RETURN PATH AND MTTR IMPROVEMENTS: NEW TOOLS, NEW RULES

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Abstract

While broadband networks have seen many advancements and technical innovations in recent months, one in particular stands out as a rule changer – that of digital return.

The return or upstream path of HFC network architectures has seen a dramatic change over the last 18 months as a new technology – known as baseband digital reverse has been deployed in increasing numbers. While the key technical benefits of a digital return band are increased return bandwidth, extended optical reach, and the elimination of performance barriers common to analog transmission, the use of baseband digital return further opens up opportunities for improving performance while lowering mean time to repair (MTTR).

A primary benefit here is realized by reducing overall equipment requirements. Architectures that are reduced in component count are made possible with this technology and this paper explores and demonstrates by example how transmitter counts have been lowered by 50%, how fiber counts have been reduced by 50% and how optical amplifiers have been eliminated altogether.

As our industry trends toward more and more interactive services, the demands on the reverse path increase dramatically. Not only are network operators concerned about whether there is sufficient bandwidth to address all the requirements, but they are equally concerned about the performance and reliability of the return path. Baseband Digital Reverse (bdr™) has emerged as a key enabler for delivering all three essential return path components – bandwidth, performance, and reliability. This paper will explore how bdr delivers on this promise by looking at the technology itself, the applications it enables, and the architectures it supports.

The Technology

Since Scientific-Atlanta first introduced bdr at the SCTE in 1999, much has changed. We are currently on our third generation of the products and are continuously finding new applications for the technology. Because much has been said over the past two years, I will not spend a great deal of time reviewing the technology in detail, but do feel it is important to establish a foundation for the benefits it can provide.

At its simplest, Figure 1. below shows a single bdr link. The 5 to 42MHz RF return is converted from analog to digital by a high speed (100Mbps), 12 bit converter. The resulting 12 data streams are sent to a serializer to produce a 1.25Gbps data stream. This signal is then transmitted upstream using a low-cost, digital laser. At the receive end, low-cost optics and

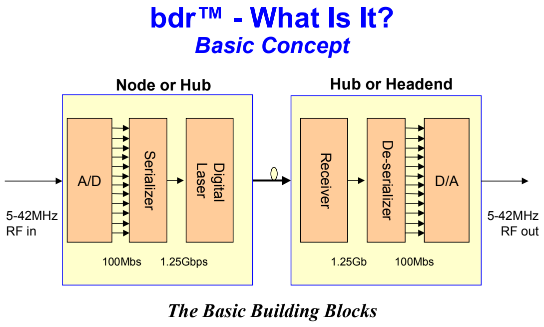


Figure 1

electronics are employed to convert the signal back to its analog format for processing.

From a performance and reliability standpoint, bdr technology exhibits several key attributes:

1. excellent carrier-to-noise performance - 12-bit analog to digital converters provide “DFB-like” performance; the noise power ratio (NPR) curves (Figure 2) perhaps best demonstrate the differences in FP, DFB, and bdr technologies.

3. distance insensitivity – digital link performance does not change in performance over distance; this simplifies installation and eliminates performance changes when systems operate over back-up paths which are typically longer.
4. optical reach – digital receiver sensitivity is greater than its analog counterpart; since no degrading of performance is experienced over distance, we are easily able to deploy links over 80km without the need for optical amplifiers.

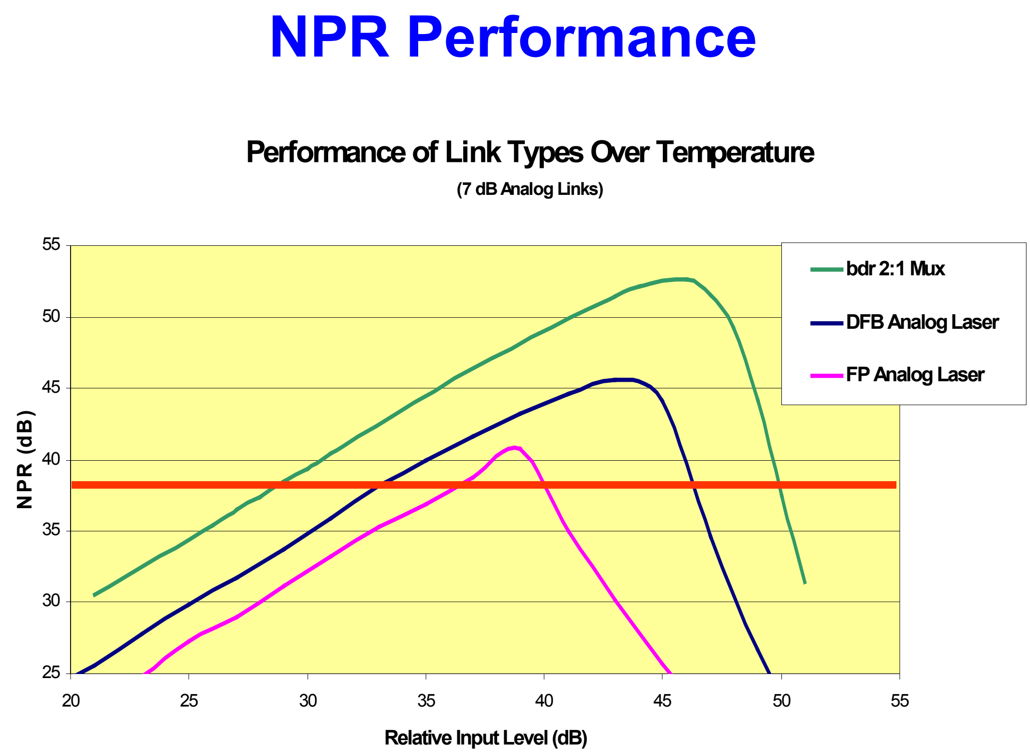


Figure 2

2. temperature stability – digital lasers are minimally impacted by temperature; therefore, negligible changes in system performance are seen over wide temperature ranges, a significant benefit over analog lasers.

The Applications

At the recent SCTE Emerging Technologies conference, it was clear that, while 2001 was the year for the emergence of VOD, 2002 promises to be the year for Voice over IP (VOIP) to be deployed in large scale. Couple VOIP with other emerging applications that are symmetrical in bandwidth usage, such as Napster (when it surfaces again), video teleconferencing, and streaming video, and the tremendous growth expected in the small office, home office market, it is clear that the reverse path of HFC networks is about to undergo a significant increase in usage.

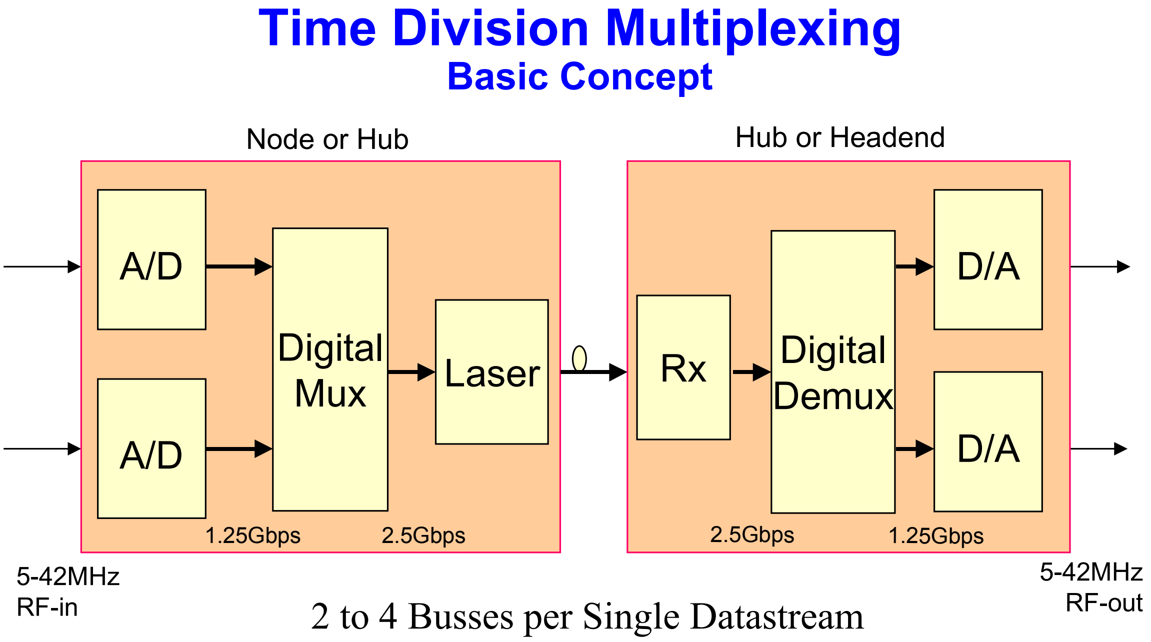


Figure 3

To meet the increased bandwidth challenge, many operators are minimally planning to adopt the DOCSIS 1.1 standard for their IP services. Equipment designed to meet this standard make use of 16QAM and 64 QAM for reverse transmissions. However, these efficient schemes require significantly better (6 and 12dB, respectively) carrier to noise performance than QPSK - the current standard approach. As a result, many operators are moving away from low-cost analog Fabry-Perot (FP) lasers and are selecting distributed feedback (DFB) lasers or bdr to achieve the required performance needed to support these higher-order modulation schemes. The temperature instability and "noisy" condition when un-modulated limit the application of the analog FP lasers.

Beyond supporting QAM transmission to increase bandwidth out of cable modems, operators are looking to increase bandwidth throughout their networks. Installing more fiber is an obvious solution, but a costly one. Technologies that "mine" more bandwidth from the existing plant are needed. This is the important role of bdr and dense wave division multiplexing (DWDM). Unlike analog, bdr enables the use of time division multiplexing (TDM) to more cost-effectively transmit multiple channels over a single fiber. An example of a simple 2:1 TDM application is shown in Figure 3. In short, two 1.25Gbps data-streams are summed together and transmitted at 2.5Gbps using higher speed optics.

Scientific-Atlanta has also announced a more complex 4:1 solution that utilizes digital signal processing to compress four channels of data into a single 2.5Gbps data-stream.

DWDM and bdr technologies working in tandem provide even greater fiber efficiency. DWDM enables multiple optical signals (Scientific-Atlanta has shipped 24 channel systems to date) to be transported over the same fiber.

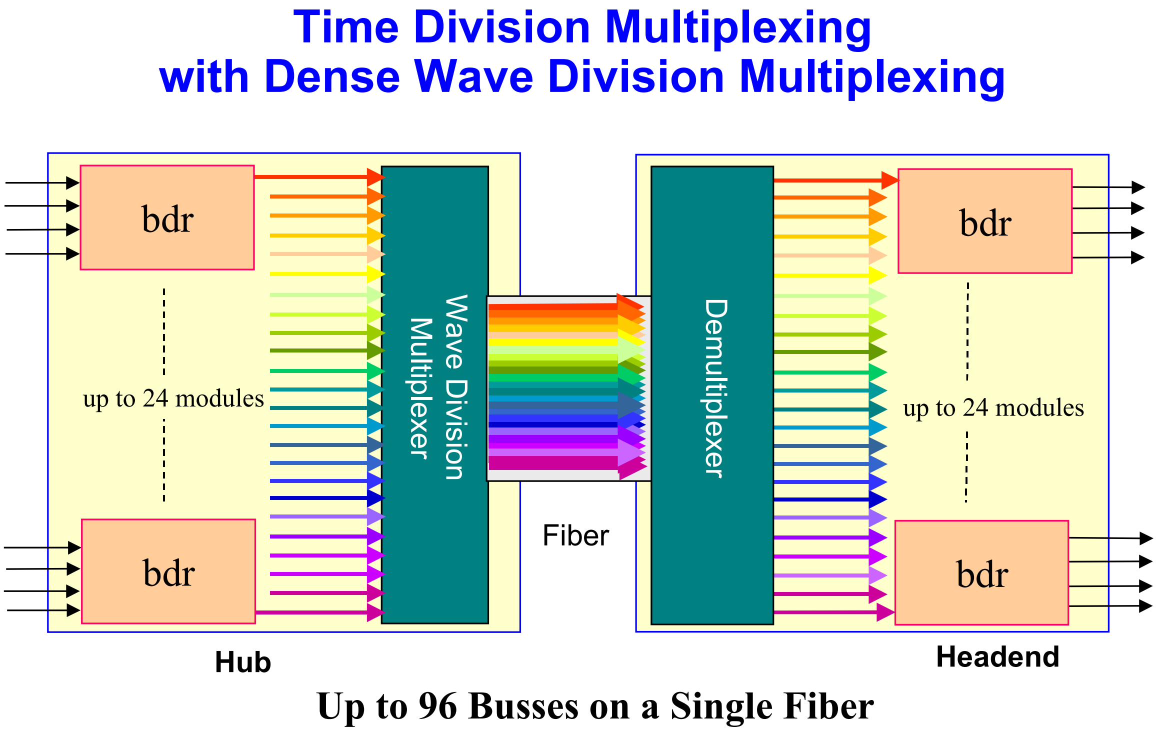


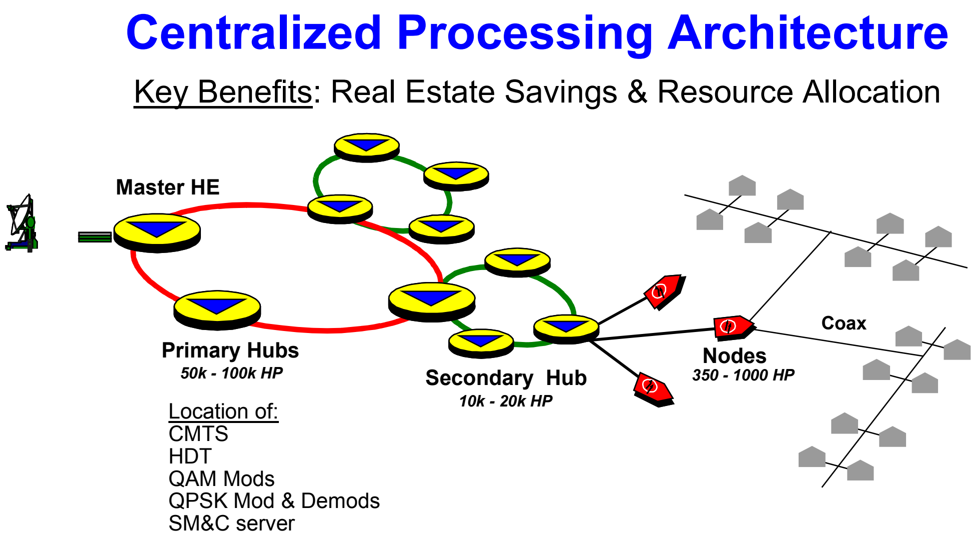
Figure 4

The TDM dimension of bdr multiplies the number of DWDM channels by up to four, enabling 96 return paths over a single fiber, as shown in Figure 4.

The Architectures

Certainly, bdr can effectively support the variety of architectures that traditionally have been deployed by network operators. However, bdr and DWDM have opened up several new options that have proven to be more cost-effective to build and, potentially, more reliable to maintain. The focus of these new architectures is a move to a more centralized processing approach.

The centralized processing architecture (Figure 5.) allows the operator to locate processing equipment – CMTSs for data and voice IP-based services, QAM and QPSK modulators and QPSK demodulators for digital video services, HDTs for circuit-switched voice services, and servers for status monitoring and control services – in primary hub or headend facilities. Under more traditional architectures, this equipment would be located in the



Centralized Processing Architecture

Key Benefits: Real Estate Savings & Resource Allocation

Location of:
CMTS
HDT
QAM Mods
QPSK Mod & Demods
SM&C server

Figure 5

secondary hubs scattered throughout the serving area. bdr is essential to this architecture because it provides long optical reach and minimizes fiber usage. The obvious key benefit to this approach is the cost savings associated to real estate and personnel. However, there are other important reliability enhancing benefits, such as improved sparing, more complete utilization of equipment, more redundancy options, and quicker response times.

Centralized Processing Architecture

The centralized architecture can be accomplished with an analog approach, as well. However, the cost and reliability of this solution are not attractive. Shown in Figures 6 and 7 are the architectural block diagrams for the analog and digital reverse solutions. Approximate costs for the return path specific components are shown for each solution. The network shown does not leverage the TDM aspect of bdr. When this is taken into account, even more significant cost savings result.

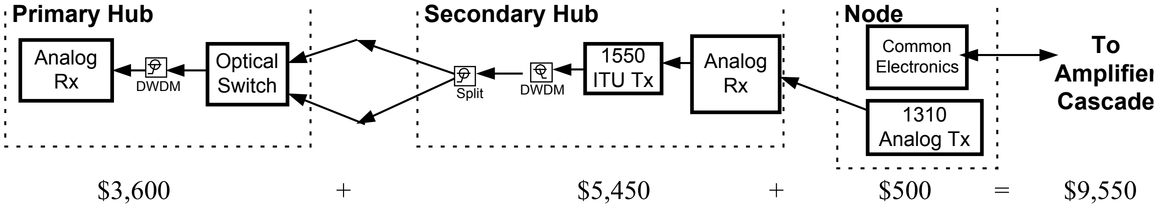


Figure 6 - Analog Solution Block Diagram

The reliability block diagrams are shown below in Figures 8 and 9. Included in the diagram are the calculated outage minutes per subscriber associated with the various network components.

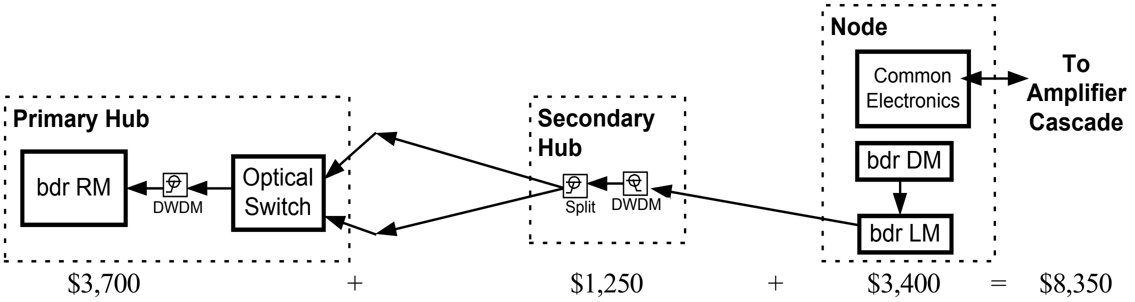
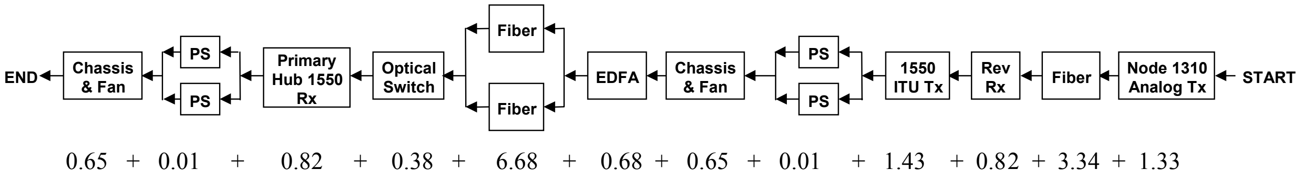


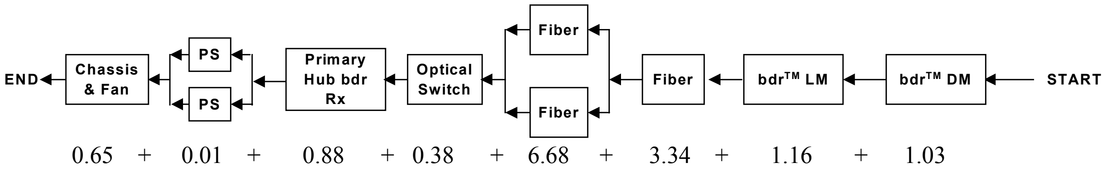
Figure 7 - bdr Solution Block Diagram

Figure 8 - Analog Solution Reliability Diagram



Total Annual Outage Time = 10.10

Figure 9 - bdr Solution Reliability Diagram



Total Annual Outage Time Per Subscriber = 7.43 minutes

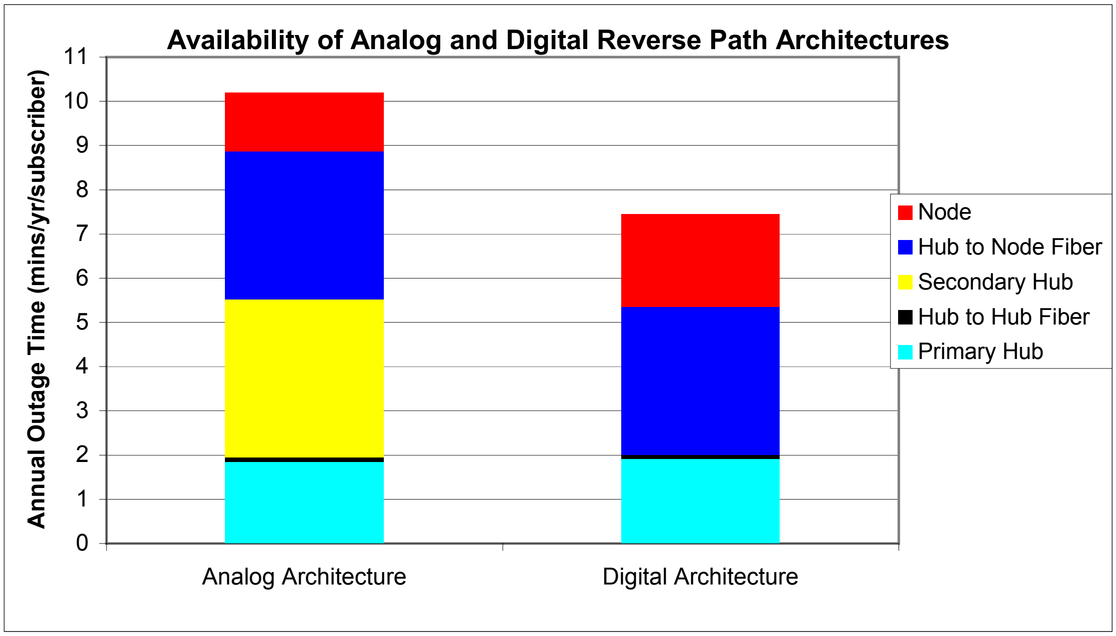
These outage time estimates are calculated using Markov Models, Bellcore Reliability Predictions and field failure data in a four step process developed by Scientific-Atlanta. The results of this modeling are shown in the table of Figure 10.

Figure 10 – Modeling Results

Location	Description	SA Part#	Type Redun	PCP - Predicted MTBF (hrs, M1C1 QL1)	Enhanced MTBF (hrs.)	MTTR (hrs.)	MTTC (hrs.)	Availability	Average Annual Outage Time (Min.)
	Analog Reverse Path Primary Hub to Secondary Hub to Node								
Primary Hub	Dual Reverse Rx, P2 - Video SA Conn	716480	2	150,234	1,606,896	24	2.50	0.99999844	0.8183
Primary Hub	Optical Switch, P2 - SA Conn	714470	2	326,456	3,491,759	24	2.50	0.99999928	0.3766
Primary Hub	P2 Chassis & Fan	594300	2	189,449	2,026,338	24	2.50	0.99999877	0.6489
Primary Hub	Prisma II Chassis PS	589254	2		833,333,333	24	2.50	1.00000000	0.0016
Fiber	40 KM fiber	NA	1/4+		314,941	4.00	NA	0.99998730	6.6800
							Primary Route Availability =	0.99998730	6.6800
							Availability with Redundancy =	1.00000000	0.0001
Secondary Hub	50 Tx, 6475-6, 750 MHz 110 Ch, Dual Output	NA	2	85,848	918,227	24	2.50	0.99999728	1.4321
Secondary Hub	EDFA, 6476-16T	573070	2	180,323	1,928,727	24	2.50	0.99999870	0.6818
Secondary Hub	P2 Chassis & Fan	594300	2	189,449	2,026,338	24	2.50	0.99999877	0.6489
Secondary Hub	Prisma II Chassis PS	589254	2		833,333,333	24	2.50	1.00000000	0.0016
Secondary Hub	Dual Reverse Rx, P2 - Video SA Conn	716480	2	150,234	1,606,896	24	2.50	0.99999844	0.8183
Fiber	20 KM fiber	NA	1		629,882	4.00	NA	0.99999365	3.3400
Node	ASSY, MFLEX FP XMTR SCA	717904	2	92,563	990,050	24	2.50	0.99999747	1.3282
	Analog Reverse Path Total							0.99998080	10.0965
	Digital Reverse Path Primary Hub to Secondary Hub to Node								
Primary Hub	ASSY,MOD,14BIT PRISMA RCVR MODULE	716157	2	139,225	1,489,145	24	2.50	0.99999832	0.8830
Primary Hub	Optical Switch, P2 - SA Conn	714470	2	326,456	3,491,759	24	2.50	0.99999928	0.3766
Primary Hub	P2 Chassis & Fan	594300	2	189,449	2,026,338	24	2.50	0.99999877	0.6489
Primary Hub	Prisma II Chassis PS	589254	2		833,333,333	24	2.50	1.00000000	0.0016
Fiber	40 KM fiber	NA	1/4+		314,941	4.00	NA	0.99998730	6.6800
							Primary Route Availability =	0.99998730	6.6800
							Availability with Redundancy =	1.00000000	0.0001
Secondary Hub	NA								
Fiber	20 KM fiber	NA	1		629,882	4.00	NA	0.99999365	3.3400
Node	IOD ASSY, 6940 BDR 2:1 DIGITAL MODULE	712892	2	119,464	1,277,782	24	2.50	0.99999804	1.0291
Node	SSY,1560.61NM 6940 BDR XMTR 2.5GBPS	713312	2	106,408	1,138,135	24	2.50	0.99999780	1.1554
	Digital Reverse Path Total							0.99998586	7.4347

A comparison of the bdr and analog approaches can best be depicted in a graph format as shown below. Notice the large contribution of the Secondary Hub analog components to the overall outage time. This link in the chain is totally eliminated in the bdr solution, greatly improving overall system reliability and simplifying any maintenance requirements.

Figure 21 – Availability



Remote Terminal Architecture

Scientific-Atlanta recently introduced a variation of the centralized processing architecture discussed above. The Remote Terminal (RT) network (Figures 12 & 13) utilizes a third ring to reliably push fiber closer to the customer, thereby significantly increasing the available bandwidth per home passed.

Figure 12 - Remote Terminal Architecture

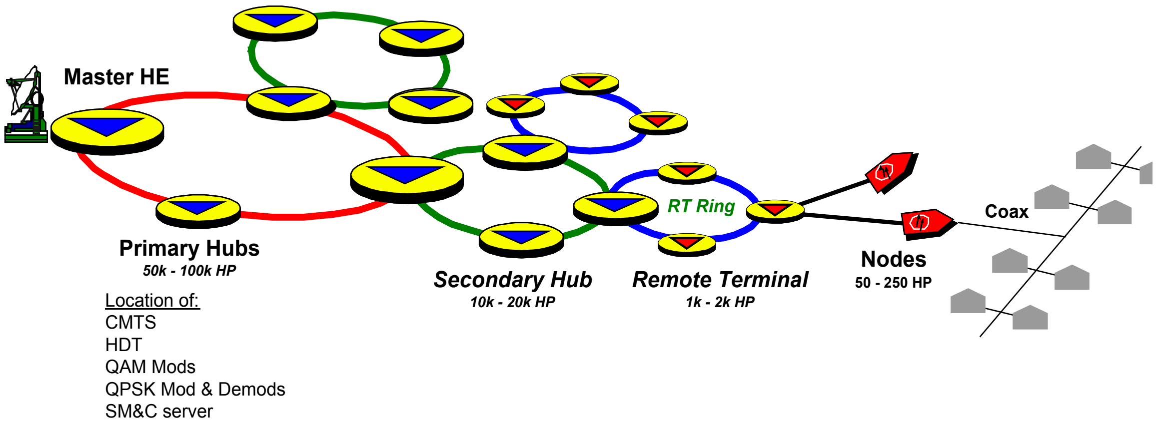
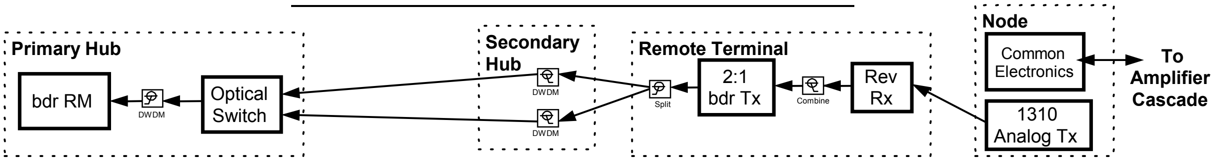


Figure 13 - RT Architecture Block Diagram



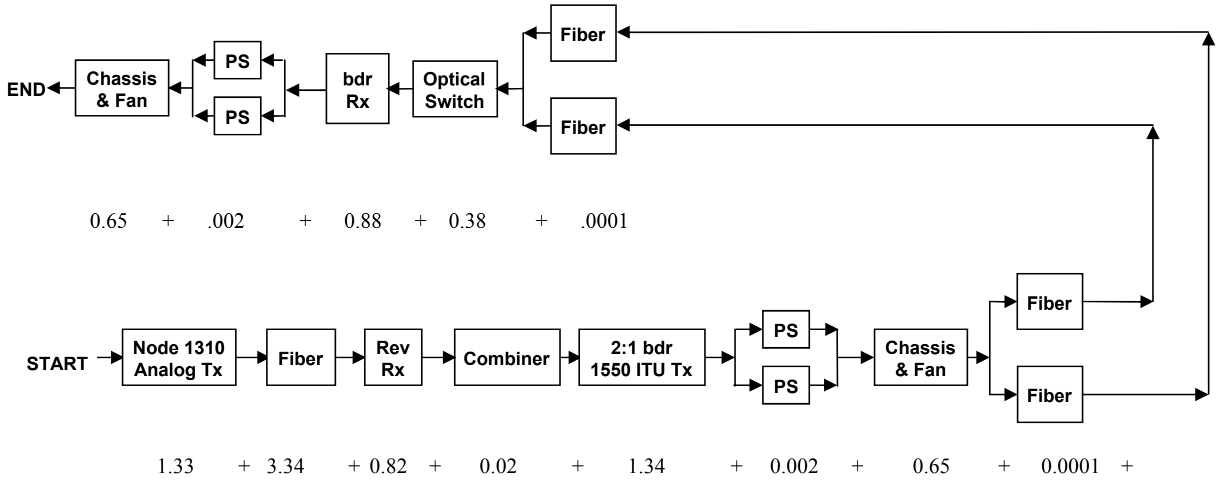
These RT locations are actually small, non-temperature conditioned cabinets that can be cost-effectively deployed on easements or on poles. This network expands the reach of the entire HFC plant, cost-effectively reducing Hub and Headend facility requirements.

Practically, the RT architecture cannot be deployed without the optical reach associated with bdr. From a reliability standpoint, the key issue is whether the reduction associated with the incremental electronics in the RT approach is outweighed by the shortening of the unprotected fiber links. The network and reliability block diagram (Figure 14) depicts the longer link, yet shows that overall outage time per subscriber is actually reduced over the centralized architecture approach examined previously.

Despite the incremental electronics and increased reach (85km v. 60km), the RT architecture is calculated to improve system availability by 10%. The key difference that enables this improvement is that the fiber links are better protected in the RT network.

As before, the complete set of outage time estimates for the RT architecture is shown in the table 15 following.

Figure 14 - RT Architecture Reliability Block Diagram



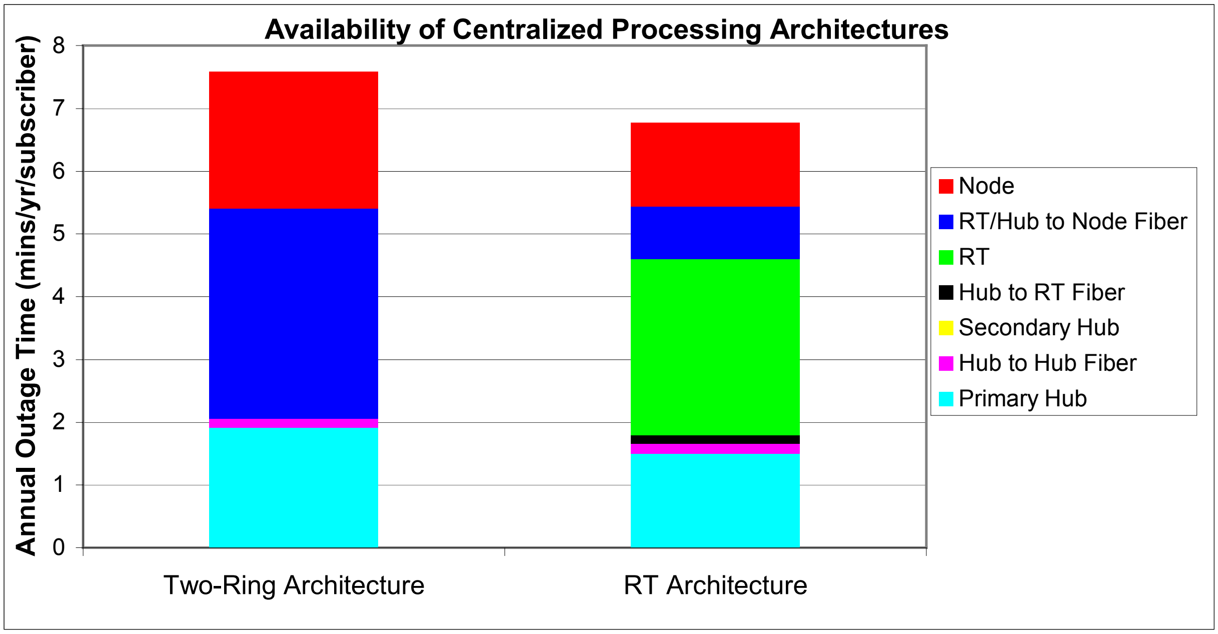
Total Annual Outage Time Per Subscriber = 6.74 minutes

Figure 15 – Table of Outage Time Estimates

Location	Description	SA Part#	Type Redun	PCP - Predicted MTBF (hrs, M1C1 QL1)	Enhanced MTBF (hrs.)	MTTR (hrs.)	MTTC (hrs.)	Availability	Average Annual Outage Time (Min.)
	Digital Reverse Path Traditional Two-Ring Architecture								
Primary Hub	ASSY,MOD,14BIT PRISMA RCVR MODULE	716157	2	139,225	1,489,145	24	2.50	0.99999832	0.8830
Primary Hub	Optical Switch, P2 - SA Conn	714470	2	326,456	3,491,759	24	2.50	0.99999928	0.3766
Primary Hub	P2 Chassis & Fan	594300	2	189,449	2,026,338	24	2.50	0.99999877	0.6489
Primary Hub	Prisma II Chassis PS	589254	2		833,333,333	24	2.50	1.00000000	0.0016
Fiber	40 KM fiber	NA	1/4+		314,941	4.00	NA	0.99998730	6.6800
					Primary Route Availability =			0.99998730	6.6800
					Availability with Redundancy =			1.00000000	0.0001
Secondary Hub	NA								
Fiber	20 KM fiber	NA	1		629,882	4.00	NA	0.99999365	3.3400
Node	MOD ASSY, 6940 BDR 2:1 DIGITAL MODULE	712892	2	119,464	1,277,782	24	2.50	0.99999804	1.0291
Node	MOD ASSY,1560.61NM 6940 BDR XMTR 2.5GBPS	713312	2	106,408	1,138,135	24	2.50	0.99999780	1.1554
	Digital Reverse Path Total							0.99998586	7.4347
	Digital Reverse Path Remote Terminal Architecture								
Primary Hub	P2-BDR-RP-2R	738959	2	169,043	1,808,077	24	2.50	0.99999862	0.7273
Primary Hub	Optical Switch, P2 - SA Conn	714470	2	326,456	3,491,759	24	2.50	0.99999928	0.3766
Primary Hub	P2 Chassis & Fan	594300	2	189,449	2,026,338	24	2.50	0.99999877	0.6489
Primary Hub	Prisma II Chassis PS	589254	2		833,333,333	24	2.50	1.00000000	0.0016
Fiber	40 KM fiber	NA	1/4+		314,941	4.00	NA	0.99998730	6.6800
Secondary Hub	NA								
Fiber	40 KM fiber	NA	1/4+		314,941	4.00	NA	0.99998730	6.6800
Fiber					Primary Route Availability =			0.99997460	13.3600
Fiber					Availability with Redundancy =			1.00000000	0.0003
Remote Terminal	P2-BDR-TP-2R	738961	2	92,017	984,210	24	2.50	0.99999746	1.3361
Remote Terminal	P2 Chassis & Fan	594300	2	189,449	2,026,338	24	2.50	0.99999877	0.6489
Remote Terminal	Prisma II Chassis PS	589254	2		833,333,333	24	2.50	1.00000000	0.0016
Remote Terminal	Dual Reverse Rx, P2 - Video SA Conn	716480	2	150,234	1,606,896	24	2.50	0.99999844	0.8183
Remote Terminal	8:1 SPLITTER/COMBINER FF	591816	2	6,830,600	73,059,805	24	2.50	0.99999997	0.0180
Fiber	5 KM fiber	NA	1		2,519,526	4.00	NA	0.99999841	0.8350
Node	ASSY, MFLEX FP XMTR SCA	717904	2	92,563	990,050	24	2.50	0.99999747	1.3282
	Digital Reverse Path Total							0.99998718	6.7409

The graph in Figure 16. best depicts the calculated outage time per subscriber differences between the RT and more traditional Two-Ring Centralized Processing Architecture. Readily apparent is the significant variation associated with the fiber links (approximately 2.5 minutes), which more than offsets the addition of the RT equipment.

Figure 16



Summary

The conversion from analog to digital technology has taken place across a wide spectrum of the products and services we touch daily – telecommunications networks, data communications networks, consumer electronics, household appliances, automobiles, etc. Baseband Digital Reverse represents the first step in the inevitable evolution of our HFC broadband networks to "all-digital".

Today, bdr technology enables the use of new products and network architectures that are cost-effective, high performance, and reliable. The technology supports the performance required to deliver the higher order modulations schemes being adopted for data and voice services. The products demonstrate greater stability and can deliver more bandwidth per fiber than analog alternatives. The long optical reach capabilities and DWDM compatibility enable the use design and implementation of more cost-effective, highly reliable network architectures.

New applications for the technology are being investigated that will further improve cost, performance, and reliability of the fiber intensive networks operators will be deploying in the future.

References:

1. Andy Drexler, "Comparison of Node-to-Hub Availability for Analog and Digital Reverse Path Architectures"; December 7, 2000; Scientific-Atlanta Quality Assurance Project Document.

2. Andy Drexler, "Comparison of Fiber Deeper Remote Terminal Architecture Availability for Analog and Digital Reverse Path Approaches"; March 6, 2001; Scientific-Atlanta Quality Assurance Project Document.