FIBER TO FEEDER DESIGN STUDY

John A. Mattson
Scientific-Atlanta

Abstract

The Fiber-To-Feeder (FTF) design approach is analyzed in comparison to tree-and-branch design for rebuilds. Data from numerous design studies is used to develop a "typical" FTF design. Total material cost is compared using several alternative FTF design approaches, and an optimal solution, known as Fiber to the Serving Area (FSA) is recommended. System performance and material costs are compared to conventional designs for varying plant densities. Additional benefits of FSA design are also discussed, including improved picture quality, increased reliability, reduced operating costs, and more compatibility with future services.

THE FIBER-TO-FEEDER DESIGN

The Fiber-to-Feeder architecture is dramatically different from the traditional tree-and-branch design in a rebuild situation. It should be noted that this paper is confined to the study of rebuild architectures only. In a Fiber-To-Feeder (FTF) design, AM fiber links comprise the trunk portion of the system, performing the function of a cascade of trunk amplifiers in a tree-and-branch design. The feeder portion of the cable system in an FTF design is similar to a conventional plant in that it is made up of RF amplifiers, which perform as bridgers and line extenders. A schematic of a generic FTF design is presented in Figure 1. From a system engineering standpoint, FTF offers significant improvement over tree-and-branch by eliminating cascades of trunk amplifiers, thereby removing a major source of noise. In fact, in an FTF design the target for end-of-line carrier-to-noise ratio is generally around 48 to 50 dB.

The only way to achieve this type of performance using a tree-and-branch architecture is to run AM fiber nodes to every bridger location. At today's AM fiber prices, however, this approach is not practical from a cost standpoint. Therefore, it is necessary to reconfigure the feeder plant in order to improve the design's economics. The key features which separate FTF from tree-and-branch designs, and in fact determine the success of a particular FTF design, are the technology and architecture used in the feeder.

FTF Design Principles

In order to illustrate the important aspects of FTF, a sample FTF design will be used as a reference point. The system under study is essentially a "typical" cable system, which is the result of averaging the data from a number of FTF designs. Figure 2 summarizes the basic elements of the sample design system. The comparative results of various design approaches are presented in Figure 3.

The simplest approach, followed in many of the early FTF designs, is to parallel the tree-and-branch approach by locating a bridger at the output of the AM fiber node and then cascading two or three line extenders from there. (1) As designers became more proficient, it became apparent that the critical factor in producing an

FIGURE 1

FIBER-TO-FEEDER DESIGN

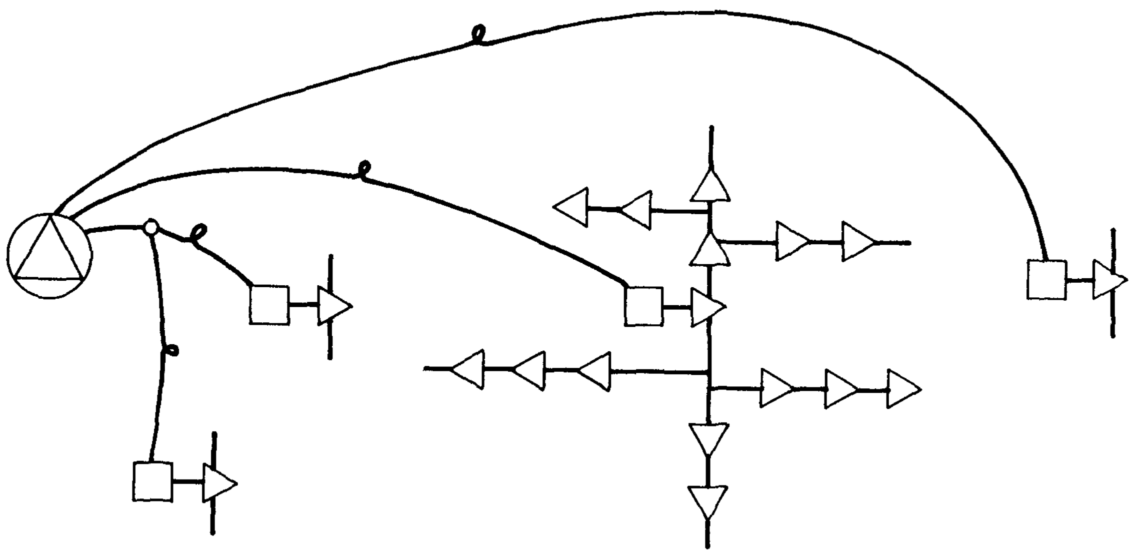


FIGURE 2

SAMPLE DESIGN PARAMETERS

Project Type:	Rebuild
Plant Size:	750 Miles
Bandwidth:	550 MHz
Density:	100 Homes/Mile

Conventional Design

Trunk Cable:	0.875" P-3
Trunk Electronics:	Feedforward
Feeder Cable:	0.625" P-3
Feeder Electronics:	Power Doubling
Fiber Cascade:	Node + 12 Trunks
Headend Cascade:	16 Trunks
Feeder Cascade:	Bridger + 2 LEs

economical FTF design is the miles of plant served by each AM fiber node. As the "serving area" of the AM fiber node increases, the FTF design becomes more and more economical. The approach described above, essentially copying a conventional feeder layout, is the least efficient in terms of the size of the serving area, covering generally 1 to 3 miles of plant.

In order to maximize the serving area of the AM fiber nodes, and thus realize the most efficient design, it is necessary to utilize feedforward technology in order to maintain the desired distortion performance level over the maximum distance. Since the amplifier cascade will by definition be relatively short, the noise contribution of the amplifiers will be minimal, and distortions become the critical parameter.

When push-pull amplifiers are used, the total cost is highest, and the average size of the serving area is about four and one half miles. Moving to power doubling amplifiers reduces the total cost and increases the size of the serving area to five and one half miles. Using feedforward amplifiers results in the lowest total cost, with the srving area expanded to seven and one half miles. By using feedforward technology, higher feeder levels can be maintained, thereby reducing the quantity of amplifiers needed. In short, although feedforward amplifiers are more costly, the use of fewer total amplifers will more than offset the cost difference and yield the lowest total cost.

To increase the size of the serving area still further, and thus make the design more economical, it is desirable to incorporate some trunk design principles into the feeder. Working from the output of the first amplifier after the AM fiber node, "Express Feeder" runs, or essentially supertrunks, are used to extend the reach of the amplifier cascades. The serving area is further subdivided into mini-serving areas, each of which is fed by an Express Feeder. The use of the combination of Express Feeders and feedforward amplifier technology in the feeder plant is referred to as Fiber to the Serving Area (FSA). The resulting design, which is illustrated in Figure 4, yields the lowest total cost, with a serving area of about twelve miles on average. The typical serving area contains approximately 2,000

FIGURE 3

SAMPLE DESIGN COMPARISON

	CONVENTIONAL TRUNK & FEEDER	FIBER-TO-FEEDER CONVENTIONAL FEEDER P-P	PHD	FF	FIBER TO SERVING AREA EXPRESS FEEDER FF
END-OF-LINE CNR (DB) :	46	49	49	49	49
SERVING AREA SIZE (MILES) :	2.0	4.5	5.5	7.5	12.0
MATERIAL COSTS (PER PLANT MILE)					
COAX MATERIALS:					
COAXIAL CABLE:	$2,275	$2,000	$1,950	$1,900	$2,050
ACTIVES & PASSIVES:	$3,225	$3,250	$3,050	$3,000	$2,850
TOTAL COAX:	$5,500	$5,250	$5,000	$4,900	$4,900
FIBER MATERIALS:					
OPTICAL CABLE:	$ 175	$1,000	$ 725	$ 550	$ 300
ACTIVES & PASSIVES:	$ 325	$3,500	$2,775	$1,950	$1,200
TOTAL FIBER:	$ 500	$4,500	$3,500	$2,500	$1,500
TOTAL MATERIAL:	$6,000	$9,750	$8,500	$7,400	$6,400
% OF CONVENTIONAL:	100%	163%	142%	123%	107%

NOTES: 1) Conventional trunk-and-feeder design required some fiber overlay to achieve end-of-line performance required.
2) All systems 550 MHz bandwidth.
3) AM fiber is dual tier.

homes, and this has become the key parameter in identifying serving areas. (2)

Each serving area will be fed by an AM fiber node. An optical loss budget is selected for all of the AM links, which is usually equal to the path loss to the most distant nodes. The system optical budget is generally set in the range of 10 to 12 dB, which allows optical splitting to be used in feeding the nodes which are closer to the headend. The result is that all of the nodes are virtually identical in terms of loss budget, and costs are reduced by sharing transmitters across multiple nodes. Figure 5 shows an overview of a CATV plant, with concentric circles around the headend representing the number of AM fiber nodes fed per transmitter. Figure 6 provides a more detailed look at a section of AM fiber trunk, showing the configuration of transmitters, nodes, and optical splitters.

FSA DESIGN PARAMETERS

The preceding discussion has been based, as mentioned above, on average

FIGURE 4

FIBER TO SERVING AREA DESIGN

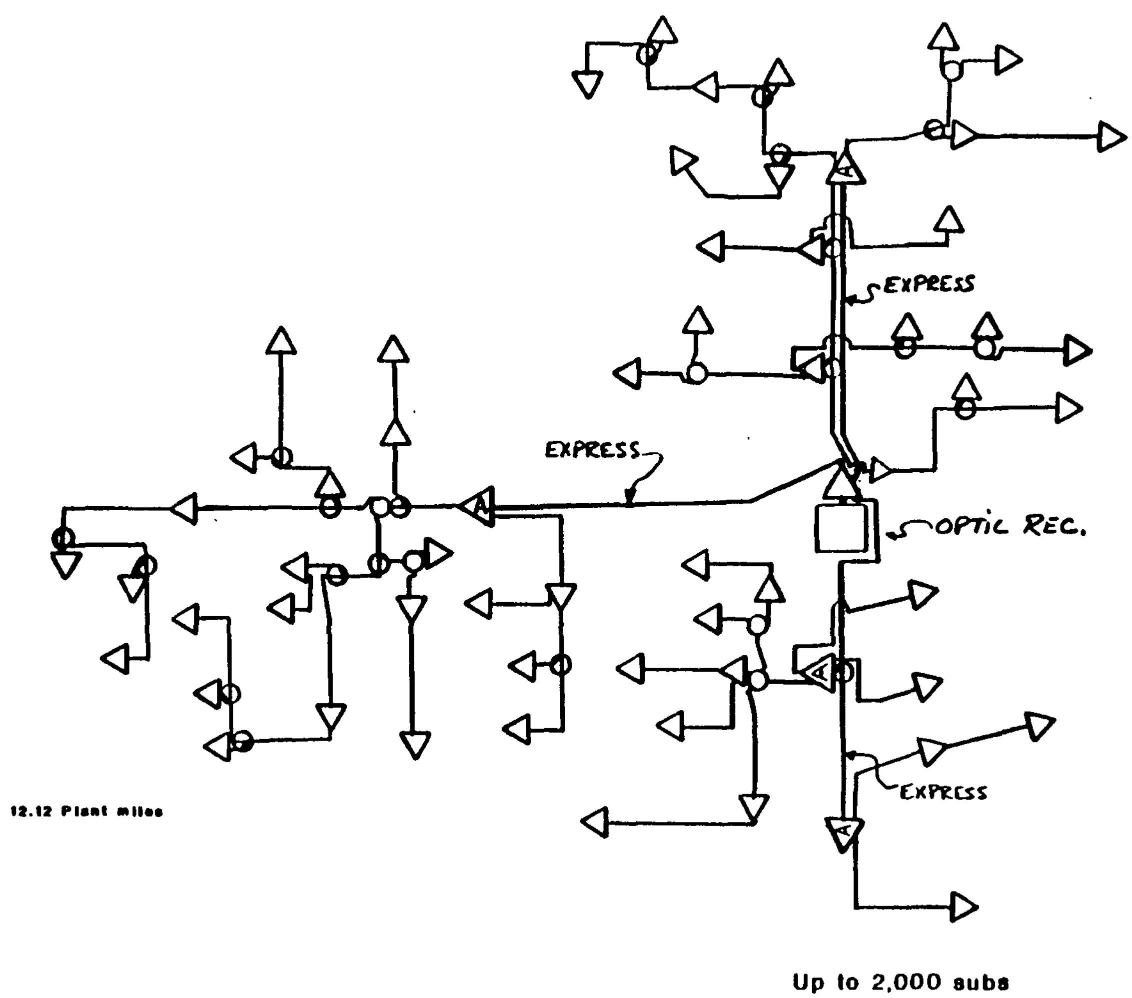
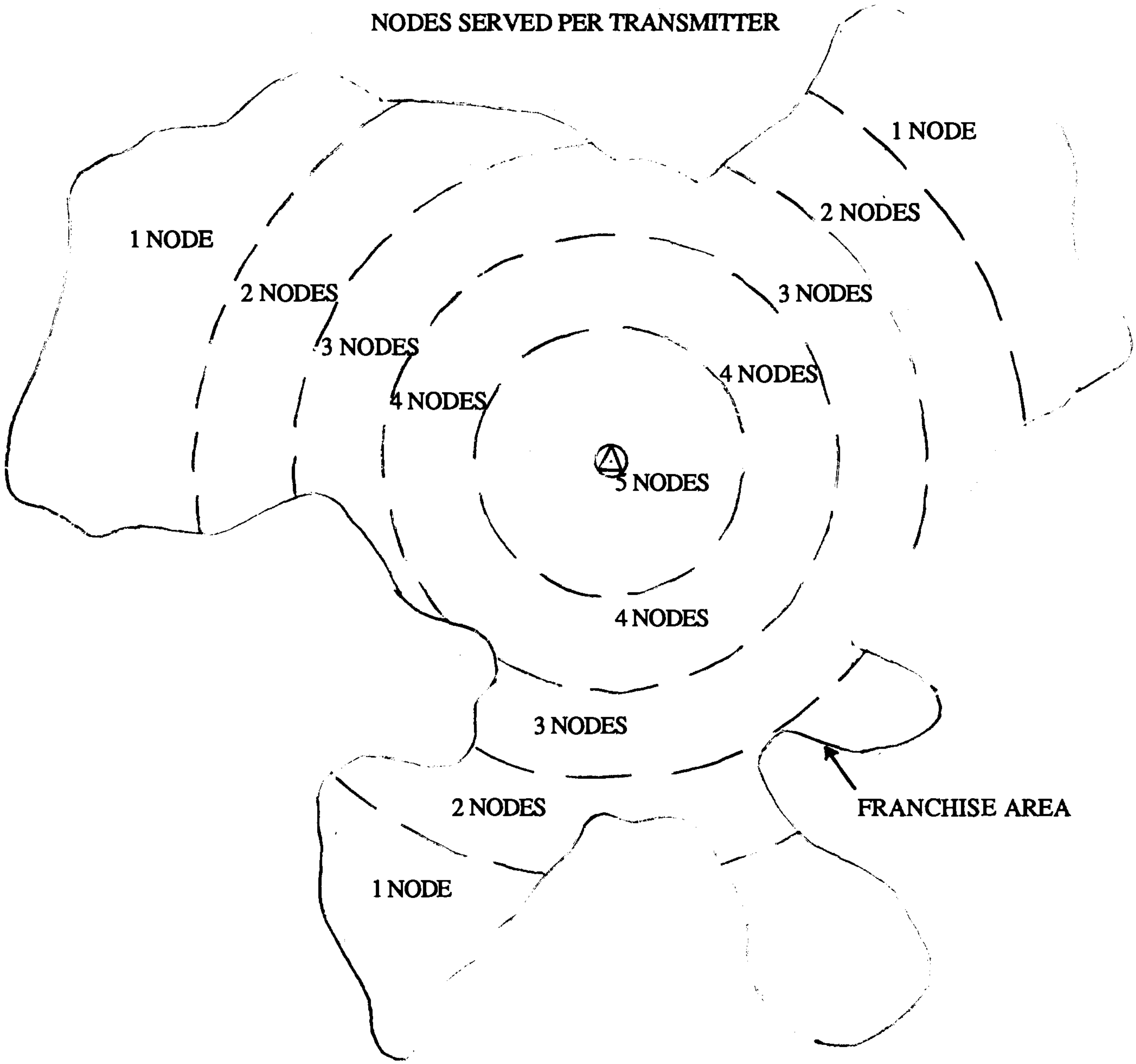


FIGURE 5

AM FIBER RANGE FROM HEADEND



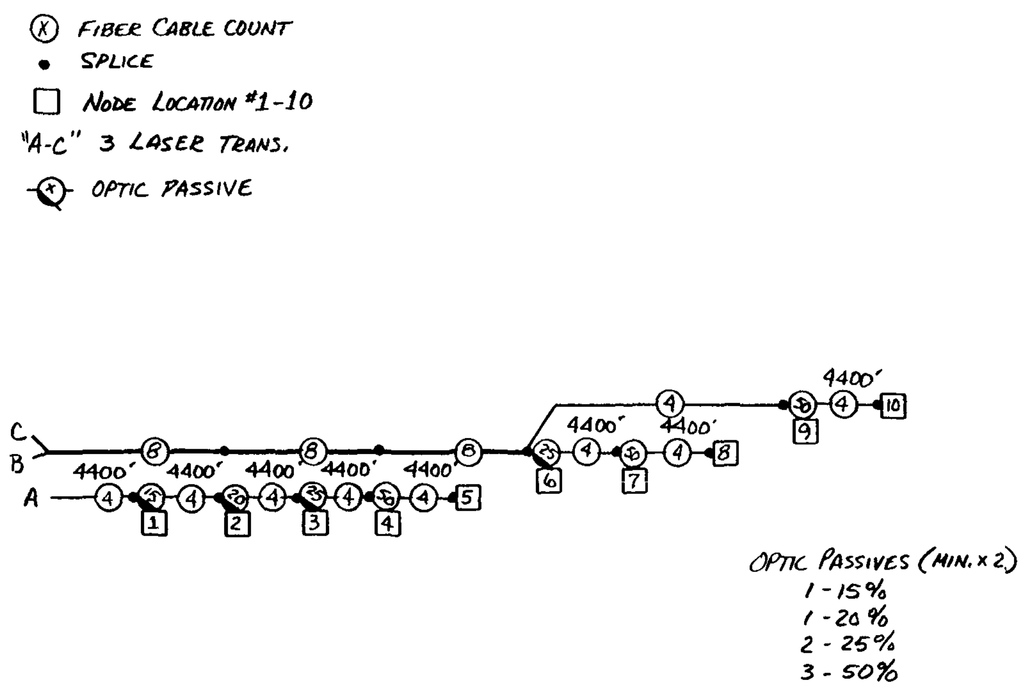
data generated from numerous individual designs. In looking through all of the specific cases, it is possible to identify some of the key design parameters, as well as looking at how the design differs from system to system. In all cases, it is desirable to divide the plant into serving areas of 2,000 homes. Smaller areas may be selected, but a cost penalty will be incurred. In any event, Express Feeders will be used from the output of the first amplifier, which support further subdivision of the serving areas. The design is most cost effective when the serving area is equal to or greater than 12 miles of plant.

The most significant factor impacting an FSA design is the density of the homes in the system being designed. As the system density decreases, the length of the amplifier cascade in each serving area increases. However, even in the densest systems, the minimum number of amplifiers in cascade is four, so at least every third amplifier in each cascade must be equipped with Automatic Gain Control (AGC) to maintain constant output over

FIGURE 6

AM FIBER TRUNK SECTION

FIBER TO SERVING AREA



plant. The carrier-to-noise ratio at the last tap is targeted in the range of 48 to 50 dB, as opposed to 45 to 47 dB in a comparable tree-and-branch design. In an FSA design, the fiber links add virtually no distortions and the amplifiers add very little noise. As demonstrated in Figure 8, the relatively short amplifier cascade sets the composite-triple-beat performance of approximately 56 to 57 dB, which in combination with the essentially tranparent fiber distortions results in end-of-line distortions of about 54 dB. In the same fashion, the fiber link sets the noise limit at about 50 dB, with no more than 1 dB noise addition in the amplifier cascade.

Reliability

The number of outages experienced by each subscriber is dramatically reduced as compared to a conventional plant. In an FSA design, the total number of active devices between any subscriber and the headend is reduced to a maximum of five in the typical case. Even compared to a fiber backbone with four trunk amplifiers in cascade, the number of hybrids in cascade is reduced by 40%. This means that any single failure affects a much smaller group of subscribers than in a conventional plant.

In addition, the number of outages

FIGURE 7

MATERIAL COST COMPARISON

	LOW DENSITY 60 HOMES/MILE	MEDIUM DENSITY 125 HOMES/MILE	HIGH DENSITY 200 HOMES/MILE
TRUNK-AND-FEEDER:	$6,200	$5,975	$6,785
FIBER TO SERVING AREA:	$6,625	$6,155	$7,070
FSA PREMIUM:	6.9%	3.0%	4.2%

NOTES: 1) All systems 550 MHz bandwidth.
2) AM fiber is dual tier.

plant. The carrier-to-noise ratio at the last tap is targeted in the range of 48 to 50 dB, as opposed to 45 to 47 dB in a comparable tree-and-branch design. In an FSA design, the fiber links add virtually no distortions and the amplifiers add very little noise. As demonstrated in Figure 8, the relatively short amplifier cascade sets the composite-triple-beat performance of approximately 56 to 57 dB, which in combination with the essentially tranparent fiber distortions results in end-of-line distortions of about 54 dB. In the same fashion, the fiber link sets the noise limit at about 50 dB, with no more than 1 dB noise addition in the amplifier cascade.

Reliability

The number of outages experienced by each subscriber is dramatically reduced as compared to a conventional plant. In an FSA design, the total number of active devices between any subscriber and the headend is reduced to a maximum of five in the typical case. Even compared to a fiber backbone with four trunk amplifiers in cascade, the number of hybrids in cascade is reduced by 40%. This means that any single failure affects a much smaller group of subscribers than in a conventional plant.

In addition, the number of outages

FIGURE 8

FSA PERFORMANCE COMPARISON

	FEEDER LEVEL	FIBER C/N	FIBER CTB	COAX C/N	COAX CTB	TOTAL C/N	TOTAL CTB
LOW DENSITY : (4 AMP FEEDER)	47	50.0	65.0	60.2	57.0	49.6	54.1
MEDIUM DENSITY : (5 AMP FEEDER)	46	50.0	65.0	58.2	57.0	49.4	54.1
HIGH DENSITY : (8 AMP FEEDER)	44	50.0	65.0	54.2	56.9	48.6	54.0

NOTES:
1) All systems 550 MHz bandwidth.
2) AM fiber is dual tier.
3) Optical loss budget is 10 dB.
4) 4 and 5 amp cascades: every third amp operated in AGC mode.
5) 8 amp cascades: every other amp operated in AGC mode.

in the plant as a whole is reduced. The total number of active devices employed in the system is reduced, so the number of system outages is lower as well. In fact, the FSA design uses 10% fewer hybrids plant-wide than a comparable fiber backbone or trunk-and-feeder. In previous AM fiber design approaches, while the reliability experienced by indivdual subscribers has improved, the overall system reliability has actually been degraded. This phenomenon is intuitive, since fiber cable and electronics were added to the existing cable plant. However, in FSA designs there is a net gain in reliability, since fiber cable and electronics replace trunk cable and amplifiers. (3)

Operating Costs

The plant operating costs in an FSA architecture are lower than a tree-and-branch design. The total power consumption of an FSA plant is lower than conventional trunk and feeder or fiber backbone designs. There are two primary reasons for this: 1) fewer hybrids are used, and 2) a standby power supply can be used for the optical receiver and surrounding amplifiers while the remainder of the feeder is served by much lower cost non-standbys. The maintenance requirements are lowered by at least an order of magnitude. It is relatively simple to balance and align the short amplifier cascades in an FSA plant. The combination of fewer failures and simpler maintenance procedures reduces the number of truck rolls and simplifies the tasks required, with corresponding reductions in spare parts inventories, technical training, employee turnover, etc. (4)

Compatibility with Future Services

The FSA architecture supports future services. The overall quality of the signals delivered to the subscriber is compatible with HDTV standards. Bandwidth expansion can be accomodated by electronics upgrades, and digital compression offers even more dramatic expansion capabilities. The double-star configuration is compatible with telephony type services; the 2,000 home serving areas are roughly parallel to those of the local telephone system. The use of Express Feeder lends itself to further overlays of fiber nodes. By locating future nodes at the termination of the Express Feeders, mini-serving areas of 500 homes each are established, and the design becomes a triple star. Cells of this size are compatible with switched services, such as video-on-demand. In fact, the advent of Personal Communications Network (PCN) technology makes even the transmission of voice and data services a real possibility.

CONCLUSIONS

In a rebuild situation, Fiber to the Serving Area brings cable operators a number of benefits for about the same capital investment as a conventional trunk and feeder plant design. The picture quality viewed by subscribers is greatly enhanced: the carrier-to-noise ratio at the last tap is from 49 to 50 dB. The number of outages experienced by each subscriber is dramatically reduced, and the number of outages in the plant as a whole is reduced as well. The plant operating costs are lower; the total power consumption of an FSA plant is lower than conventional trunk and feeder or fiber backbone designs. Finally, the FSA architecture supports future services, including High Definition Television, switched services such as video-on-demand and telephony-based services such as Personal Communications Networks.

Fiber optics has the potential to revolutionize the landscape of cable as we know it today. Once in a great while, a technology and a market come together to create a dramatic opportunity. In 1975 the marriage of cable television and satellite transmission technology opened up a whole new world for the CATV industry. Today AM fiber optic technology, combined with the vision embodied in FSA, positions the cable industry to serve the video entertainment and information needs of the twenty-first century.

REFERENCES

1) D. Pangrac and L. Williamson, "Fiber Trunk and Feeder -- The Continuing Evolution," NCTA Technical Papers, May 1990.

2) R. Loveless, "Fiber to the Serving Area: A 'Star' Architecture," SCTE Technical Papers, January 1991.

3) R. Loveless and J. Mattson, "A Fiber Optic Design Study," NCTA Technical Papers, May 1989.

4) K. Casey, "Performance and Economic Implications of Fiber Optics in Cable Television Transmission Systems," SCTE Technical Papers, January 1991.