QFlex: The science behind multi-gigabit return paths.

ACI

QFlex®

Stability, higher throughput, and just better.

It's ACI's mission to bring DOCSIS 3.1+ capabilities to HFC networks without major infrastructure changes. We specialize in low-cost solutions that clear up bottlenecks and weak spots in the existing network. In the last-mile plant, we bring a suite of automatic gain control solutions with full drop-in AGC modules that play fully to bidirectional 4k QAM OFDM DOCSIS 3.1 with digital control loop level stability along with autonomous noise mitigation.

Introducing QFlex.

For the fiber return path of the next decade and beyond, ACI delivers the QFlex in anticipation of high split, 4k QAM, fully segmented return paths over a single lambda. QFlex is the workhorse that brings upstream throughput capability to levels much higher than what even state-of-the-art digital return can manage. This is achieved by employing a few basic principles to laser operation, and with the prudent use of digital control loops for temperature compensation, gain control and phase lock. This results in all the stability of a digital return, but with higher throughput and better segmentability.

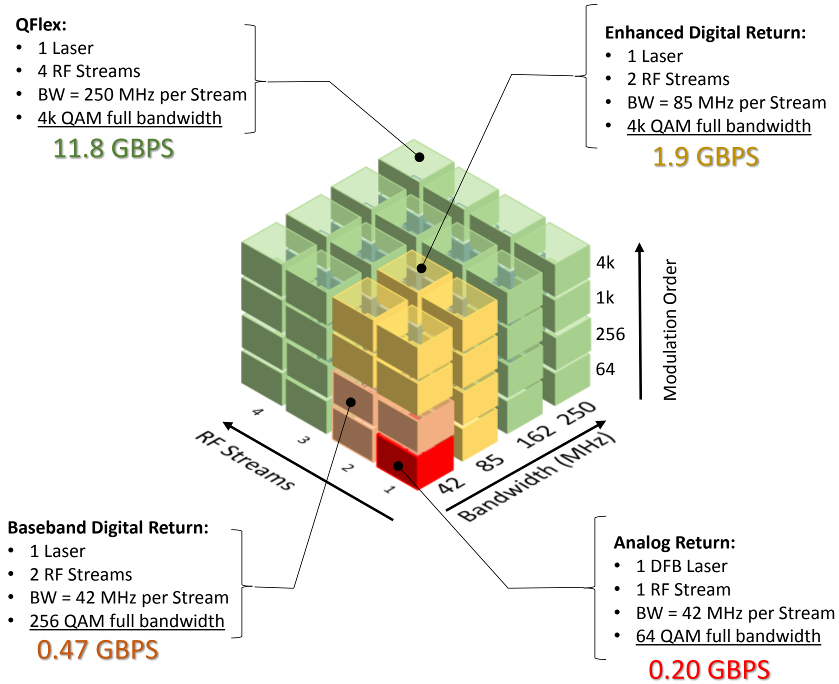

Figure 1.
How reverse link technologies stack up. Total per-lambda throughput capacity of a QFlex link is enormous when compared to other leading technologies. Unlike proprietary solutions aimed at slightly increasing throughput with cutout and replace plans, QFlex supports existing infrastructure with drop-in compatibility.

An analog laser with the right modulation scheme.

Almost since their introduction to HFC systems, analog return lasers have been criticized for their perceived instability and diminishing performance from increased channel loading. It's an unfair and untrue characterization. Today, some are surprised to learn that QFlex – built around an analog laser – achieves remarkably higher peak NPR and multiples of bandwidth beyond even the highest performing digital return system.

QFlex does this by applying a simple mathematical modulation technique to the laser called Second Order Avoidance. In an ordinary directly-modulated upstream analog laser, second order distortion is the dominant link impairment. Directly modulating the sub-band return spectrum causes the second order components to fall within the band of the intended signals. As bandwidth loading increases, second order further limits the link's ability to carry higher order modulation QAMs. This is not so with QFlex because it up-converts an RF stream so to avoid its own second order. What's more, QFlex can multiplex multiple streams with the appropriate up-conversion spectrum selected mathematically so to avoid any second order products from these streams' own block, or any other block under conversion. In this way, not only can the signal blocks exhibit extraordinarily high NPR, but the blocks can also be incredibly broad when compared to traditional analog return or even enhanced digital return.

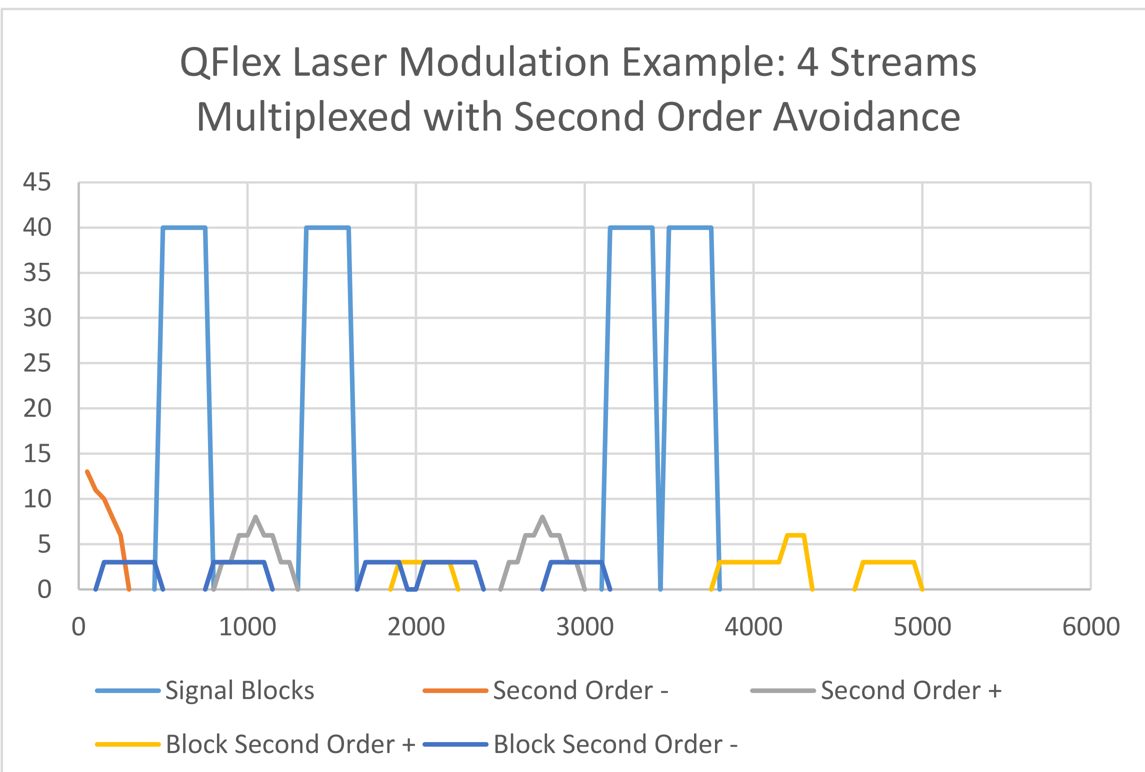

Figure 2.
By up-converting the optical node's 4 RF streams to mathematically optimized frequency slots, large, high-split sized blocks can be transmitted together in distortion free areas. Using this technique, the analog laser is capable of carrying a total of 250 MHz x 4 = 1 GHz, sufficiently clean to support full 4k-QAM loading.

QFlex: It's not a frequency stacker.

Some may be familiar with return path block upconversion from the 1990's, or what was known as frequency stacking. Up conversion was used in these frequency stackers, too, but unfortunately not for Second Order Avoidance. In those systems, one of the RF streams was left unconverted and the remaining three streams were converted to higher blocks sequentially without regard to where second order products fell. This arrangement led to subpar performance of the link, as the payload spectrum was fully immersed in its own second order products. Its bandwidth per-stream was also fixed at a 42 MHz maximum to avoid further diminishing of performance, but at the cost of bandwidth flexibility.

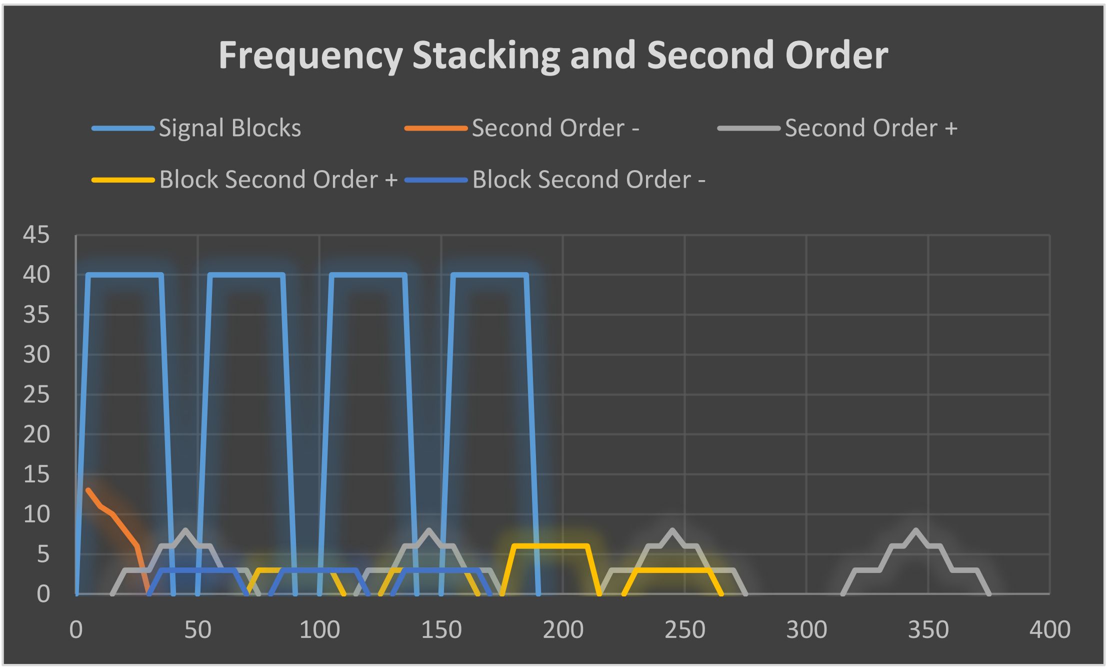

Figure 3.
Frequency stacking does not take Second Order Avoidance into consideration as part of its up-conversion scheme. Therefore, the unconverted baseband block gets swamped with lower second order products. All other blocks suffer other second order impairments, as well.

Digital Return: Advantages and limitations.

Digital return brings phenomenal stability to return paths. In digital return, the entire return path RF spectrum is run through an analog-to-digital converter. While most, if not all, of the information carried on a typical return path today is already digitally coded in the form of QAM carriers, the re-digitization process performed in a digital return link serves two key advantages:

1) Lowest possible laser coherency threshold (just on or off).
2) Time Division Multiplexing of two or more streams possible.

Laser coherency means a bit can be interpreted even with significant noise and low signal strength. This makes digital return suitable for long transport links. The re-digitized serial data stream presented to the laser is actually a form of Second Order Avoidance, since the spectrum is converted to a completely different format that renders any laser second order inconsequential, at least at current upstream bandwidths.

But digital returns have limitations. Over the next decade, they will experience troubling limitations in handling return system upstream bandwidth demands. For one thing, digital returns require a very high data rate to transmit a relatively small spectrum. For example, a return spectrum from just 5 to 42 MHz loaded with 64 QAM carriers may require a 1.25 GBPS data rate per stream. The higher the required NPR, (analogous to order of modulation) the higher the required data rate. If the system operator wishes to change frequency splits, the data rate would need to be raised as well. Unfortunately, the real possibilities for higher orders of modulation or changing frequency splits to open more return bandwidth are not readily entertained by the most widely-deployed digital return systems. In fact, digital return design counts on *limiting* any unused headroom to reduce data rate. For the return bandwidth, most digital returns have anti-aliasing filters hard wired in to prevent digitization of anything above the Nyquist sampling rate. Consequently, trying to push a 42 MHz digital return to work beyond 42 MHz simply will not happen. Unlike even traditional analog lasers – for all their faults – at least most of them can be loaded beyond the node's current frequency split. Also, firmware algorithms are used to limit digitization of signal transitions that are below what the digital return designer decides to be the maximum anticipated order of QAM. Even the number of RF streams to be carried are limited in many digital returns to trade off bandwidth or resolution. These tradeoffs expose the operator to the risk of having to either change hardware or pull more fiber and split more nodes as necessary to accommodate these limitations. In a world where Moore's law continues to prevail, and more bandwidth-intensive services and apps become part of our daily lives, such limitations can become outright nightmares for a system operator with capital budget constraints.

Incidentally, in order for a digital return system to carry the same 1GHz/4k-QAM load for which QFlex is designed, a digital return serial link would require a clock rate of about 33 GHz. In the digital domain, this clock rate presents significant technical challenges, particularly over long fiber distances. Silicon design availability is a current issue and significant fiber dispersion impairment is another.

QFlex uses simple digital control loops to bring the stability of digital return to the analog laser. Temperature controls maintain laser output level within a tight window while optical modulation index is maintained through an RF power-sensing AGC. No complicated user setup routines are required to get the QFlex up and operating.

Comparing QFlex at the Hub: Throughput, rack density, and infrastructure impact.

ACI QFlex brings up to 33-times the throughput and infrastructure advantages over WDM solutions, BDR and EDR. Even given this clear advantage in throughput, the case for rack density and hub space are other practical considerations in the employment of new link technologies such as QFlex.

The true measure of a link system's effective physical use of hub space is a combination of throughput, capacity, efficiency and longevity measured by MBPS/lambda/RU. And, with ACI's broader scope of system performance metrics that prove QFlex superiority, we're moving a very important conversation well beyond just simple rack density.

Optical Return Path Rack Density Planning vs. Service Capacity Planning

Parameter	Analog Retur	BDR	EDR	Qflex-A8k
Shelf RU	2	2	2	3
Receivers/Shelf	11	11	11	12
Ports/Shelf	44	44	44	48
Ports/RU	22	22	22	16
Lambdas/Shelf	44	22	22	12
Ports/Laser (OSP Infrastructure Implication)	1	2	2	4
Max QAM modulation index	256	256	4096	4096
Rtn BW (MHz)	35.25	35.25	80	245
Max QAM Bits/s/Hz	6.67	6.67	12	12
MBPS/Port	235	235	960	2,940
MBPS/RU	5,173	5,173	21,120	47,040
MBPS/Lambda/RU (OSP infrastructure, rack density, and capacity)	**118**	**235**	**960**	**3,920**
MBPS/RU Capacity Ratio (x/Qflex)	11%	11%	45%	100%
MBPS/Lambda/RU Capacity Ratio (x/Qflex)	3%	6%	24%	100%

The cost of rack density planning: Continuous splitting to increase bandwidth...

Year	Analog Retur	BDR	EDR	QFlex
0	$ 22,000	$ 44,000	$ 55,000	$ 36,000
3	$ 44,000			$ -
6	$ 88,000	$ 88,000		$ -
9	$ 176,000		$ 110,000	$ -
12	$ 352,000	$ 176,000		$ -
Final Link Split Cost	**$ 682,000**	**$308,000**	**$165,000**	**$36,000**

...and ever increasing demand for rack space.

Year	Analog Retur	BDR	EDR	QFlex
0	2	2	2	3
3	4			
6	8	4		
9	16		4	
12	32	8		
Final RU	62	14	6	3

Figure 4. Hub technology stack-up: Throughput potential of QFlex shifts hub expansion and node split capex to more practical use.

There should be no doubt about it. QFlex is the industry-leading upstream throughput solution for DOCSIS 3.1

The graphic in Figure 4 summarizes the overwhelming advantage QFlex enjoys when compared to return technology currently on the market, including the most recent Enhanced Digital Return.

In the first cluster of rows, we describe the physical density of hub shelves. This cluster illustrates rack density in numeric terms. In this comparison, we focus on two differing rack densities, the first being the industry standard for so-called high density, a 2 RU chassis for analog, BDR and EDR solutions. We also list the ACI 3 RU Acion 8000, which houses the QFlex receiver modules, in the rightmost column for comparison.

The second cluster of rows show how QFlex wins, big time in both the contest of rack space and infrastructure growth control over time.

The QFlex answers the call for customers who face ongoing investments to solve their rack and floor space growth challenges, all while facing the certainty of receiver expansion to support their ongoing node splits. QFlex protects legacy system investments while delivering the industry's best performance metrics.

The traditional analog return – regardless of fiber rich, CWDM, or DWDM implementation – is 1-port per 1-wavelength. This arrangement crowds valuable fiber capacity that should otherwise be available for backhaul and business class services. The analog return's ability to carry the highest order QAM modulation is severely limited as we attempt to expand bandwidth per port. This means increased bandwidth demands will only be satisfied with the addition of more links in analog return. The need to split will come in regular increments, with each successive full division requiring twice the number of links as the last. That's because the very first iteration analog return can appear to be a cost effective choice, but it rapidly becomes an almost unsustainable cost burden as bandwidth demand increases, as seen in the final 2 row clusters in the table's analog return column.

The original baseband digital return (BDR) – which all major brands make – is typically characterized by 2-port time division multiplexing and 5-42 MHz paths. Some implementations of BDR use full 4-port segmentation but, much like the 4-port frequency stacker, they are both bandwidth and modulation depth limited.

Enhanced digital return (EDR) is a viable upgrade for BDR but it aims at addressing only a medium level implementation of DOCSIS 3.1. At 85 MHz maximum bandwidth, another technology upgrade would be required to get to a 230 MHz high split, where QFlex currently resides along with symmetrical gigabit Internet that will be sustainable and deliverable to the masses with current infrastructure.

For the fiber return path of the next decade and beyond, ACI brings the QFlex in anticipation of high split, 4k QAM, fully segmented return paths over a single lambda.

When you climb Mt. Rainer – a short drive from our office in Kent, Washington – the first mile is said to be as exciting as the last. Traversing the HFC network is similar. Being equipped for *that* begins with ACI fiber products for the first mile of the network and ACI coax products for the last. The HFC network is remarkably adaptable to the continuing demand for applications and services. Even with decades of advancements behind us, people are surprised to learn we've barely scratched the surface of capacity potential. ACI's climb to enable the first mile of fiber and last mile of coax is thrilling because we help HFC networks deliver the next wave of advanced services.

Delivering the most advanced optics in the industry today, many of ACI's new fiber-based products still fit directly into the same amplifier housings originally selected to drive legacy system builds. This helps our customers take their services even deeper into their networks while enjoying the ACI tradition of investment protection against dreaded teardowns and costly rebuilds. In many cases we've supported customer progression from 550 MHz to 1002 MHz without teardowns or re-spacing. With decades of industry successes and an expanding portfolio of leading HFC solutions, ACI has earned a picturesque view from the top of the industry.

ACI is a leading manufacturer of high performance broadband amplifier products, optical nodes and head end optronics for the cable television and telecommunications industries worldwide. Headquartered in Kent, Washington, U.S., with international offices in Taiwan, Vietnam, Thailand, Chile and China, ACI helps improve the resiliency and utility of the HFC network for the next wave of advanced services. With a proud lineage of having evolved from Augat and Thomas & Betts, ACI is a wholly owned subsidiary of TwoWay Communications, Inc.

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Rev A 10-02-2015 Printed in U.S.A.