Understanding Equalizers, Pre-Equalizers, and Their Use in Localizing and Troubleshooting HFC Issues

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This document explains adaptive equalizers and how they help quickly locate and troubleshoot issues in coaxial networks. It discusses adaptive equalizers, pre-equalization, the Proactive Network Maintenance initiative, and troubleshooting techniques using equalization.

Impedance

To transfer maximum power from a source to a load, variations in the characteristic impedance should be minimized throughout the coaxial part of the transmission system. In the case of coaxial broadband networks, this nominal impedance is $75\,\Omega$. If the impedance is changed in any way, it results in a loss of power at the receiver and some of the transmitted signal is reflected back toward the source. Impedance mismatches are everywhere in broadband networks. They include amplifier inputs and outputs and passive devices in subscriber networks and even the cable itself. The reflections caused by impedance mismatches usually affect the return path more than the forward path—cable loss is less at the lower frequencies. Therefore, the reflected signals are higher in amplitude.

Factors affecting the impedance of coax include the inner diameter of the outer conductor, the outer diameter of the inner conductor, and the constant of the dielectric material. Crushed, partially severed cable or water-soaked dielectric alters the impedance of coax.
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Return Loss (RL)
Return Loss (RL) is the ratio of the amplitude of a transmitted signal to that of a reflected signal. RL is measured in terms of dBc, is frequency dependent, and is stated at the worst-case frequency. The higher the ratio, the lower the reflected signals. As an example, a 20 dB RL means that 10% of the transmitted signal is reflected back toward the source. A 16 dB RL means that 16% of the signal is reflected back. Typical RL specifications for input and output ports on amplifiers are 14 dB. This means 20% of the transmitted signal reflects back, making them a major source of reflections. Coax generally has a minimum-rated RL of 28 dB.

Velocity of Propagation (VoP)
Velocity of Propagation (VoP) is a ratio of how fast RF signals travel in a medium in relation to the speed of light in a vacuum. For example, if a cable has a VoP of 87, RF travels through the cable at 87% of the speed of light. The speed of light in a vacuum is 186,000 miles/sec or 982,080,000 ft/sec, which equates to about 1.016 ns/ft. VoP depends on the dielectric material of the cable, so different types of cable have different VoPs. A cable datasheet usually lists VoP along with loss rates. Typical examples of VoP are RG6 at 85, PIII at 87, and MC2 at 93. Water-soaked dielectric can change coax VoP.

Adaptive Equalizers (AEs)
Adaptive Equalizers (AEs) are the first stage found in most digital receivers. They condition incoming RF signals before demodulation, thus minimizing bit errors due to impaired RF carriers. AE have no relationship to the hardware components found in amplifiers that aid in the frequency response of the system. Also, when taps are discussed with AEs, these are not the directional taps found in HFC distribution systems. Equalizer taps are comparable to the poles in a filter. CMTSs, cable modems, STBs, and test equipment typically include AEs. They automatically and dynamically compensate for frequency response and group delay (linear distortions) caused by reflections. Figure 2 shows the improvement in MER before and after equalization.

In addition to optimizing RF signals before demodulation, AEs:
- Analyze incoming signals
- Display linear distortions directly in real time
- Remove the need for additional test signals
- Provide visibility into plant problems and the location of problems that don’t show up with typical spectrum analysis
- Measure amplitude response and group delay simultaneously and without service interruption

Tap 00 in Figure 3 is the current symbol passing through the AE. Each of these taps relates to a time period based on the symbol rate of the channel. When a tap is elevated in amplitude, it indicates an impedance mismatch at that time period. If the VoP is known and the time period for each tap is known, the approximate distance to the mismatch can be calculated.

The red dots in Figure 3 indicate the maximum allowable reflected power limit for each tap, per DOCSIS specifications. In the diagram, the two red taps that are higher in amplitude indicate reflected signals. These reflected signals are arriving at the receiver at certain times after the desired signal.

Taps closest to the desired symbol indicate issues in the drop network close to the modem itself. Taps further away indicate problems outside in the hard cable. The higher the amplitude of the reflected tap, the worse the impedance mismatch.
Adaptive equalizers can also display the in-channel frequency response (ICFR) of a digital channel. The ICFR is the response of the channel being measured, not the frequency response of the broadband network. Ideally, the frequency response is flat. The peak of the signature is measured against the valley and is usually stated as the difference in dB between the two. Figure 4 shows an example of the ICFR. The Y-axis is the frequency span of the channel and the X-axis is amplitude of signal at each frequency relative to the average carrier level. The DOCSIS specification for in-channel response is .5 dB per each 1 MHz. If a channel is 6 MHz wide, the specification is 3 dB peak-to-valley.

AEs can also measure group delay. Group delay is a measurement of different frequencies traveling through the same medium at different speeds. For example, a 6 MHz-wide carrier has different frequency components that arrive at the receiver at different times. Figure 5 shows a group delay measurement where the X-axis is the frequency span of the channel. The Y-axis is time measured in differences of ns. The DOCSIS specification calls for no more than 200 ns delay within a 1 MHz bandwidth. In the diagram below, the shaded area is 1 MHz wide and the maximum group delay within that 1 MHz bandwidth is measured by comparing the maximum and minimum delay within that 1 MHz span. This is also expressed in terms of the worst case within the channel.

AEs in the CMTS can also discern multiple problems by comparing amplitude response signatures. In Figure 6, there are two distinctive signatures indicating two different problems.

Pre-Equalization (Pre-EQ) Equalizers

Pre-EQ equalizers are located in the upstream transmitter of each DOCSIS 2 and higher cable modem. In the upstream, modems use pre-equalization to pre-distort carriers that cancel linear distortions caused by reflections in the network. In most scenarios, upstream pre-equalization completely compensates for certain problems in the network. As a result, no symptoms are detected at the CMTS, in FEC statistics, or through other metrics. Pre-EQs compensate for network linear distortions and give an operator time to resolve issues before they impact quality of service.

Pre-equalization also enables proactive network maintenance. Operators can triangulate problems based on modem pre-equalization tap coefficients. If pre-equalization is enabled, it turns all cable modems into devices capable of doing upstream signal analysis.
The values used to set a modem’s upstream transmitter pre-equalizer coefficients are derived from the initial post equalization of the CMTS receiver. When a modem is first turned on, it sends a ranging burst to the CMTS (the outer four symbols of the constellation). The CMTS’s AE looks at this ranging burst and sends the pre-EQ coefficients back to the modem. The modem then loads these coefficients into its transmission pre-EQ equalizer in an attempt to achieve a “perfect” signal at the CMTS receiver. Ideally, the pre-EQ equalizer exactly corrects the linear distortions of the channel received at the CMTS from the modem. The inverse of the modem pre-equalizer response is the upstream response of the system. Upstream pre-EQ is a continuously monitored process by the CMTS, with updates made at the cable modem when needed as the system changes.

Using proactive network maintenance to evaluate pre-equalization coefficients can determine the approximate distance from a reflection point to an impedance mismatch. As with the adaptive equalizer, each tap of the pre-EQ represents a period of time. It must be understood that pre-EQ shows a distance between two reflection points, not a distance to the mismatch from the modem. This reflection point could be an amplifier port, (14 dB typical SRL) or another impedance mismatch as shown in Figures 7 and 8.

![Figure 7. Amplifier as the reflection point with a problem at the 8 tap](image)

Figure 7. Amplifier reflection point, 14 dB SRL

![Figure 8. Reflection with two impedance mismatches](image)

Figure 8. Reflection with two impedance mismatches

Taps of the pre-EQ equalizer that contain more energy represent the distance from a reflection point to a mismatch and that distance can be calculated. The standard symbol rate of an upstream 6.4 MHz 64 QAM signal is 512 Msps. This equates to a symbol being transmitted in 195 ns (1 sec/512 Msps = 195 ns). The time period represented by each tap in this case of upstream DOCSIS carriers is equal to the time of the symbol rate.

Since the time for each tap is known and the VoP is known, the approximate distance of each tap is calculated as:

$$\frac{(195 \text{ ns} \times 0.87 \text{ VoP})}{2} \approx 85'$$

The product of the symbol time and VoP is divided by 2 because it represents a distance to and from the reflection. The VoP is very important in this formula and, in this example, the VoP of PIII cable was used. With a different type of cable, the change in the VoP must be factored.

In Figure 9, the 10th tap is elevated in the pre-EQ indicating a reflection caused by a mismatch approximately 850’ from the reflection point: (10 taps x 85 ft)/2 = 425 ft

![Figure 9. Cable modem pre-equalizer displaying an elevated tap](image)

Figure 9. Cable modem pre-equalizer displaying an elevated tap

**Proactive Network Maintenance (PNM)**

Cable operators can no longer tolerate interruptions in service—customers can always choose new providers. HFC plants need to be completely reliable and require remote visibility into both cable plant and equipment operations. AEs in the CMTS and Pre-EQ in the cable modems provide test points that enable characterization and aid troubleshooting of HFC plant including remote and proactive troubleshooting. The goal is increased reliability, maximum throughput, and resolution of issues before they affect subscribers.

PNM is a six-step process for identifying and localizing network problems:

1. Data collection — SNMP queries of the CMTS and cable modems obtain equalization coefficients and upstream channel descriptor (UCD) information.
2. Initial modem assessment — which modems need to be monitored more frequently.
3. Analysis of distortion signatures — AEs of the CMTS are analyzed in both the time and frequency domain.
4. Evaluation and triage — are modems failing, marginal, or operating properly.
5. Calculations of distances to reflection points — calculations based on modems with similar pre-EQ coefficients.
6. Plot modems on a map — visual representations of known issues.
Troubleshooting with Equalizers

AEs in modern meters help troubleshoot reflections when PNM footages are not clear, such as in the case of multiple problems. The AE function works by connecting the meter to the downstream output test points on most amplifiers as shown in Figure 10. This depends on the amplifier’s type of test point configuration. This method displays approximate distances from the test point to the impedance mismatches, enabling faster problem resolution. More importantly, it works without taking the network down to perform TDR measurements when PNM distances are questionable. This test function also provides amplitude response and group delay measurements.

Application Examples

The following examples show how the AE function in a Viavi DSAM meter can help quickly locate and repair issues that were identified using PNM tools and the meter’s downstream EQ measurements.

Application Example 1

With the meter connected to the output test point, the AE measurement shows an elevated tap. When the marker is placed on the tap, the reading on the meter is 1437 ft. This is the approximate distance to and from the impedance mismatch: 1437 ft/2 ≈ 718.5 ft. The distance on the map is approximately 720 ft away from the output test point of the amplifier.

Figure 11. An elevated tap

Figure 12. Mapped splitter location
Using the DSAM AE function, a technician goes directly to the splitter on the map. Using typical troubleshooting techniques, a technician would go to the 4/2-way taps to check the terminations. This technique reduces MTTR and avoids system maintenance down time.

Application Example 2

The first step is to read the PNM map.

The next step is to analyze the system map. It shows a distance of 370 ft to termination. In this example, the problem is termination at the 14 tap. The actual footage was measured at 340 ft; system map footages aren’t always correct.

On the DSAM, the amplifier 3C location shows a reflection at approximately 323 ft. In actuality, the problem was a blown terminator found at the 14 terminating tap on the map in Figure 14.

Application Example 3

In this example, the PNM analysis shows a problem with two different issues fed from the same amplifier. Problems are separated by blue and red ICFR signatures.
Map analysis shows an amplifier with both problems.

Figure 20. Measuring the lower channels

Using the DSAM equalizer to check the lower channels does not display the issue well. Higher frequencies must be checked as well, as shown in Figure 21.

Figure 21. A higher-frequency channel shows issues more clearly

A repair tap with a bad shorting bar approximately 323 ft away caused the problem.

Figure 22. Faulty repair tap

The problem with the blue response (shorted tap bar) issue has been cleared. The PNM map shows that the problem with the red signature still exists.

Figure 24. DSAM equalizer showing remaining issue

The ETDR reads 1208 ft. The PNM shows the problem, but it appears on a different feeder leg. All test points must be checked.

Figure 25. The red signature still exists

The DSAM EQUALIZER analysis shows a problem at 2099 ft; low-frequency equalization at 2099 ft/2 = 1050 ft.

Figure 26. System map analysis

Figure 27. DSAM equalizer analysis
Summary

Adaptive equalizers in digital receivers can quickly and effectively determine the approximate distance to a fault from a measurement point. Pre-equalizers in digital transmitters such as modems can be just as successful in determining the approximate distance to a reflection point. Lastly, downstream equalizer analysis helps greatly in locating issues that may be difficult to find with other tools.

References

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In this example, the problem was burnt cable caused by downed power lines. Notice the pitted cable and lashing wire melted into the jacket in Figure 28.

The PNM map verifies the problem was repaired after cable replacement.

The DSAM shows measurements after repairing the burnt cable with the red trace. Notice that after the cable was replaced, equalization is clean and the equalizer now shows the next amp in cascade.