Designing “Outside The Box”:
An Alternative Solution for High-Density Architectures

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Abstract

Today’s HFC designs are limited by three main factors: End-of-line (EOL) performance, cascade limitations, and homes passed per node. In high-density architectures (urban areas or MDUs with greater than 150 subscribers per mile), the number of homes passed is the primary issue. This factor, coupled with the practice of dividing a node into sections for future fiber migration plans, leads to shorter amplifier cascades instead of maximized cascades. Why are the forward path system designs of today being limited by unclear, future return path usage? Why is the optical receiver/node a bottle neck for return signals? Can we eliminate these limitations by using readily available equipment in an asymmetric cascade?

This paper suggests an alternative, cost-effective broadband network design for high-density architectures that allows the operator to use fewer forward transmitters to serve more customers today, while building a future-proof system for tomorrow.

TODAY’S ARCHITECTURE

Over the past few years, the future of digital services and the return plant has been the subject of much debate, which is certain to continue. In the meantime, we continue designing CATV networks based on these primary limiting factors: end-of-line (EOL) performance, cascade limitations, and total homes passed per node.

EOL Performance and Cascade Limitations

Currently, the Federal Communications Commission (FCC) requires a minimum EOL performance of: 43 dBc* Carrier to Noise ratio (CNR); -51 dBc Composite Triple Beat (CTB), Cross Modulation (XMOD), and Composite Second Order (CSO) distortions. (*Note: CNR is to be raised to 45 dBc.)

Most CATV operators, however, aim to provide a better-quality picture signal to their customers than merely the minimum performance. Typical EOL performance for a 750 MHz design (77 analog channels and 550-750 MHz reserved for digital) is: 48 dBc CNR; and -53 dBc CTB, XMOD, and CSO.

With readily available nodes and radio frequency (RF) amps, one fiber optic link (typical performance) from the headend to the node easily can provide a cascade of the node plus four actives (see Figure 1). Many cable operators, however, have reasons – such as total system reliability – for keeping the RF amplifier cascade as low as possible; also, these operators can achieve desired EOL performance with reduced fiber optic link performance and/or higher RF output levels. This paper discusses the cascade options available to operators who desire to keep their options for future services flexible.

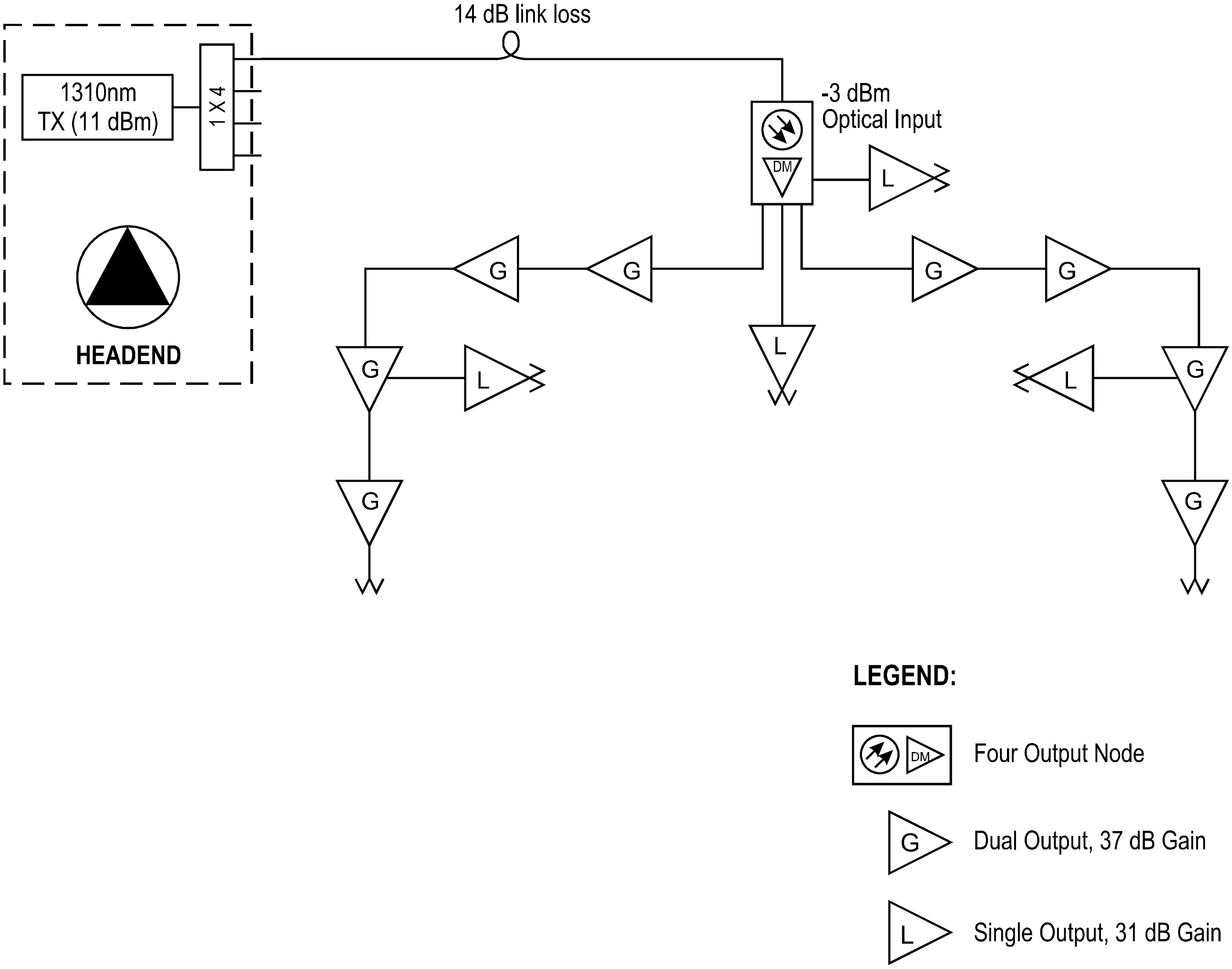

Figure 1. HFC Cascade: Node Plus Four Amplifiers (48 dBmV output level for all devices)

In this cascade, the RF output of all actives is +48 dBmV. The operating gains of the dual- and single-output amps are 37 and 31 dB, respectively. Typical performance of the fiber optic link provides for: 51 dBc CNR; -68 dBc CTB and XMOD; and -64 dBc CSO. The calculated EOL performance for the cascade in Figure 1 is: 49 dBc CNR; -54 dBc CTB and XMOD; and -60 CSO.

Total Homes Passed Per Node

Again, apart from system reliability, the issue of the maximum number of homes passed in any given node is related primarily to anticipated future usage patterns of the return path for telephony or other digital services. Figure 2 uses a Plain Old Telephony Service (POTS) chart to illustrate the relationships between available return bandwidth and concentration level.

	Concentration Level							
Available Return Bandwidth	none	2:1	3:1	4:1	5:1	6:1	8:1	10:1
4.5 MHz	72	144	216	288	360	432	576	720
9.0 MHz	144	288	432	576	720	864	1,152	1,440
15.0 MHz	240	480	720	960	1,200	1,440	1,920	2,400
19.5 MHz	312	624	936	1,248	1,560	1,872	2,496	3,120
24.0 MHz	384	768	1,152	1,536	1,920	2,304	3,072	3,840
30.0 MHz	480	960	1,440	1,920	2,400	2,880	3,840	4,800
34.5 MHz	552	1,104	1,656	2,208	2,760	3,312	4,416	5,520
39.0 MHz	624	1,248	1,872	2,496	3,120	3,744	4,992	6,240
45.0 MHz	720	1,440	2,160	2,880	3,600	4,320	5,760	7,200
49.5 MHz	792	1,584	2,376	3,168	3,960	4,752	6,336	7,920

Figure 2. System POTS Line Capacity per Available Bandwidth

The bandwidth is based on the fact that a T1 line provides 24 subscriber lines and requires approximately 1.5 MHz of bandwidth. The concentration level is the ratio of the number of subscribers that the system is designed to handle versus the actual number of subscribers on line simultaneously. For example, if only 15 MHz was available in the return spectrum, and the system was designed to handle 100% (1:1) of the subscribers (for example, on Mother’s Day), then a node with only one return transmitter and no frequency up converter should have no more than 240 homes passed in it. As shown, many different configurations can be derived from this type of predicted usage pattern. Contemporary node sizes generally range from 500 to 2000 homes passed. Also, most designers try to create some sort of node segmentation to enable future fiber migration plans without the need for much redesign or additional cable.

Example of a Traditional System Design

A cable operator plans to upgrade a system to 750 MHz (77 analog channels and 550-750 MHz reserved for digital), with no more than 1800 homes per node or 450 homes per quadrant of a node, using a four-port optical receiver/node.

This example assumes the following: 300,000 potential subscribers (total homes passed); 1,500 plant miles; and an average density of 200 homes per mile.

In a perfect plant, which has a consistent density throughout the entire system, 167 nodes would be needed. This assumes that the cascade length selected (node plus four amplifiers, as in Figure 1) will be able to reach the extents of every node. Since the total number of homes passed per node is the most likely limiting factor in high-density areas (such as in this example), the longest cascade in a node often will be only the node plus three amps.

In the headend, assuming that one transmitter will feed no more than four nodes, this system will need at least 42 high-powered, 1310 nm transmitters. If long fiber optic links or other factors reduce the ratio of nodes fed from one transmitter to 3:1, then the number of transmitters needed will increase to 56. Table 1 displays these numbers and compares them with the alternative system design.

As the first step in the system upgrade, the network is "cut" into sections to create the nodes. In the traditional fiber migration plan, sections are divided up by the maximum number of subscribers per node, or 1800 homes passed. Then, the designer creates the subsections while laying out the design.

As system demand (mostly return path bandwidth) grows, and/or return noise and ingress increase, the cable operator has a few options: 1) dividing the return path into smaller sections by adding one or more optical return transmitters into the node housing itself; 2) employing a form of return frequency block up-conversion at the node and then down-converting back at the head end; or 3) upgrading the sub-sections, or quadrants, to complete, stand-alone node stations. Most migration plans recommend installing reserved, or "dark," fiber in the system to easily facilitate this transition. (Refer to the 1997-8 CED Cable TV Fiber Topologies Comparison for examples.) Also, many manufacturers have nodes capable of adding extra forward optical receivers and return transmitters to increase bandwidth both downstream and upstream.

ALTERNATIVE INCREMENTAL SYSTEM DESIGN

Why are the forward path system designs of today being limited by unclear, future return path usage? Why is the optical receiver/node a bottleneck for return signals? Can we use an asymmetric cascade? CATV operators without concrete plans for future return services may find building a future-proof network through an incremental system design process more cost effective than traditional methods.

With the very first step, the architecture's optimization should be based on all three main limiting factors – not one individual factor. These are: 1) EOL performance; 2) amplifier cascade; and 3) number of subscribers per node segment.

EOL Performance and Amplifier Cascade

This design process will not lower the desired EOL performance. The signal's target performance from the headend transmitter through the single fiber optic link to the node and through the RF cascade will still be 48 dBc CNR, and -53 dBc CTB, XMOD, and CSO.

Figure 3 shows a cascade of the node plus six RF amplifiers. The fiber optic link performance remains the same in both scenarios. As compared to Figure 1, this cascade extends each node's reach by two actives; this is accomplished by lowering the RF output levels of all amplifiers by 1 dBmV, from +48 dBmV to +47 dBmV. The EOL performance for this system is: 48 dBc CNR; -53 dBc CTB and XMOD; and -59 dBc CSO.

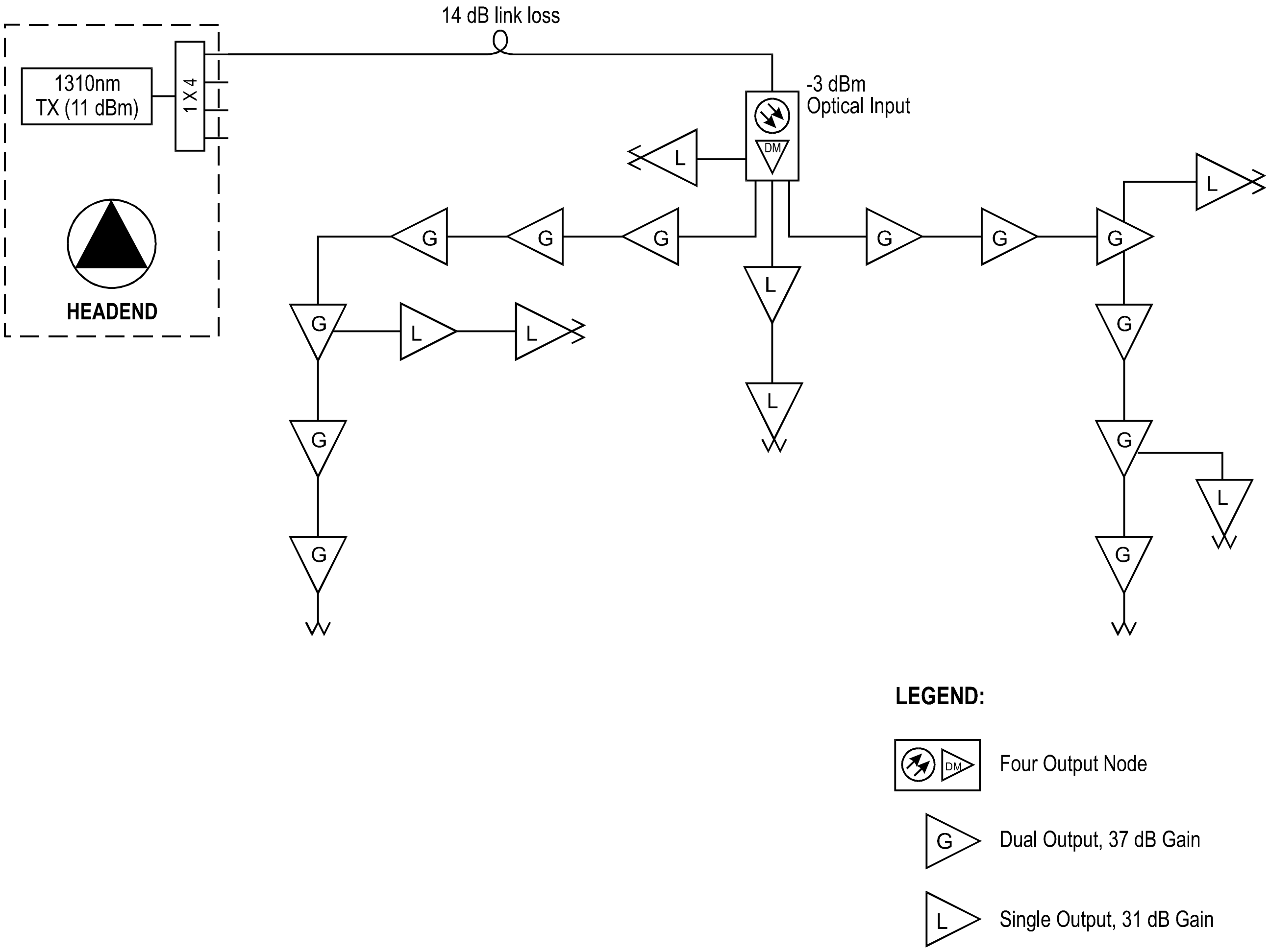

Figure 3. **HFC Cascade: Node Plus Six Amplifiers (47 dBmV output level for all devices)**

Number of Subscribers Per Node Segment

The next step of this system design “cuts” the network into sections to create nodes. Since this is a time-consuming process and the ultimate goal of the incremental architecture, the entire system should be divided into sections based on the smallest desired service area. This could be 300-500 home pockets. Then, the nodes can be placed at optimum locations to use the full reach of the amplifier cascade, with minimal regard to the total number of homes passed. Important to note, at this step, is that each pocket does not have to originate from the node. The node can be at a location where the last four actives of a six-amp cascade form a 300- to 500-home pocket. For example, in a highly populated area, this sort of node may now feed 2000-3000 homes, with a node plus six-amp cascade. Figure 4 gives an example of this system layout.

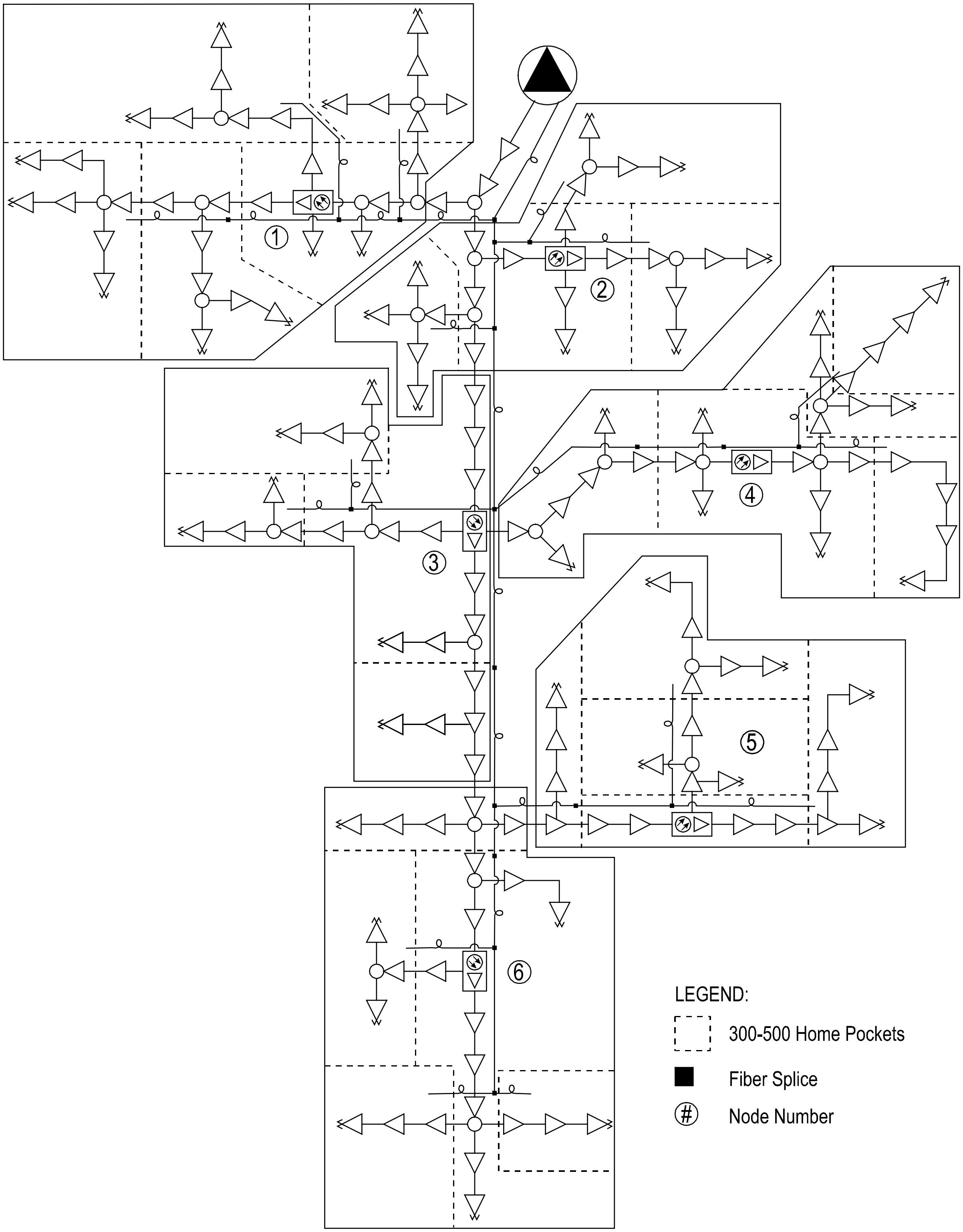

Figure 4. Segmented HFC Plant with Fiber Optic Overlay

As in the traditional fiber migration plan, several dark fibers should be placed into the system for each node as the main fiber cables are installed. This includes running the extra fiber out to the smaller home pockets. The costs of fiber optic cable and electronics may increase or decrease with time; however, labor costs certainly will increase.

The next steps involve the incremental increase in system bandwidth per home based on subscriber usage patterns, return noise funneling, and ingress. While all the above-mentioned upgrade options are still available, this plan offers an *extra* option.

The three premises of this incremental design are that: 1) most readily available nodes will not hold more than three forward receivers and two return receivers, in addition to any status monitoring or extra features; 2) return frequency block conversion currently is neither readily available nor cost effective; and 3) the forward path is not a source of congestion.

Asymmetric Cascade

That being said, as data usage increases demand for return bandwidth, and noise/ingress becomes more of a problem, a return transmitter can be placed into an amplifier station currently downstream of the node!

Thus, the forward and return signal paths will be of different cascade lengths in each node service area. The forward video and downstream data still travel through the node and the complete RF cascade; however, the return path is reduced. The return transmitter sends the upstream signals directly to the headend without bottlenecking all of the signals in the optical node itself! Figure 5 details how this works.

As more downstream digital bandwidth is needed, this system offers two options:
1) adding extra receivers in the node for narrowcasting; or 2) fully converting the subsection of the original node, which was upgraded with an optical lid and a return transmitter, to an independent node.

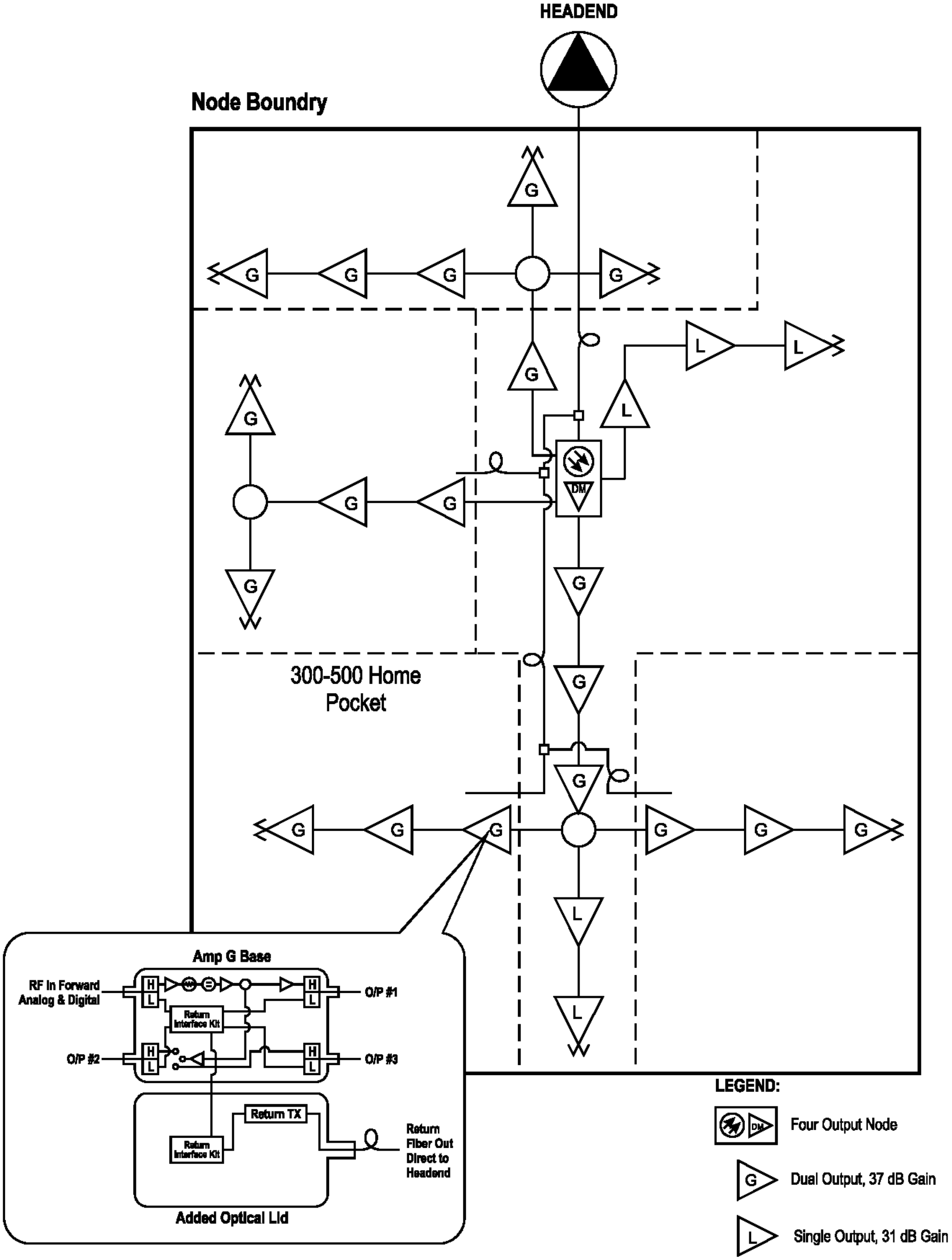

Figure 5. Proposed Alternative Design Solution

Homes per Node		Number of Nodes	Number of TXs 4:1 Ratio	Number of RXs 3:1 Ratio
	1800	167	42	56
	2500	120	30	40
% Change (2500 home node relative to 1800 home node)	+39%	-28%	**-29%!**	**-29%!**

Table 1: Sample Comparison Between Homes Per Node and Number of Forward 1310 nm Transmitters Required for Initial System Upgrade

What does this save the cable operator?

The bulk of the cost savings would be seen in the initial forward fiber optic laser deployment. In the above example, assuming that the nodes now are expanded to serve an average-sized node of 2500 homes and that the system is equally dense, at least 120 nodes are necessary. Applying the same generalizations to the node-per-transmitter ratio, between 30 and 40 transmitters are necessary, as compared to 42-56 transmitters if the nodes were smaller. This represents a *29% decrease* in forward transmitter requirements! (Refer to Table 1.)

Extra initial savings result from the reduced need for return receivers and associated hardware in the headend, along with *28% fewer* optical node stations in the field.

The extra material costs of adding the return transmitter downstream of the node will be limited to the return transmitter, a return receiver (if spare port is not available in the head end), a return interface kit, an optical lid, and possible status monitoring or ingress protection accessories. This option, however, is still less expensive than completely upgrading an RF station to a stand alone-node.

CONCLUSION

This unique alternative incremental architecture is not consistent with many telecommunications operators' plans. Companies that already have a solid idea of what they want from their system in terms of bandwidth capacity and reliability are already past this phase. Likewise, many low- to medium-density systems have all the return bandwidth necessary. These system operators ask manufacturers for equipment that will work in longer cascades at 750 MHz. The asymmetric cascade described in this paper, however, may offer some of the high-density system operators a cost-effective architectural option when upgrading existing networks or planning a completely new system.

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