off to the limit. In this system we have reduced the "cascade" to a single amplifier that is located in a pedestal within drop-length reach of a substantial number of subscribers (appropriately called "fiber to the pedestal" or FTP).

FIBER-TO-THE-PEDESTAL SYSTEM

Increasingly during the past year cable TV operators and equipment vendors have been faced with a dilemma. There has been a clear need to increase bandwidth for additional programming services in the United States and for UHF transmission compatibility in Europe, but the key electronic components -- the amplifier hybrids -- have not generally been available in the bandwidths, gains and technologies required. Recently this has begun to change, however, as push-pull hybrids with good distortion performance up to 1GHz have come onto the market, but in limited gain versions. The challenge for the equipment vendors, then, has been to find ways to apply this limited selection of hybrids to solve the requirements of system operators without developing whole new product lines for each application.

Recalling that the fiber-to-the-feeder architecture was based on the idea of running a small number of amplifiers at relatively high levels -- thus enduring high distortion levels in individual amplifiers but compounding these distortions over only a few units -- we were led to explore what would happen if the amplifier cascade was reduced down to its minimum, one amplifier. It was proposed that this might permit the use of push-pull hybrids in applications where only power doubling and feedforward would normally have been considered. What we found was that one could, in fact, have considerable reach and reasonable costs in cases where one was able to reach each of 20-30 homes with 100-meter-long drop cables from that single amplifier. The amplifier would be a combination fiberoptic node and post-amp, with the optical and RF signals split as many times as possible.

The system architecture is shown in Figure 1. In the following sections the individual components are described, the system performance is reported and the system economics are discussed.

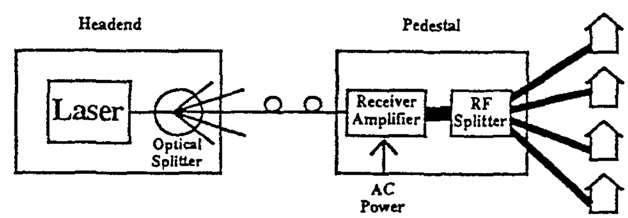

Fig. 1. Fiber-to-the-pedestal system architecture

SYSTEM COMPONENTS

Laser Transmitters

Clearly one of the keys to any cost-effective application of fiberoptics in cable television is the availability of high-power, low-noise and low-distortion laser transmitters. In this application the requirements are the same as in others, so the laser options are, as well: single-output DFB lasers and multiple-output YAG lasers. In particular we have designed for DFB's with output powers of

4-6mW (6-8dBm) and for YAG lasers with four 10mW (10dBm) outputs.

Commercially available DFB lasers have RF input drivers capable of 860MHz operation. These can be upgraded to 1GHz using the new push-pull hybrids. The modulators in the YAG laser systems, on the other hand, require high enough drive levels that feedforward amplifiers appear to be required. Since the commercial availability of such high bandwidth feedforward gain blocks is unclear at the present, this paper deals only with tests of the DFB's.

For European applications, where UHF frequencies are needed but the channel count is modest (i.e., 30 to 40, approximately), single-fiber transmission appears to provide quite adequate performance. For US applications, where a full 150-channel line-up is intended, dual-fiber systems appear to be required.

Optical splitting is called for and is generally done in the headend. We have designed for splits up to 16-ways, which adds 13dB to the optical link loss.

Receiver/amplifiers

Two different fiberoptic receiver/amplifier stations have been developed for this application. One is a single-output "GlasPAL" device in a line-extender housing, with plug-in single or dual receiver and transmitter cards. The unit utilizes two 18dB hybrids in the forward path and provides a 40dBmV output level for typical received optical powers.

The second unit is a four-output "Flamethrower" station with similar plug-in optical receive and transmit capability. This unit uses up to seven of these hybrids and can provide high-level outputs from each of its four ports.

Tap array and drop cable

The system design objective is to be able to reach 24-36 homes located within a 100m radius of the amplifier, for each of the amplifier outputs. This is done by providing an assembly of taps immediately at the amplifier output ports inside the pedestal enclosure. As can be seen from Figure 1, there is no need for passing AC power through the taps, thus they can be designed for minimum loss. Typical loss values at 1GHz would thus be 3.6dB for a 2-way split and 19dB for a 24-way.

In order to reduce losses at these high frequencies the drop cable selected is 1.6/7.3 (Cordaillod) cable. A 100m length of this cable has attenuations of 15dB and 4dB at 1GHz and 100MHz, respectively.

SYSTEM CONSIDERATIONS

Powering

AC power must be provided at each pedestal since there is no other way to bring power to the receiver/amplifier. In these units the power enters the station via a separate AC feed and is transformed down to 48VAC for direct application to the power pack inside the unit.

Return signals

Laser transmitters for data return can be provided in each station at reasonable cost (see economic discussion below). The need for video return at specific locations can also be accommodated (at an increased cost, however). Perhaps of greater interest is the ability to readily plug-in one of the higher-cost video laser cards temporarily at any station for "on-the-spot" remote transmissions (such as electronic newsgathering), since one is never far from an optical node station in the FTP architecture.

END-OF-LINE PERFORMANCE

Design objectives

The intriguing aspect of FTP systems is that the end-of-line performance is determined, for the most part, by the characteristics of only one fiberoptic link with post-amp.

In the most immediate application of this system architecture -- a European system transmitting forty 8MHz channels plus data spread over the spectrum from 87-860MHz -- the performance required at the set-top is:

Carrier-to-Noise:	49dB, min
Composite Triple Beat:	-55dB
Composite Second Orders:	-53dB

The level to the subscriber is 6-18dBmV, but the maximum difference in signal levels at any particular set-top can be no more than 8dB.

Furthermore, the system economics require that all of these specifications apply to lengths of drop cable from 15 to 100m emanating from each receiver/amplifier.

The average fiber cable length in this system is 6km, which translates to an optical loss of 2.4dB, plus splitting loss.

Performance test results

In order to deliver the required levels to 24 homes from one receiver/amplifier, the output of the amplifier has to be 40dBmV. This results in the system configuration shown in Figure 2.

At a -4dBm input to the optical receiver and a 4% optical modulation depth, the CNR and CSO performance requirements can be achieved and the CTB requirement well exceeded. Interestingly, there is essentially no distortion contribution from the receiver/amplifier hybrids at this output level and loading.

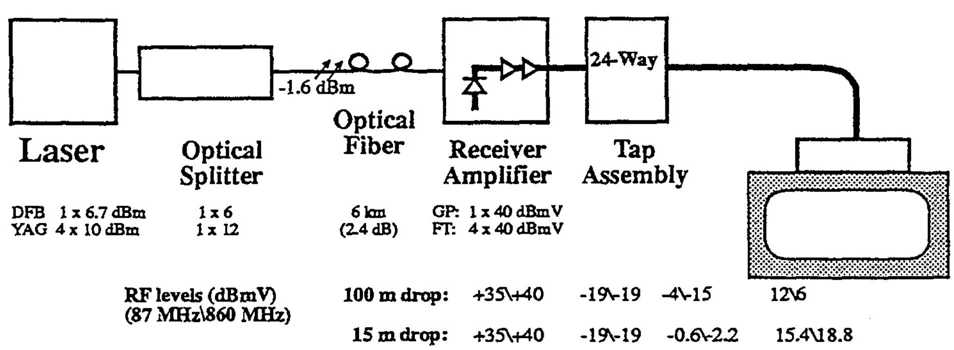

Fig. 2. Specific architecture to be deployed

In order to supply -4dBm to the receiver with a 6km fiber length, the output of a 4.7mW laser can be split six ways. Each output of a 10mW YAG laser can be split twelve ways.

SYSTEM ECONOMICS

Using published laser transmitter cost estimates[2], we can analyze the costs of the opto-RF equipment for FTP in various service scenarios. (See Table 1 for the assumed prices for the key components.) It must be kept in mind that each of these scenarios will assume that all of the calculated number of homes can, in fact, be reached by drop cables from the receiver/amplifier node. This works out to a required subscriber density of 2000 per square mile, which is certainly not typical either in the US or Europe. There are numerous urban locales where such densities are found, however. For reference, the average household density in Bern (Switzerland), Washington, DC (US), and Paris (France) is approximately 2800, 5000 and 27,000 per square mile, respectively.

In the remainder of this section, we will examine the cost per subscriber and the group size in a few different deployment scenarios for this architecture. The costs of the opto-RF equipment and the sizes of the service groups are summarized in Table 2.

Scenario 1: High density, low channel load

We first consider a scenario similar to the one discussed above in the performance testing section. It applies to many situations in Europe, where there is sufficient residential density and the programming is limited to about 40 channels that are widely spaced across the VHF and UHF bands. As has been shown above, a single DFB laser can provide transport of these signals with acceptable CNR and distortion performance. In Table 2, the columns labelled 1a and 1b show the results of a 4-way and a 6-way split of this optical output, followed by a single-fiber GlasPAL whose RF output is split 24-ways. The additional optical split in case 1b limits the fiber loss budget. On the other hand Column 1c shows that (for the particular equipment prices given in Table 1) a YAG laser can deliver as much optical power to each pedestal as the initial case (1a) but at the same cost as case 1b, because the YAG laser allows much more splitting. This has unfavorable failure group size implications, however. Note that case 1b is the same as that shown in Figure 2, except for the optical fiber loss.

Table 1. Estimated costs of opto-RF components

DFB laser transmitter (DFB)	$12500[2]
YAG laser transmitter (YAG)	65000[2]
Single-fiber receiver/amplifier (1GP)	1750
Dual-fiber receiver/amplifier (2GP)	2250
Single-fiber Flamethrower rcvr/amp (1FT)	3250
Dual-fiber Flamethrower rcvr/amp (2FT)	4000

Table 2. Fiber-to-the-pedestal scenarios

Scenario:	1a	1b	1c	2a	2b	3a	3b	3c	
Transmitter type	DFB	DFB	YAG	DFB	YAG	DFB	DFB	YAG	DFB
No. of transmitters	1	1	1	1	1	2	2	1	1
No. of outputs	1	1	4	1	4	1	1	4	1
Opt pwr/output (mW)	5	5	10	5	10	5	5	10	5
Optical splits	4	6	8	4	8	4	5	8	4
Opt fiber loss (dB)	4	4	4	4	4	4	4	4	4
Opt pwr rcd (dBm)	-3.5	-5.4	-3.8	-3.5	-3.8	-3.5	-4.6	-3.8	-3.5
Receiver/amp type	1GP	1GP	1GP	1FT	1FT	2GP	2GP	2GP	
No. of outputs	1	1	1	4	4	1	1	1	
RF splits	24	24	24	24	24	24	24	24	
No. homes served	96	144	768	384	3072	96	120	768	96
Opto-RF $/home	203	160	158	66	55	354	302	309	

Scenario 2: Very high density, single fiber

In an area of high subscriber concentration, where a four-output receiver/amplifier may be used to advantage, we can see dramatic dilutions of the laser transmitter cost. Case 2a shows that a DFB laser system delivers signals at a cost of only $66/sub. In comparison a YAG-based sytem delivering the same picture quality can reduce that cost by 17%, but at a eight-fold increase in failure group size.

Scenario 3: High density, dual fiber

In a scenario more relevant to the US, where one fiber could carry the lowest 77-channels and a second fiber could carry almost 500MHz in a single octave, the costs are, of course, higher, as shown in case 3a. Case 3b shows that an extra optical split reduces the cost/sub, but delivers what may be marginal optical signals for this loss budget. An interesting possibility is the use of a YAG laser for the lower band, where distortion performance will be critical, along with a DFB laser of lower linearity spec for the upper band. If the high output power of the YAG laser can be shared efficiently, as outlined in the final two columns of Table 2, this scheme would lead to a cost of just over $300/sub. Furthermore fewer than 100 homes would be served by the high-band laser, so considerable market segmentation would still be retained.

Discussion

There are a few additional observations that we have made in the course of this investigation. First the models for single-fiber systems should be applicable to 550MHz transport in the US today. Future upgrades could be obtained by substituting dual-fiber receiver cards for the single-receiver plug-ins (provided, of course, that enough extra fibers have been included in the cable provisioning).

As with all of the new fiber-based architectures, the system operator will have to make sometimes difficult trade-offs between service group size and capital cost. It should be noted that the high-power YAG laser may be most useful for long optical loss budgets, where its power is needed. In the scenarios we have discussed above, which had relatively short fiber lengths, the YAG unit tended to generate excessively large group sizes.

Finally the additional cost for 2-way systems must be considered. The return of conventional data (in this case by laser, of course) adds approximately $2000 to the cost of a fiber node. Since the node serves 24 homes, this would add about $85/sub. In the future, one might envision that return of video might be required, which could also be done with a plug-in card, but at a significantly higher cost.

SYSTEM EVOLUTION

Fiber-to-the-feeder designs being installed today provide highly cost-effective systems that serve on the order of 2000 subscribers from each fiber node. In addition there are ways to readily adapt some of these installed systems so that the fiberoptic signals can be brought further into the network and the service group decreased by a factor of four, to about 500 subs.

The fiber-to-the-pedestal architecture can be made to supplement such systems. As has been mentioned, FTP applies today to high concentrations of subscribers, as in urban areas. It can also be used to bring new services to specific areas within a larger system.

As costs decrease (particularly for the lasers and photodiodes) the cost-effective group size will also decrease, which means that FTP systems will apply to less dense population areas. Specifically, it should be noted that when the cost can be divided among as few as four subscribers, then this equipment would be capable of full 2-way video service, since four NTSC channels can be accommodated on one video laser return.

CONCLUSIONS

In recent years many people have endeavored mightily to bring the advantages of fiberoptic transport to users of AM video signals. The technical successes on the component level has engendered great changes in the way we think about our cable TV system architectures. In this paper we have explored yet another step in this conceptual evolution. Our observation is that a single-amplifier FTP system can be deployed effectively today in certain cases. We also see it as a logical outgrowth of the fiberoptic technology and systems already deployed and as further evidence of the strong position of the CATV industry as the provider of broadband services in the future.

REFERENCES

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2. Paul Kagan Associates, "Cable TV Technology", No. 170, Carmel, CA, August 1991.