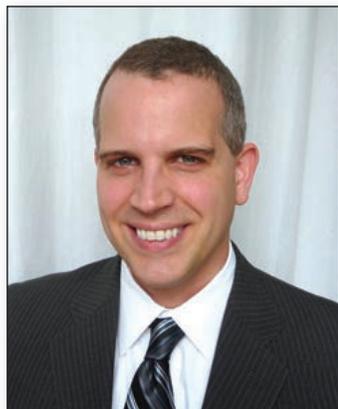# It's All About FEC: Like a Box of Chocolates

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We have all heard the stories of how well DOCSIS 3.1 is working. Perhaps your system has been involved in one of these stories too. One thing is true, DOCSIS 3.1 is working really well — even better than we had anticipated. Here is why DOCSIS 3.1 is working really well — it is all about forward error correction (FEC). [For the purpose of this article we will only discuss error correction in the downstream]

Reed Solomon forward error correction (RS-FEC) has been used in all previous generations of DOCSIS. I've previously covered RS-FEC and how it works here (https://volpefirm.com/docsis-codeword-errors/). RS-FEC has served DOCSIS very well, but advances in silicon technology enable us to take advantage of more powerful error correction techniques now, which provide significantly better data transmission robustness.

DOCSIS 3.1 has a major update in forward error correction moving from RS-FEC to a concatenated Bose, Ray-Chaudhuri, Hocquenghem (BCH) and low-density parity check (LDPC) or for short, BCH-LDPC FEC. Try saying that 10 times really fast.

BCH is an outer encoding and LDPC is an inner encoding. This means that the CMTS encodes the data to be sent with BCH FEC first and then a second layer of protection using LDPC FEC. When the cable modem receives the data frame it has to first decode the LDPC and then the BCH. Let's think of this as a box of chocolates, where BCH is the small foil wrapper around each individual chocolate and LDPC is the box protecting all of the chocolates inside. Together BCH and LDPC are providing two layers of protection around our data frame (the chocolates). Most importantly we just want to make sure that the chocolates are okay before we eat them, or the data frame is okay before we pass it on. For example, if something is wrong and the box (the LDPC codeword) is crushed, we would assume the chocolates inside could be damaged also. However, due to BCH the data frame could still be intact or recoverable. Once we open the box we see the BCH as the foil wrappers protecting the chocolates. If the BCH is okay, then the chocolates are okay. If the BCH is bad, then we have bad chocolates and an uncorrectable codeword error.

Currently we are collecting field data, and technicians are seeing correctable and uncorrectable codewords coming from LDPC and BCH FEC in DOCSIS 3.1 modems or field meters. However, an interesting phenomenon has occurred where it is very common to see up to 100% correctable LDPC codeword errors and zero uncorrectable BCH codeword errors. In a pre-DOCSIS 3.1 Reed-Solomon FEC environment this would be a big concern, because having so many correctable codeword errors is usually an indicator that uncorrectable codeword errors are immediately upon us. Not so in DOCSIS 3.1. In fact, it is very common to have up to 100% correctable LDPC codeword errors with zero uncorrectable BCH codeword errors. This is because LDPC is quite good at fixing errors and we see the accumulation of errors. In the box of chocolates analogy, consider the box to be very resilient, as is LDPC.

Once the cable modem is done decoding LDPC it moves on to BCH — our wrapper on the chocolate. If the final wrapper is good, we get no uncorrectable codeword errors. If there are problems, then we get uncorrectable errors. It is the uncorrectable codeword errors that we must concern ourselves with as these are subscriber impacting. Again, let's reinforce: in DOCSIS 3.1 it's okay to have very high levels of correctable codeword errors as long as uncorrectable codewords are non-existent or less than 1%. Once uncorrectable codeword errors increase the CMTS should reduce the modulation order.

Real-World Data

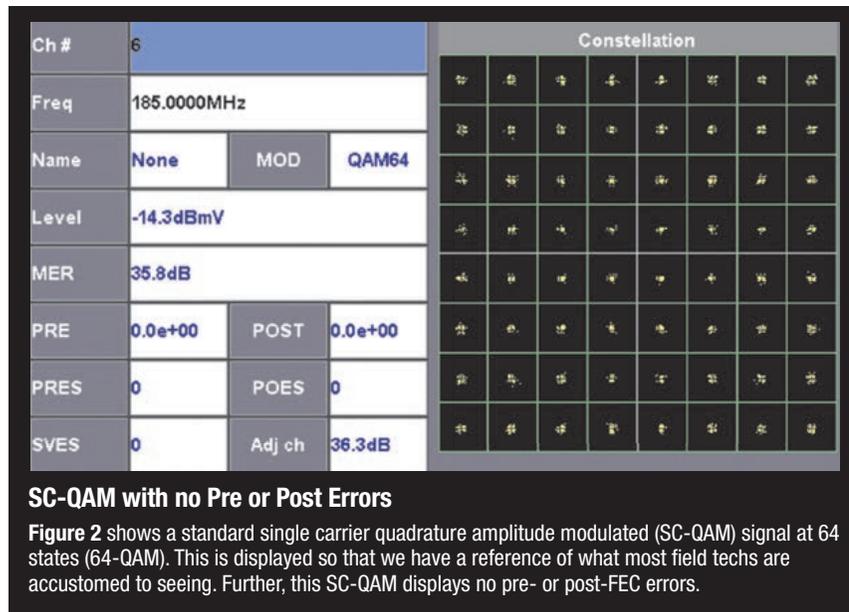Let's look at some real-world data to better help illustrate these points.

First let's understand the test setup as shown in Figure 1:
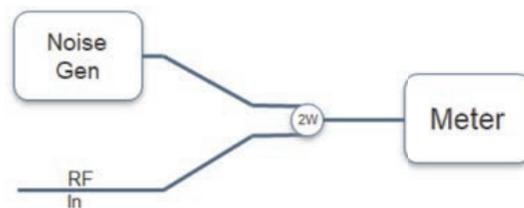
Figure 1 shows a test meter connected to a two-way splitter. The two-way splitter is connected to a cable plant (RF-in) and a broadband white Gaussian noise generator. The output of the noise generator can be increased during the testing in order to severely impair the cable plant.

Now let's look at Figure 2.

Ch #	6		
Freq	185.0000MHz		
Name	None	MOD	QAM64
Level	-14.3dBmV		
MER	35.8dB		
PRE	0.0e+00	POST	0.0e+00
PRES	0	POES	0
SVES	0	Adj ch	36.3dB

SC-QAM with no Pre or Post Errors

Figure 2 shows a standard single carrier quadrature amplitude modulated (SC-QAM) signal at 64 states (64-QAM). This is displayed so that we have a reference of what most field techs are accustomed to seeing. Further, this SC-QAM displays no pre- or post-FEC errors.

Next, we move to Figure 3.

Level (Avg)	2.3 dBmV	MER (Avg)		41.4 dB
Level (Max)	2.3 dBmV	MER (Std Dev)		0.9 dB
Level (Min)	2.3 dBmV	MER Percentile	02 %	39.5 dB
PLC Frequency	951 MHz	Subcarrier Bandwidth		50 kHz
OFDM Bandwidth	192 MHz	Active Subcarriers		3800

	Modulation (QAM)	Level (dBmV)	MER (dB)	C CWE	U CWE
PLC	16	2.3	41.0	1.00e+00	<1.00e-9
NCP	16		41.5	9.78e-01	<1.00e-9
Profile A	256		41.5	<1.00e-9	<1.00e-9
Profile B	1K		41.5	<1.00e-9	<1.00e-9
Profile C	4K		41.5	<1.00e-9	<1.00e-9
Profile D			N/A	N/A	N/A
Profile E			N/A	N/A	N/A

OFDM Channel with no Pre and Post Errors at 41.5 dB MER

Figure 3 shows an OFDM signal with three data profiles. Profile C is 4096-QAM (4k), profile B is 1024-QAM (1k) and profile A is 256-QAM (256). These are the three available profiles provided by the CMTS to the CMs. The modulation error ratio (MER) at the cable modem is 41.5 dB, which is a very good MER. At a near ideal MER we can observe correctable codeword errors (C CWE) and uncorrectable errors (U CWE) for each of the three profiles, A, B and C. There are no errors present (a value of <1.00e-9 is effectively zero errors).
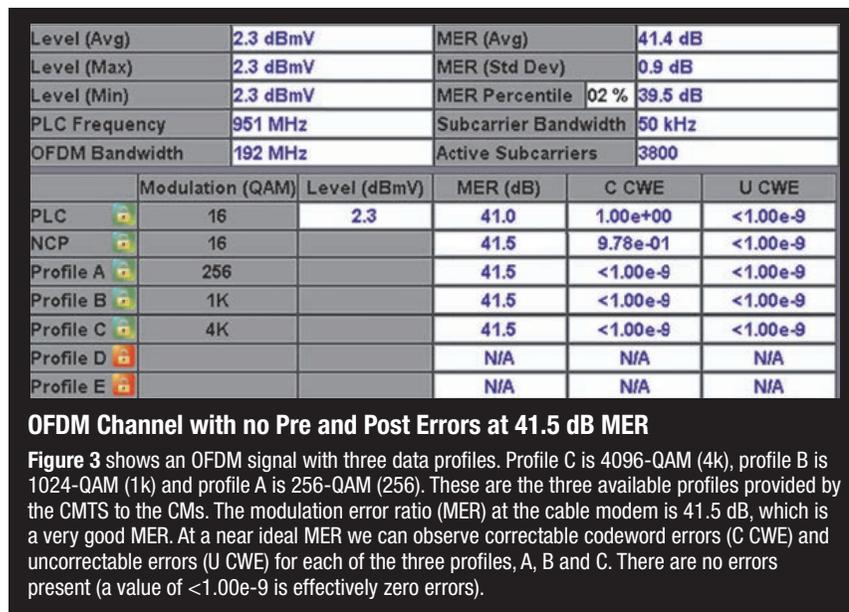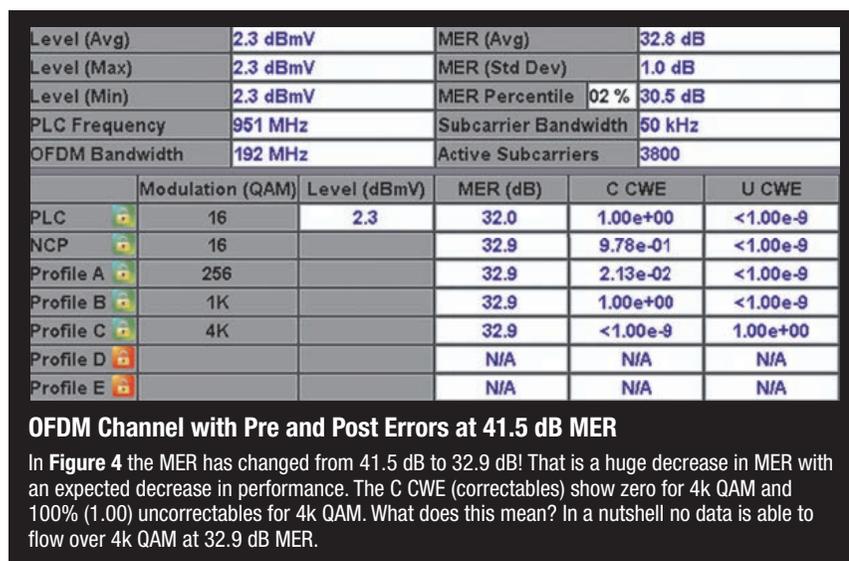
Figure 4 shows what happens when we inject noise from the test setup noise generator in order to simulate an RF impairment such as LTE interference.

Level (Avg)	2.3 dBmV	MER (Avg)		32.8 dB
Level (Max)	2.3 dBmV	MER (Std Dev)		1.0 dB
Level (Min)	2.3 dBmV	MER Percentile	02 %	30.5 dB
PLC Frequency	951 MHz	Subcarrier Bandwidth		50 kHz
OFDM Bandwidth	192 MHz	Active Subcarriers		3800

	Modulation (QAM)	Level (dBmV)	MER (dB)	C CWE	U CWE
PLC	16	2.3	32.0	1.00e+00	<1.00e-9
NCP	16		32.9	9.78e-01	<1.00e-9
Profile A	256		32.9	2.13e-02	<1.00e-9
Profile B	1K		32.9	1.00e+00	<1.00e-9
Profile C	4K		32.9	<1.00e-9	1.00e+00
Profile D			N/A	N/A	N/A
Profile E			N/A	N/A	N/A

OFDM Channel with Pre and Post Errors at 41.5 dB MER

In **Figure 4** the MER has changed from 41.5 dB to 32.9 dB! That is a huge decrease in MER with an expected decrease in performance. The C CWE (correctables) show zero for 4k QAM and 100% (1.00) uncorrectables for 4k QAM. What does this mean? In a nutshell no data is able to flow over 4k QAM at 32.9 dB MER.

Looking at the 1024-QAM (aka 1k QAM) profile we see that C CWE (correctables) are at 100%, while U CWE (uncorrectables) are basically at zero. This means most traffic is flowing over the 1k QAM profile. As mentioned previously it is okay to have very high correctable codewords, in this case 100% correctable codewords, as the resulting uncorrectable codewords are at zero (<1.00e-9).

Profile A (256-QAM) is showing pretty high levels of correctables (C CWE) as well, but zero uncorrectables. We can see similar events for the next codeword pointer (NCP) and the PHY link channel (PLC) profiles, which are both running at 16-QAM. Both experience minor correctable codeword errors, but never experience uncorrectable codeword errors until the MER is dropped to 14 dB (not shown in this article due to page constraints).

Summary

First, we can no longer use correctable codeword errors as a leading indicator of uncorrectable errors in DOCSIS 3.1. Correctable codeword errors are still valid on any SC-QAM channel.

Second, uncorrectable codeword errors are still one of the most valuable indicators of an impaired signal. Uncorrectable codeword errors will always tell you if the data going to a subscriber is being negatively impacted. If you see uncorrectable codeword errors this means that the cable modem is not able to repair the corrupted data and is then also discarding the data. If the data can be re-transmitted, as an email, the cable modem will ask the remote server to resend. If the data is voice packets, then it's keys in lava. Man, they are just gone.

Third, MER is a very good leading indicator in DOCSIS 3.1. In the accompanying figures, 2% MER values were displayed out of 4000 subcarriers. This means that the worst 2% of the individual MER measurements per subcarrier were displayed. However, we do not know which subcarriers they were. An even better measurement is MER per subcarrier which I provided an example of in my previous article in *Broadband Library* — https://broadbandlibrary.com/docsis-3-1-test/.

In conclusion there are some very important takeaways in test and measurement in DOCSIS 3.1 as discussed in this article. The future with DOCSIS 3.1 is very exciting.