Using Automated Live QC to Reduce Construction Costs and Improve Readiness

An Operational Practice prepared for SCTE by

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1. Introduction

Multiple systems operators (MSO) are deploying a remarkable number of new amplifiers in modern hybrid fiber coaxial (HFC) systems to facilitate mid-split, high split, and data over cable system interface specifications (DOCSIS) 4.0 full duplex (FDX) and frequency division duplex (FDD) deployments. This capital investment is focused entirely on our industry's ability to increase the bandwidth needed to satisfy our expectations around customer expansion. This capital investment doesn't come cheap, and all operators are interested in a rapid return on investment. Network upgrades should yield the desired result on the day of the cut. Remediations in the form of partner go-backs or internal investigations are very costly. Lost partner time result in construction slowdowns as crews are required to go back to areas they've previously worked. Network investigations performed by the local plant maintenance team take away from demand and preventive maintenance activities. The customer experience is lackluster due to additional, unwanted service interruptions. Regardless of who is going back, the cost is high, and the impact is an overall reduction in value.

If we look at today's construction environment, we find ourselves in a fast-paced culture of cut, swap, and align. The desired end state in terms of network architecture dictates whether business partners, generally, will only cut the amplifiers in the HFC node or the taps and passives as well. As one can imagine, the "amplifier only" solution is the most affordable and straightforward option. Typically, a single node with four bus legs can be cut in as little as two days depending on the number of homes passed and the workforce doing the job. Resources, time, and peoplepower are in limited quantity in today's world. This upgrade activity requires a high level of trust between both the MSO and the business partner. Expectations must be clearly delivered in the statement of work and both parties must be made aware of the overall objective and the focus on quality. In most upgrade situations, we're trusting the splicers, technicians, and coordinators to manage the quality and performance of the amplifier setup with limited interaction.

This focus on quality is generally assumed as both parties work with each other in good faith. But, as inferred, the upgrade process must be completed with limited error. MSOs expect to turn up more advanced modulation methods in larger sections of bandwidth in both the forward and return paths. Those turn-ups are the foundation for increased speeds, lower latency, and additional capacity for the customer to utilize and enjoy. Many of our splicers and technicians are extremely capable, talented, and trusted, while some need more training. Given the varying levels of knowledge, skill, and ability, we expect inconsistent outcomes at the end of the day. Since skill variation does exist, the quality assurance (QA)/quality control (QC) process continues to be a valuable function in the construction process often constrained to the lowest common denominator. Our biggest problem is that Quality Assurance/Control coordinators simply cannot be in all places at all times to evaluate network performance.

2. Using Cloud-Based Meter Technology to Increase Consistency and Quality

Today's modern signal meters are more than a standalone testing tool. Several of the industry-available meters currently operate as part of an ecosystem. The platform typically consists of a hand-held field unit, a communications device (either embedded in the unit or via a mobile device), and a back-end cloud data storage system. This meter platform is extremely powerful as it collects an incredible amount of data with unique identifying properties. Using these platforms, we immediately know the following:

1. Who's logged into the meter platform taking the measurements
2. Where these measurements were taken
3. The time the measurement was taken

4. Detailed signaling information inside the scan payload (signal level, modulation error ratio (MER), bit error rate (BER), in channel frequency response (ICFR), ping, throughput, etc.) (Curran/Martushev SCTE 2020)

With this detail, we know exactly who is doing what, where, when, and how. Managing performance, outcome, and accountability is clear. The power of the platform is self-evident and should be applied in a professional and ethical manner.

2.1. Sweep and Balance

The replacement of any HFC amplifier necessitates the use of hand-held test equipment in order to properly balance and sweep. If you're not already familiar with sweep and balance, the process is used to achieve the proper inputs and outputs to the amplifiers in the cascade. This ensures that the last amplifier in sequence performs similarly to the optical node at the head of the cascade. This "unity gain" is what drives a consistent experience for any of our customers whether they are connected to a tap the node or a tap at a remote line-end in the network; a technical advantage over DSL systems and an equalizer when looking at a fiber competitor.

Properly setting this frequency response and unity gain in the outside plant yields a layer-one environment suitable for anything that network engineering (or marketing) chooses to place on it. A linear response set to the correct signal level ensures packet performance. When networks are constructed and swept to design specifications the system will provide maximum throughput and a full return on capital investment.

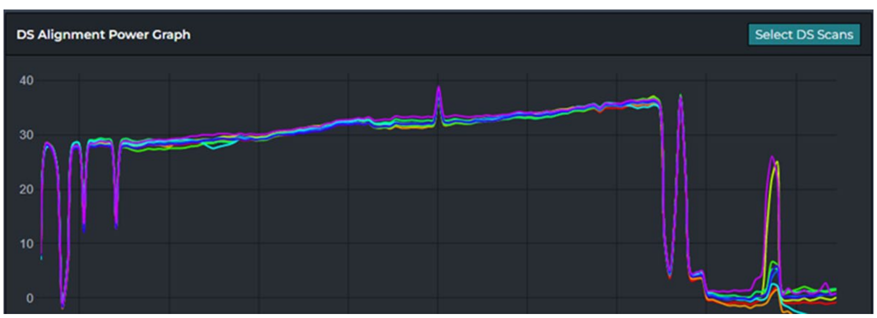

Figure 1 - A clean, linear frequency full band capture response

2.2. Leveraging Automation in the Cloud Environment

In times past, sweep technicians were required to store images of sweep; either in the form of polaroid photos or dot matrix printouts placed in binders for each node worked. Today technicians are using a cloud-based meter platform. The data collected can be used to automatically grade the outcome of a sweep and balance evolution.

In order to setup automated Live QC, you will need to have the following components in place:

1. Cloud-based meter/platform
2. Back-end software that can record/grade the work
3. Statement of work requirements for your business partners and internal technicians
    a. User guides and technical articles
    b. System parameters and performance expectations including pass/fail ranges
4. Scans taken and uploaded to the cloud platform

Next, we will define the basic requirements for performing this task in automation:

Your back-end cloud must be able to accommodate multiple users sending scans to one job/record. Historically most sweep and balance tasks are done by one technician. In today's fast paced construction environment, many work crews consist of four or more splicers/sweep techs that cut amps very quickly in sequence.

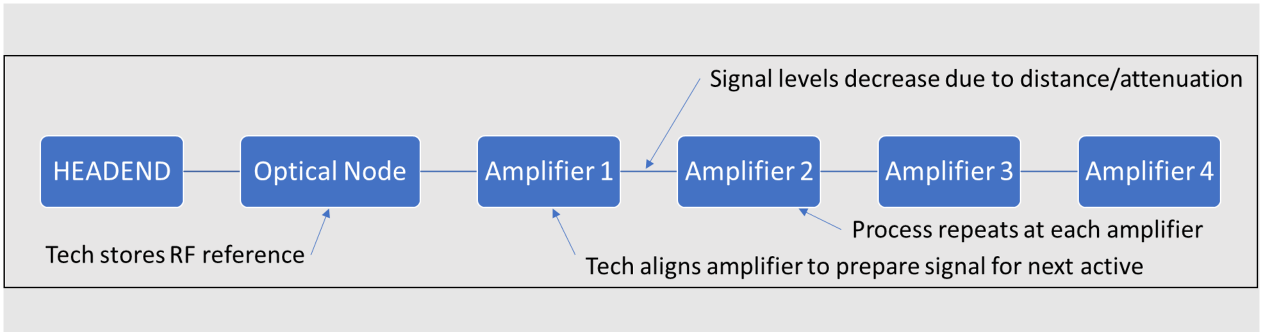

Figure 2 - Typical amplifier upgrade order of operations

Since there are component level differences and tolerances in each field signal meter, the technicians must store their own reference at the optical node to ensure that their individual amplifier sweeps are as close to "true" to the node as possible. Running channel scan comparisons between meters is a recommended step in order to ensure that each meter is within a reasonable measurement tolerance to each other. Meters that are significantly disparate should be factory/bench calibrated as soon as possible to improve the overall outcome of a group sweep and balance effort.

Thresholding must be set via variables in the back-end cloud to grade the activity. Typical amplifier sweep and balance consists of setting the amplifier to the low-frequency level and the high frequency level. Example: a standard level set in recent years would be 31 dBmV at 54 MHz and 41 dBmV at 750 MHz (10 dB tilt) using digital levels. The quality of the sweep is dictated by the Peak to Valley measurement between 54 and 750 MHz in this example. In a typical six-amplifier deep cascade a 3.5 dB peak to valley measurement would be acceptable to most technicians and field leaders. (Hranac, Broadband Library Spring 2022)

DS Alignment Info

Sweep	Low Ch. 3 31	High Ch. 120 41.5	Tilt	Peak to Valley	Test Point Compensation
Reference 3/29/19 11:02 AM	30.8dB	41dB	10.2dB	---	20dB
3/29/19 11:40 AM	31.1dB	41.3dB	10.2dB	1.1dB	20dB
3/29/19 12:30 PM	31.4dB	41.5dB	10.1dB	1.3dB	20dB

Figure 3 - DS Sweep/Alignment Low/High/Peak to Valley Values

In the example shown below (Figure 4), the red line is the “normalized” reference. Although the Y axis clearly shows a level of zero the actual RF spectrum levels have a value other than zero. The reference data is flattened visually while maintaining its true level information. Subsequent scans are contrasted against the reference (each color is a physical location) to show the end user the extent of the frequency response variations in the band. As you can see most of the individual amplifier sweeps are within approximately 2dB peak to valley until approximately the 600 MHz range. Two amplifier sweeps instantly stand out to the viewer as a notch/suck-out is seen at approximately 690 MHz (red oval). This notch is roughly 10-12dB down from the reference. Delivering the highest bit rate and modulation in this impaired frequency spectrum will be improbable (Leech/Martushev SCTE 2022). Additional analysis of Figure 3 shows that the high balance frequency is not being set properly (yellow oval). There are several real-world reasons for this inadequacy or it’s possible that the technician doing the balancing is not aligning to ~750 MHz but instead choosing a high level/channel closer to 600 MHz.

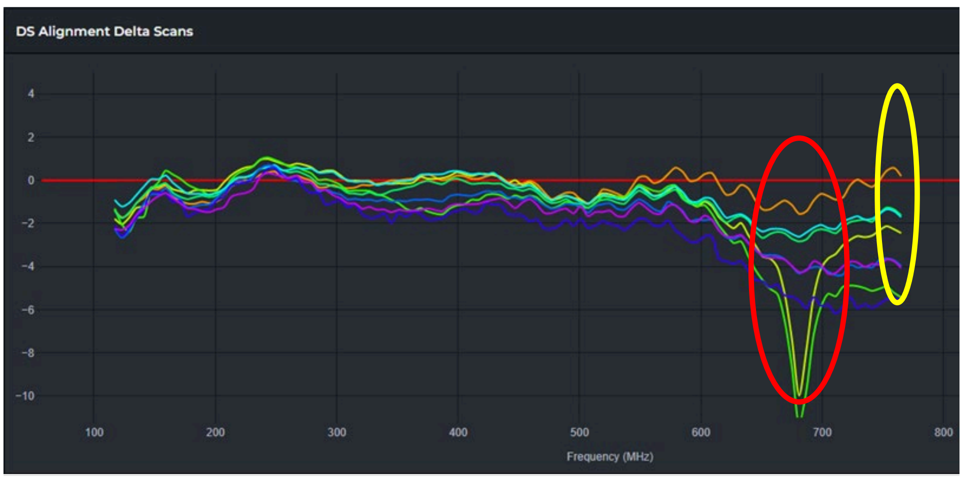

Figure 4 - Reference and subsequent sweeps

2.3. Change is a Constant

One anticipated behavioral change is regarding pass/fail implications and technician reaction. If splicers/sweep techs are held accountable via real-time QC, compliance becomes crucial to move to the next amplifier in cascade and complete the job. Some people have anticipated slowdowns in work completion and overall productivity. Internal trials have shown that cloud-monitored sweep and balance processes set clear expectations while driving quality and training efforts. Most technicians will quickly learn or discover what actions are necessary at the amplifier to pass a quality control check. Immediate notification can alert the technician if the alignment widget in the meter application is programmed to advise the technician when the optimum levels window is achieved. They won’t have to wait for end-of-day reporting nor should they as the preceding amplifier’s performance partially dictates the proceeding.

2.4. Database Connections

This automation process requires several different database connections. When the automation platform is properly synchronized with the construction management platform, moving a job number from one to the other should be a fairly easy task. Multiple technicians will need to work from the same job number in order to properly organize all of the sweep and balance records and construction coordinators will need to be able to reference the construction job to the appropriate scans and grading reports.

A connection to the MSOs monitoring and maintenance platform could be made in order to automate customer-facing communications before, during, and after the day of cut so that customers who need all-day connectivity can make arrangements outside of their normal subscriber location.

2.5. Reporting and End of Job Closeout

Reports are implied in any data collecting and analysis project. For this automated QC process there are several significant items that can be analyzed. The obvious checkpoint to report would be the pass/failure percentage for the overall job. But since amplifier work relies on success at the previous station this metric is redundant. Any given job will have a preset number of amplifiers to be worked. End of job reporting will tell us if the crew touched all of the amplifiers or may have forgotten one that was on the initial job list. In short, how many amplifiers did we ask you to cut, how many did you get to in the day and how well did you do on the amplifiers that you completed?

Since time stamping is built-in to the process, reporting on job times is simple down to the individual amplifier. Making recommendations on the number of people needed to work a node in order to meet a specific timetable would be easy to calculate using the average time per amplifier cut/sweep metric.

An overall quality/experience metric could be achieved per technician. Since pass/fail metrics are graded, applying a real-time score to the individual could be a realistic option. That sort of metric would provide data on who is a quick achiever versus someone who might need some additional training or help.

At the end of the job, a full report could be created to include the personnel doing the work, the coordinator facilitating the work, the locations, and the overall outcome of the activity. Actively reporting exceptions to any of the expected requirements would allow for quick investigation and same-day or next-day repair before work crew move farther away from the node in question.

3. Future Enhancements

Currently, we trust the technician to choose the correct low and high channels and their RF levels. In the future, we hope to auto-scrape the amplifier details from digital tombstones and place them in the sweep/balance targets inside our iOS application via GPS automation. Imagine opening a pedestal and having the application ask you if you're at HR10D001. A quick verification of the system prints, and the technician knows exactly what pads and equalizers to start with to achieve the designed system levels.

Another innovation we hope to add is the use of both RF cables on our meter platform. If we can measure the input and the output on the amplifier test points at the same time it is highly likely we can advise the technician on any necessary changes to the input, mid-stage, or output stage pads and equalizers. Technicians can unfortunately achieve proper output levels and sweep response while placing the incorrect pads/equalizers in the station. Improper padding at any stage of the amplifier can result in poor RF gain/quality performance (D. Linton, Broadband Library Spring 2022).

On a related note, colleagues have discovered a tell-tale method to know if you're operating an amplifier in (low) noise range or in distortion. It's related to the optical noise power ratio curve in an optical circuit and the concept is discussed in the Diane Linton article referenced in the previous paragraph. (O'Dell and Darby, SCTE 2023) go to greater lengths to describe how observing the noise floor on any RF scan at both the low, mid, and high sections of a Gigahertz wide spectrum will tell you if you're operating in noise or in distortion. We hope to apply these concepts in our meter platform application to advise a technician that their amplifier station is at risk for self-inflicted MER degradation.

And finally, a note on next-gen profile enablement and tooling to aid in understanding proper amplifier setup. Up until now, we have avoided talking about next-generation bonding profiles other than to mention that they offer additional bandwidth. One thing to note about any sweep process is that, ideally, the channel plan doesn't matter as long as it's loaded correctly (for total composite power) and it is swept out to each last amplifier in the cascade. One advantage to pre-loading the next-gen profile is the ability to see and overcome any RF impairments in both the linear and non-linear space. Occupied bandwidth is measured bandwidth. In addition, turning up full OFMDA capabilities allows you to query all of the modems in the service group to view their bonded state. Populations of modems that fail to bond when they should be an easy indicator of an improper amplifier setup or a missing amp altogether.

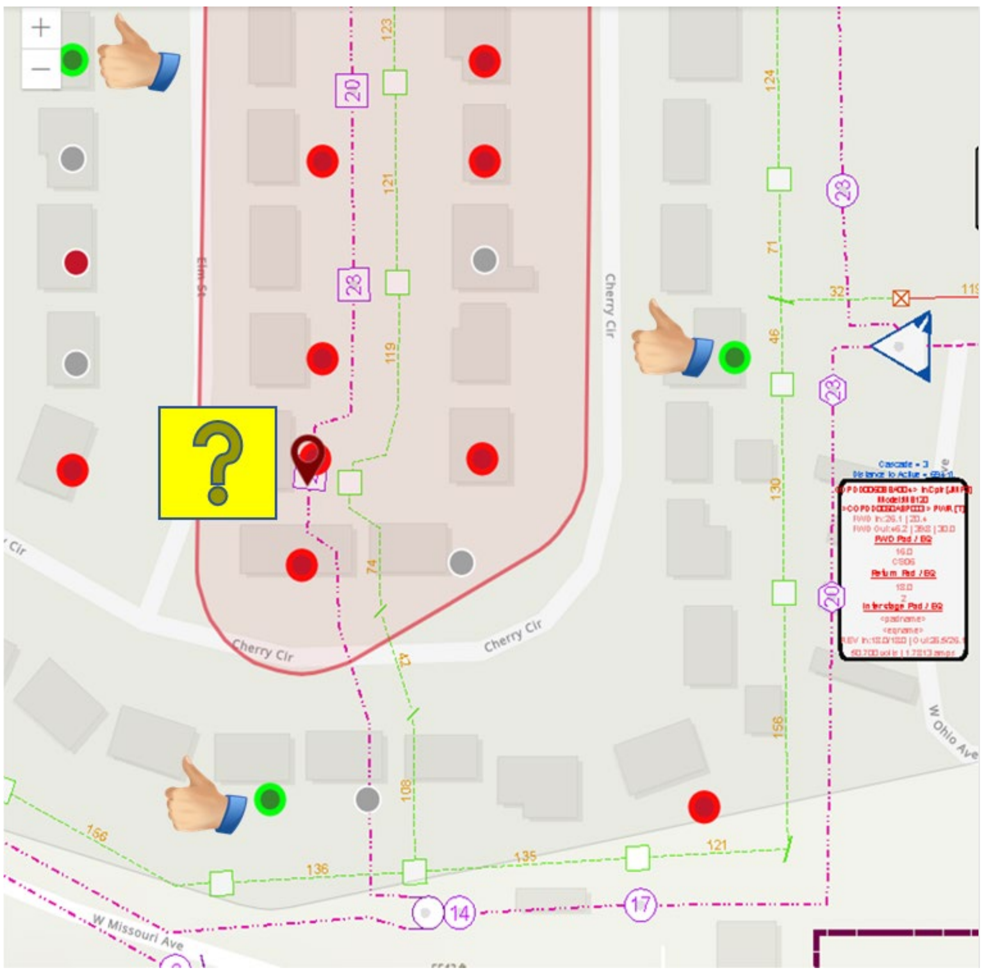

Figure 5 - Network architecture showing a group of modems not bonding to orthogonal frequency division multiple access (OFDMA)

In Figure 5, notice how the design goes from a 14 two-way tap to a splitter. The northbound leg heads to a 23 four-way tap. The amplifier icon and tombstone are missing. In this example, our tools told us that the construction team was never made aware of this amplifier. Since the system was cut with the previous generation low-split 5-42 return path configuration the amplifier was missed until the time that the next-gen bonding profiles were added to the system. This is an obvious go-back situation that resulted in additional customer downtime and pain. This would have been avoided with a comprehensive automated QC approach.

4. Anticipated and Observed (Trial) Outcomes

As stated earlier, in the short term we believe that technicians might be uncomfortable with the automation and change in expectations. Many splicers and line techs are pride oriented and don't feel the need to be observed or graded. We imagine this may be a limited sentiment as the automation allows for real-time documentation, quality control, and an unquestionable form of accountability. When one observes a sweep trace there is little to no doubt about the ability of the technician given new, high-quality materials to install. Our internal trials followed this pattern, slight apprehension, some doubt, review of expectations, a short learning curve and then adoption of the process. Nine months into our field trial the technicians under trial prefer the upload and grade method over previous methods as all parties involved have very few questions about work quality and performance.

In our forementioned ongoing field trial the results have been extremely positive. Go-backs and remediations in the trial area have dropped significantly over the control group. Pre-enablement has been in place as well and is driving down missed amplifiers and OFDMA bonding failures as well. There have been no significant increases in customer call-in rates or trouble calls in these areas.

5. Conclusion

As HFC technology has matured, the depth of the amplifier cascades has shortened. This reduced amplifier count has allowed us to slowly lose our empirical knowledge when it comes to amplifier setup; chasing noise became paramount. As the amplifiers have become more efficient along with better error correction we started walking away from sweep and balance. Technologies like profile management applications (PMA) have made it easy to disregard a physical layer issue up until the point of total failure and in some instances, we're relying on signal levels and MER at the customer premise equipment to gauge performance.

With the advent of Remote PHY, it's no longer acceptable to see MER values in the mid-thirties. Simple binary online/offline indications only tell us if we're "working." Before the widespread use of digital modulation in cable networks that may have been a sufficient metric for performance. In today's networks, we need fully quantitative measurements that nearly guarantee the maximum level of performance, availability, and reliability. Without observing the performance of every one of the new amplifiers you're putting in the network how will you know if you're truly getting your money's worth?

Abbreviations

BER	Bit Error Rate
CPE	Customer Premise Equipment
DOCSIS	Data Over Cable System Interface Specifications
FDD	Frequency Division Duplex
FDX	Full Duplex (DOCSIS)
HFC	Hybrid Fiber Coaxial (network architecture)
ICFR	In Channel Frequency Response
MER	Modulation Error Ratio
MSO	Multiple Systems Operator
OFDMA	Orthogonal Frequency Division Multiple Access
PMA	Profile Management Application
QA/QC	Quality Assurance/Quality Control
RPHY	Remote Physical Layer technology
SCTE	Society of Cable Telecommunications Engineers

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