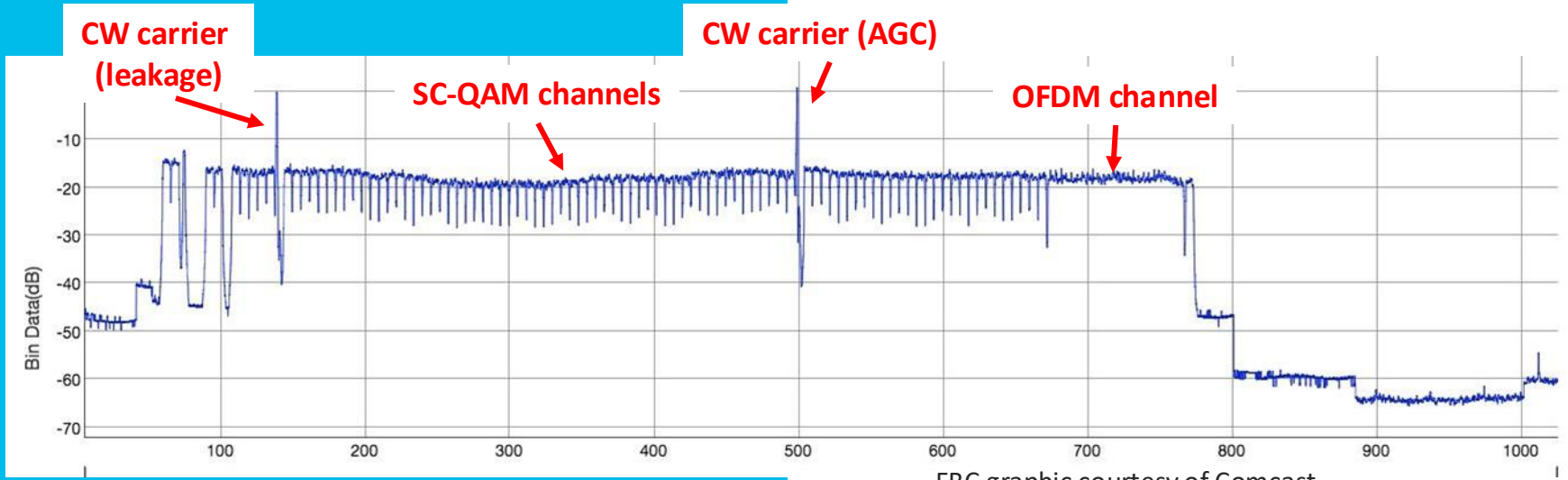
DOCSIS® 3.1 Downstream OFDM Field Measurements

Ron Hranac

- DOCSIS 3.1 downstream orthogonal frequency division multiplexing (OFDM) channels are quite different from DOCSIS 3.0 (and earlier) single carrier quadrature amplitude modulation (SC-QAM) channels.
- *How* can we measure OFDM channels, and *what* should we measure?



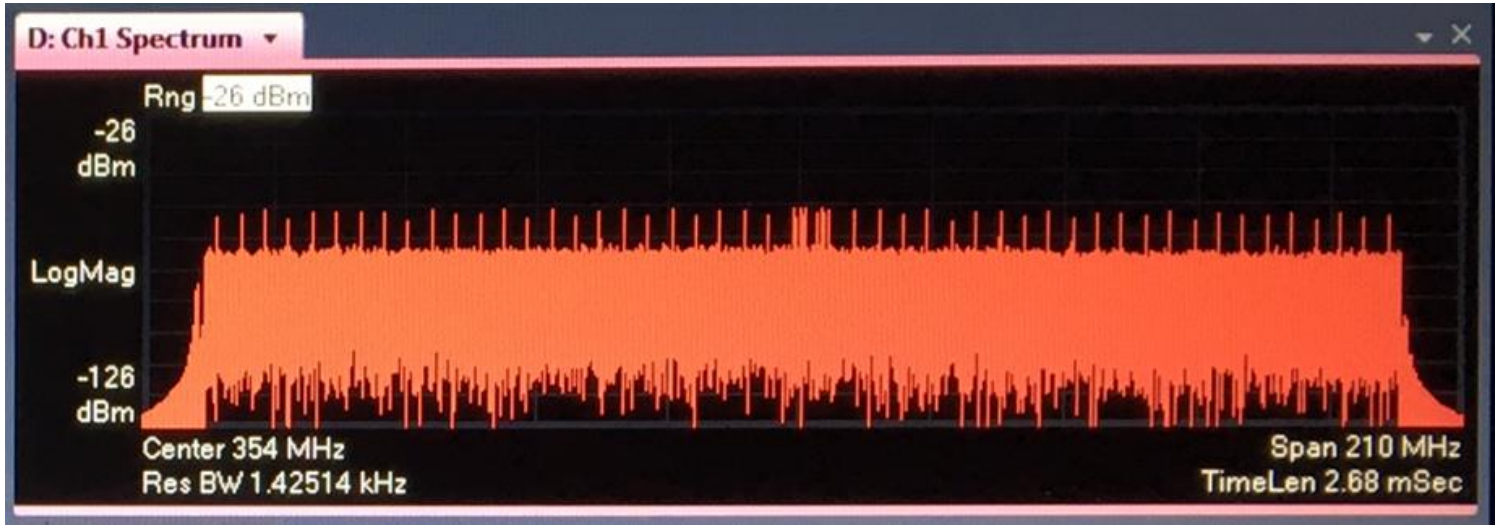
FBC graphic courtesy of Comcast

- The first thing needed is something with which to measure the DOCSIS 3.1 OFDM channel(s) carried on the network.
- Major test equipment manufacturers now have DOCSIS 3.1-capable field test instruments available.

Images courtesy of Deviser, Trilithic, VeEX, and Viavi,

- One should understand, at least from a high-level perspective, the basic characteristics of the OFDM channel.

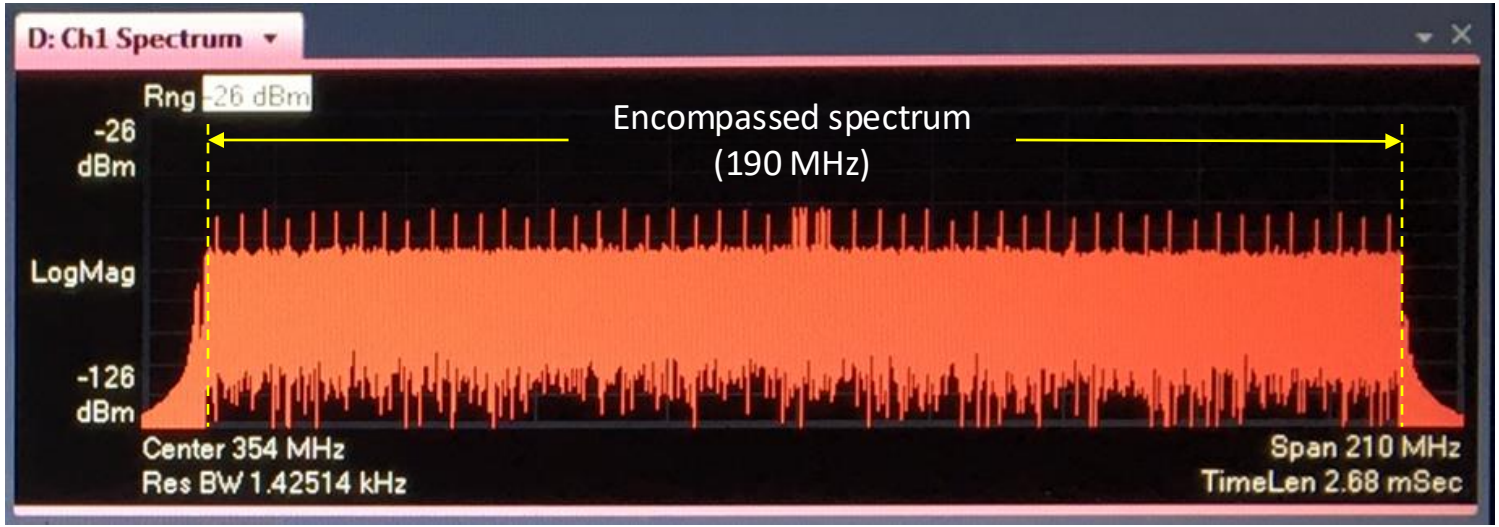
Anatomy of an OFDM channel



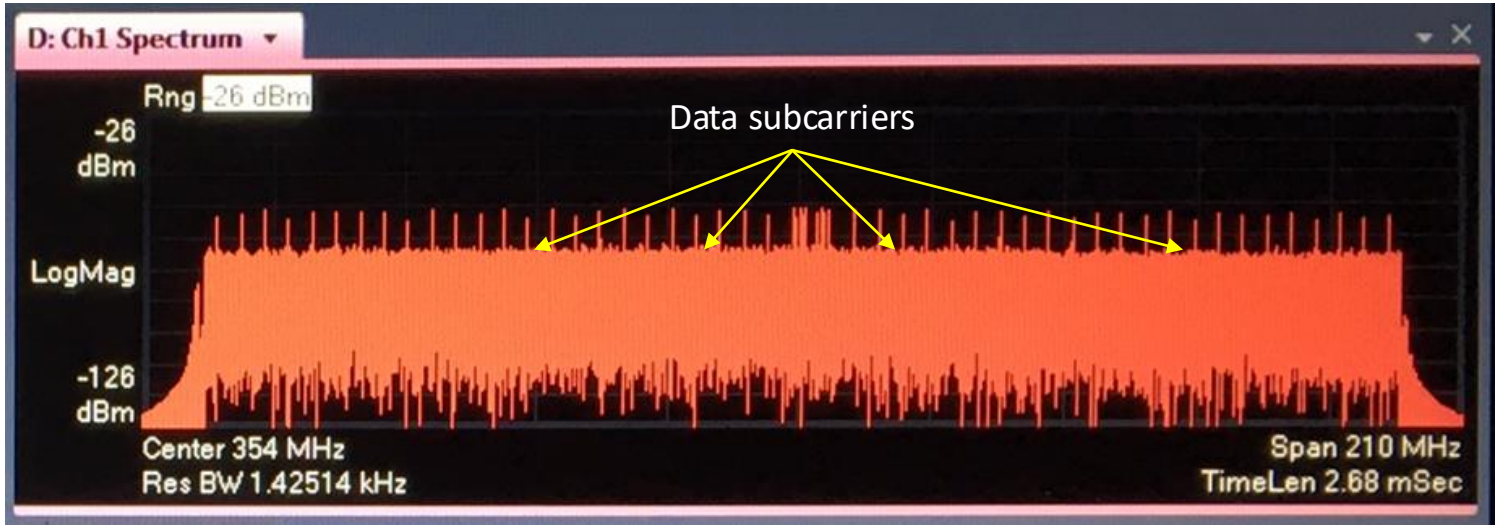
This is a spectrum analyzer screen shot of a 192 MHz-wide DOCSIS 3.1 downstream OFDM channel. Let’s take a closer look.

Anatomy of an OFDM channel

Anatomy of an OFDM channel

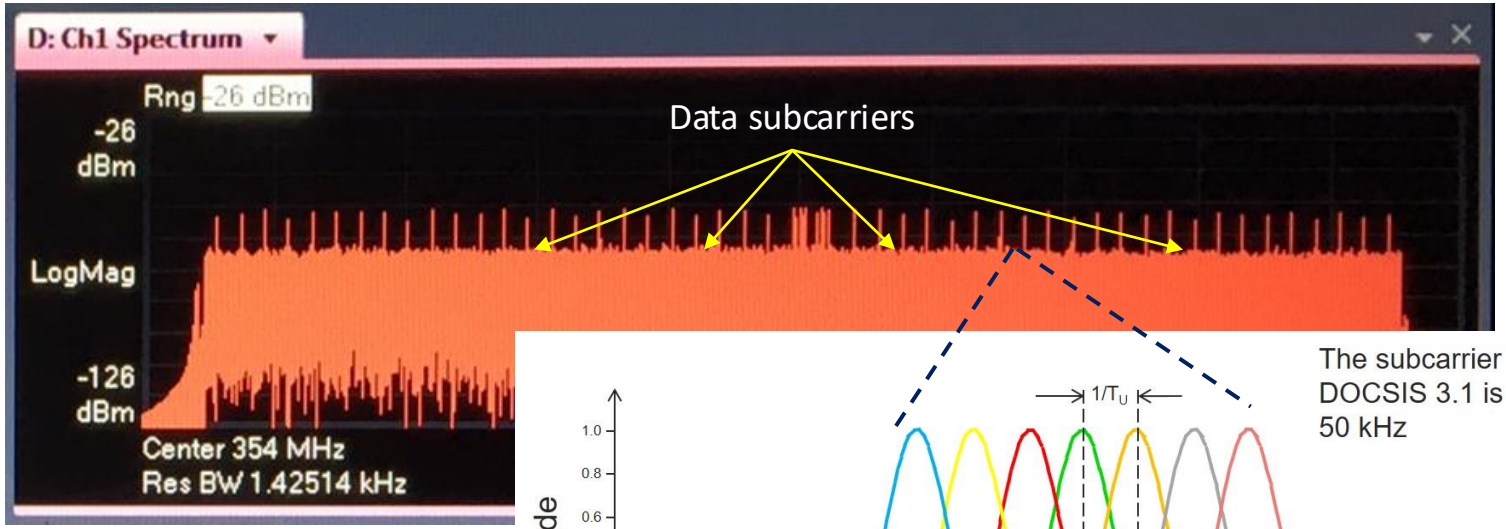


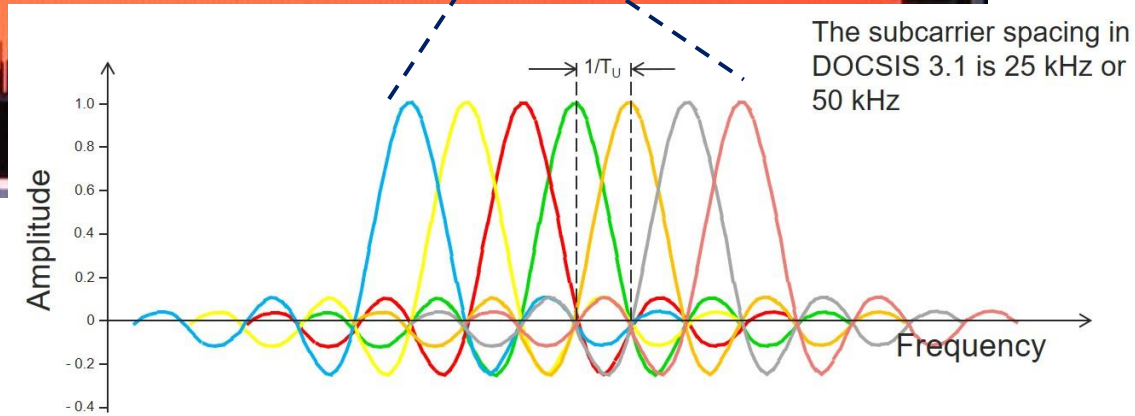
Anatomy of an OFDM channel



Anatomy of an OFDM channel

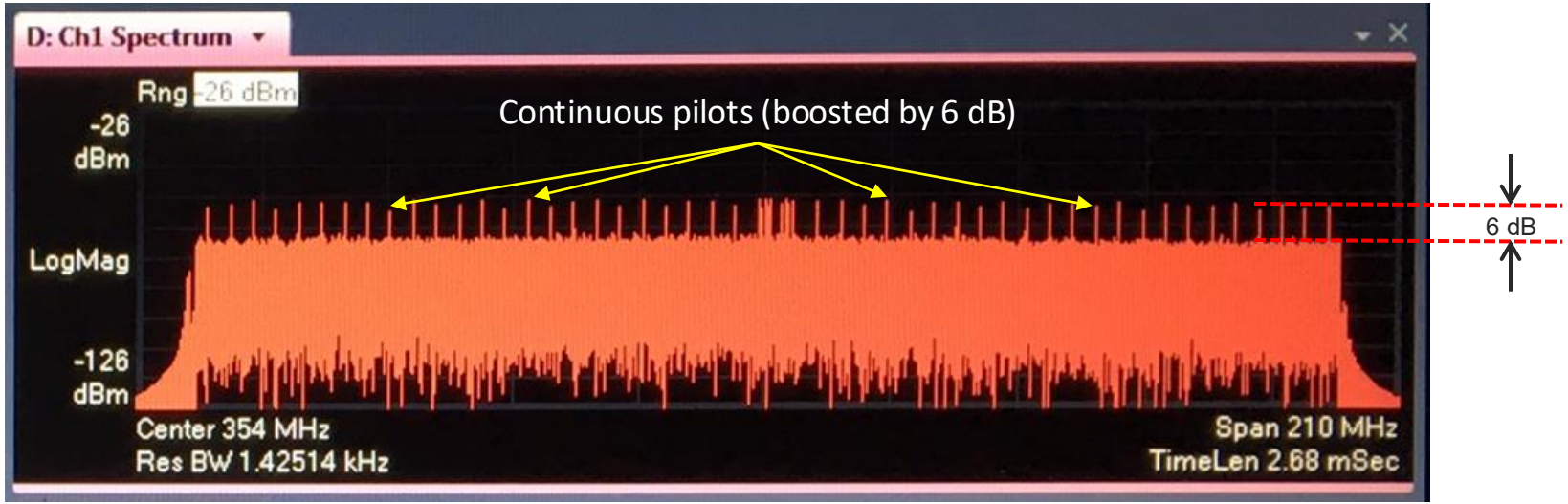
Active subcarriers in a 192 MHz-wide channel: 7600 subcarriers with 25 kHz spacing (called “8K FFT”) or 3800 subcarriers with 50 kHz spacing (called “4K FFT”)





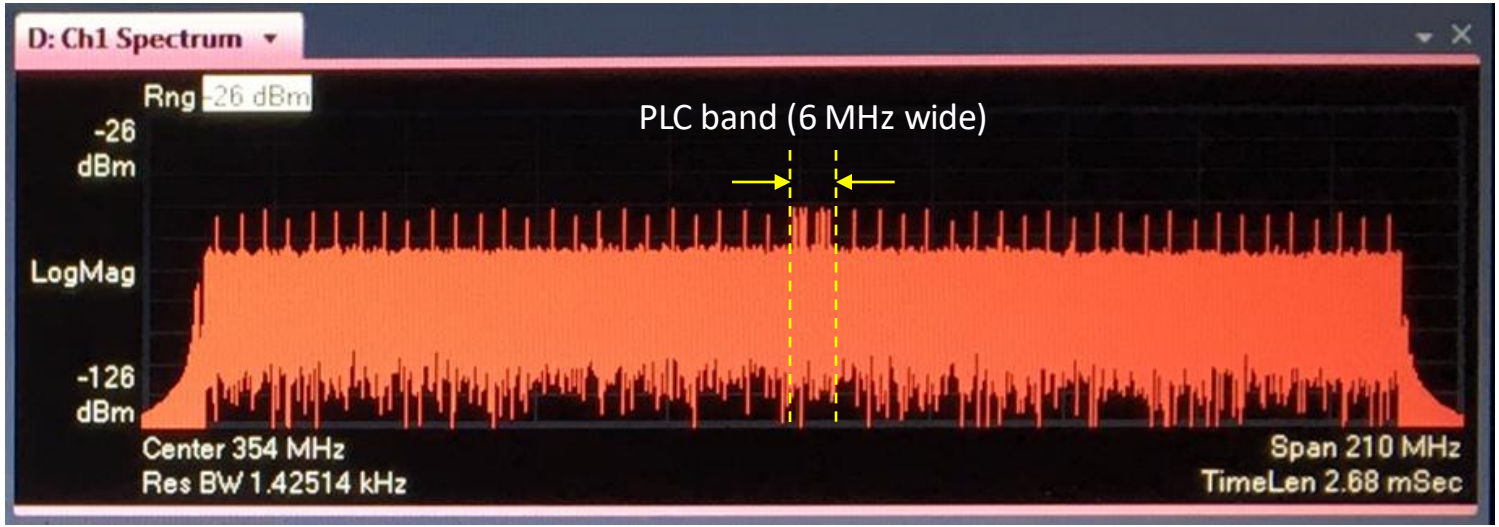
Each subcarrier is a narrow bandwidth QAM signal

Anatomy of an OFDM channel



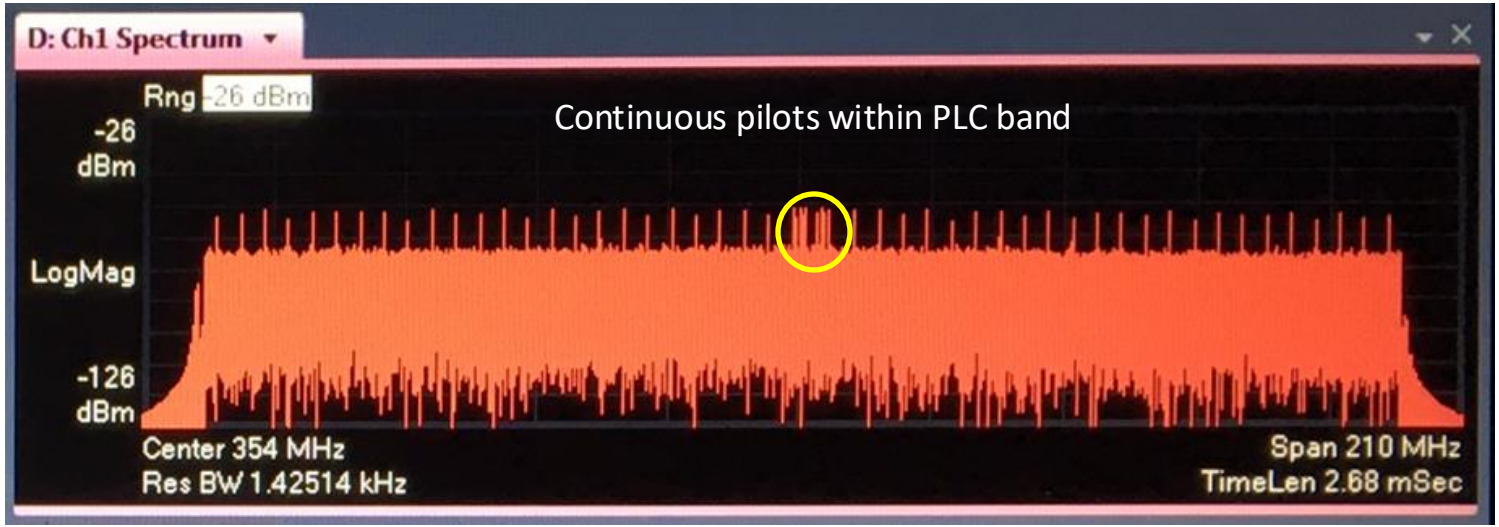
Continuous pilots always remain on the same frequencies, and are configured to be spread more or less uniformly throughout the OFDM channel. Another type of pilot called scattered pilots – which are also boosted by 6 dB – are not shown here (they change frequency throughout the OFDM channel).

Anatomy of an OFDM channel



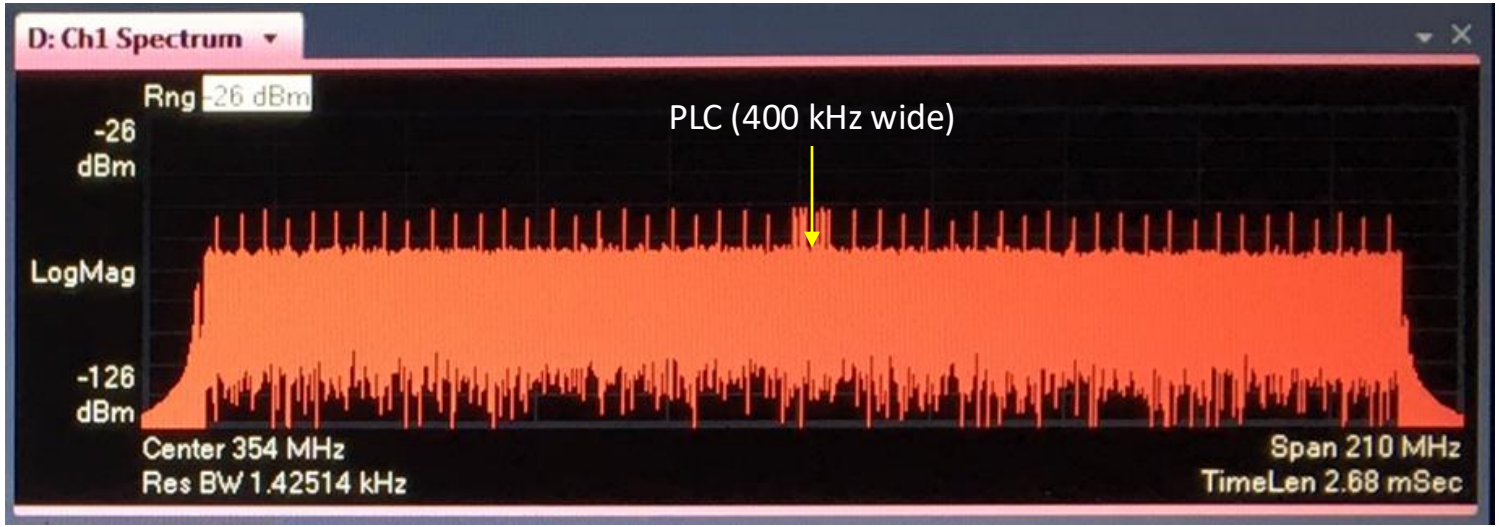
The PLC band is a 6 MHz-wide portion of the OFDM channel within which the PLC is centered. The PLC band cannot have any excluded subcarriers or exclusion bands.

Anatomy of an OFDM channel



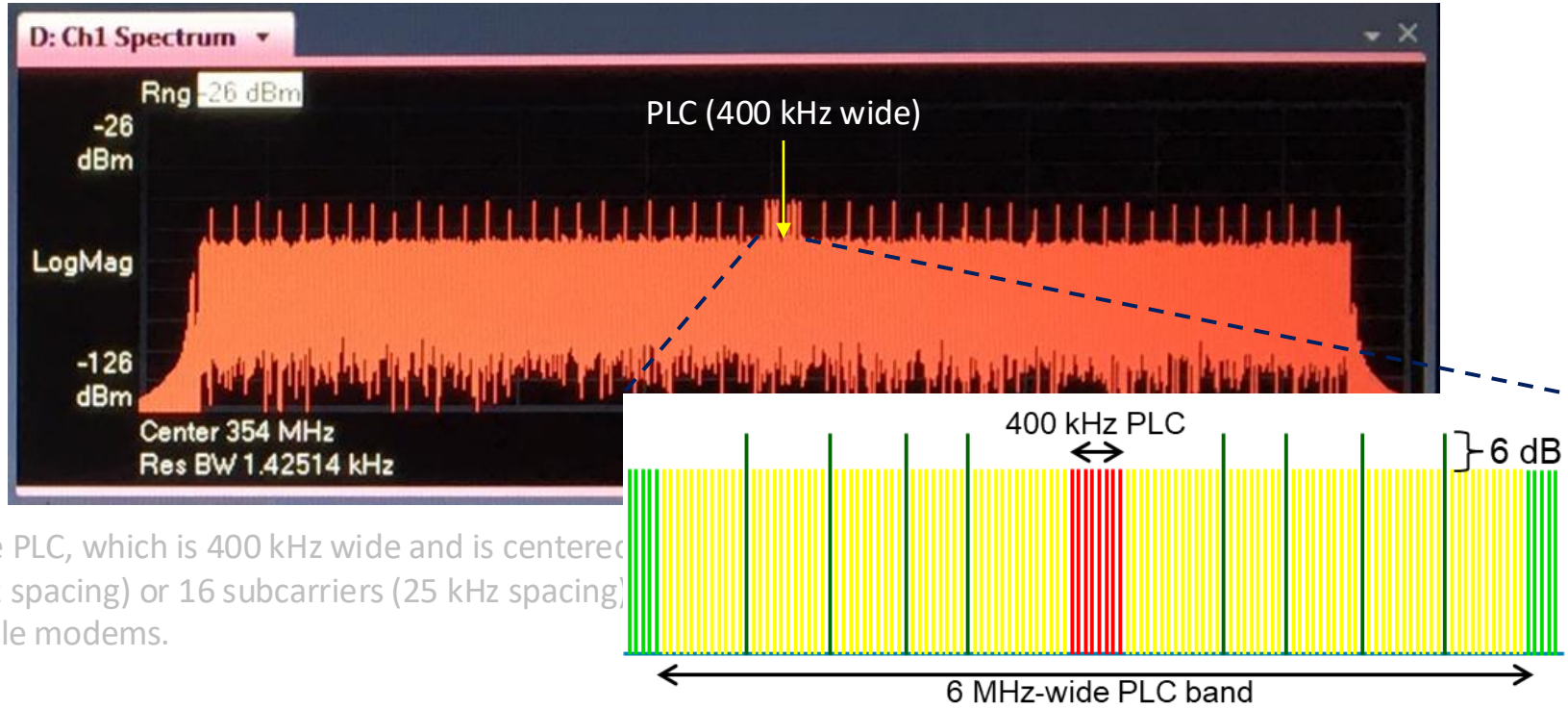
The continuous pilots in the PLC band have a unique pattern that tells the modem where the PLC is located. This pilot pattern is not user-adjustable; it is a fixed pattern defined in the DOCSIS 3.1 PHY Specification.

Anatomy of an OFDM channel



The PLC, which is 400 kHz wide and is centered in the 6 MHz-wide PLC band, comprises eight subcarriers (50 kHz spacing) or 16 subcarriers (25 kHz spacing), each using 16-QAM to convey physical layer parameters to the cable modems.

Anatomy of an OFDM signal



The PLC, which is 400 kHz wide and is centered
kHz spacing) or 16 subcarriers (25 kHz spacing)
cable modems.

- One should understand, at least from a high-level perspective, the basic characteristics of the OFDM channel.
- Next is to figure out what we should measure. Most of the metrics are familiar:
  - RF signal level
  - Error correction performance
  - Receive modulation error ratio (RxMER, often called just MER or sometimes SNR)

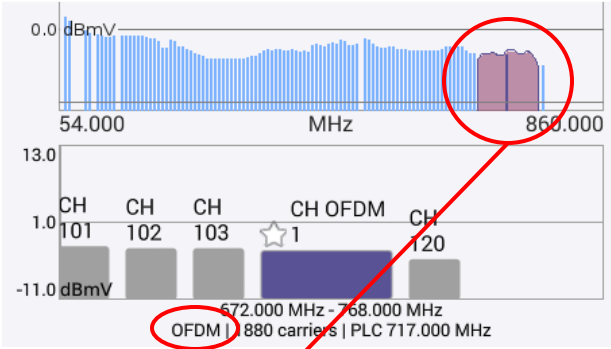
Test equipment setup

Follow the test equipment manufacturer’s instructions for setup and operation.

Note: Many of the screen captures on the following slides are from a Viavi OneExpert CATV signal analysis meter. Similar measurement functionality is available from other manufacturers’ products. This presentation is not meant to be an endorsement of any particular make/model of test equipment.

OFDM channel overview

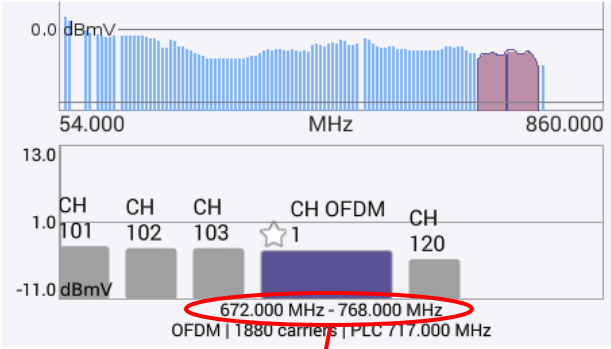
Confirm that the instrument is tuned to the OFDM channel to be measured.



- **Signal type:** OFDM

OFDM channel overview

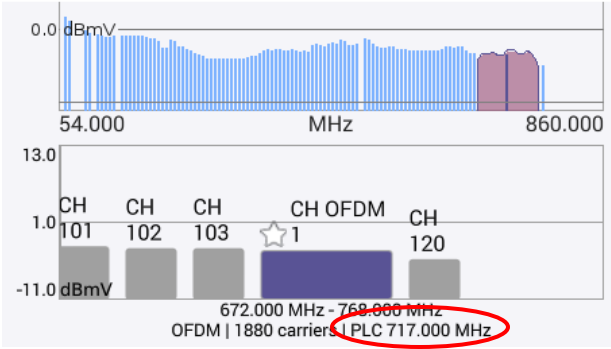
OFDM channel bandwidth can vary from a minimum of 24 MHz to a maximum of 192 MHz. A 96 MHz-wide signal is shown in this example.



- **Signal type:** OFDM
- **Channel bandwidth:** 672 MHz to 768 MHz (96 MHz)

OFDM channel overview

The PHY link channel (PLC) conveys physical layer information to the cable modems. Ideally, the PLC should be located on a frequency that is not susceptible to ingress and other interference.

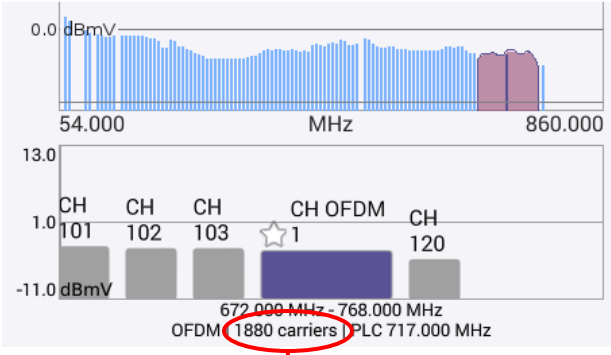


- **Signal type:** OFDM
- **Channel bandwidth:** 672 MHz to 768 MHz (96 MHz)
- **PLC frequency:** 717 MHz

OFDM channel overview

In this example, the 96 MHz-wide OFDM channel uses 50 kHz subcarrier spacing:

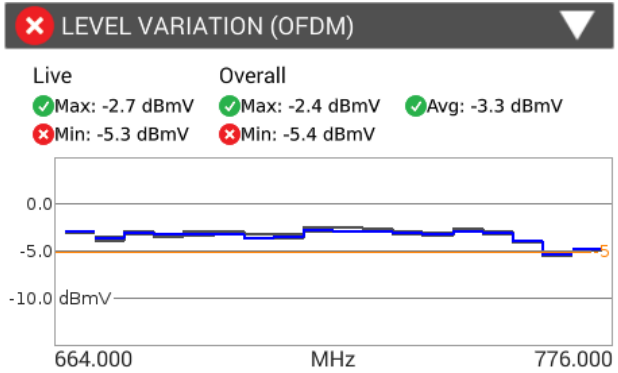
- Here, the 96 MHz channel bandwidth includes a 1 MHz guard band on each end of the channel, so encompassed spectrum is 94 MHz.
- 94 MHz/1880 subcarriers = 50 kHz per subcarrier.



- **Signal type:** OFDM
- **Channel bandwidth:** 672 MHz to 768 MHz (96 MHz)
- **PLC frequency:** 717 MHz
- **Number of subcarriers:** 1880 (50 kHz subcarrier spacing)

OFDM channel power (signal level)

OFDM channel power is the RF power per CTA channel (6 MHz bandwidth), which provides signal level information comparable to SC-QAM digital channel power.

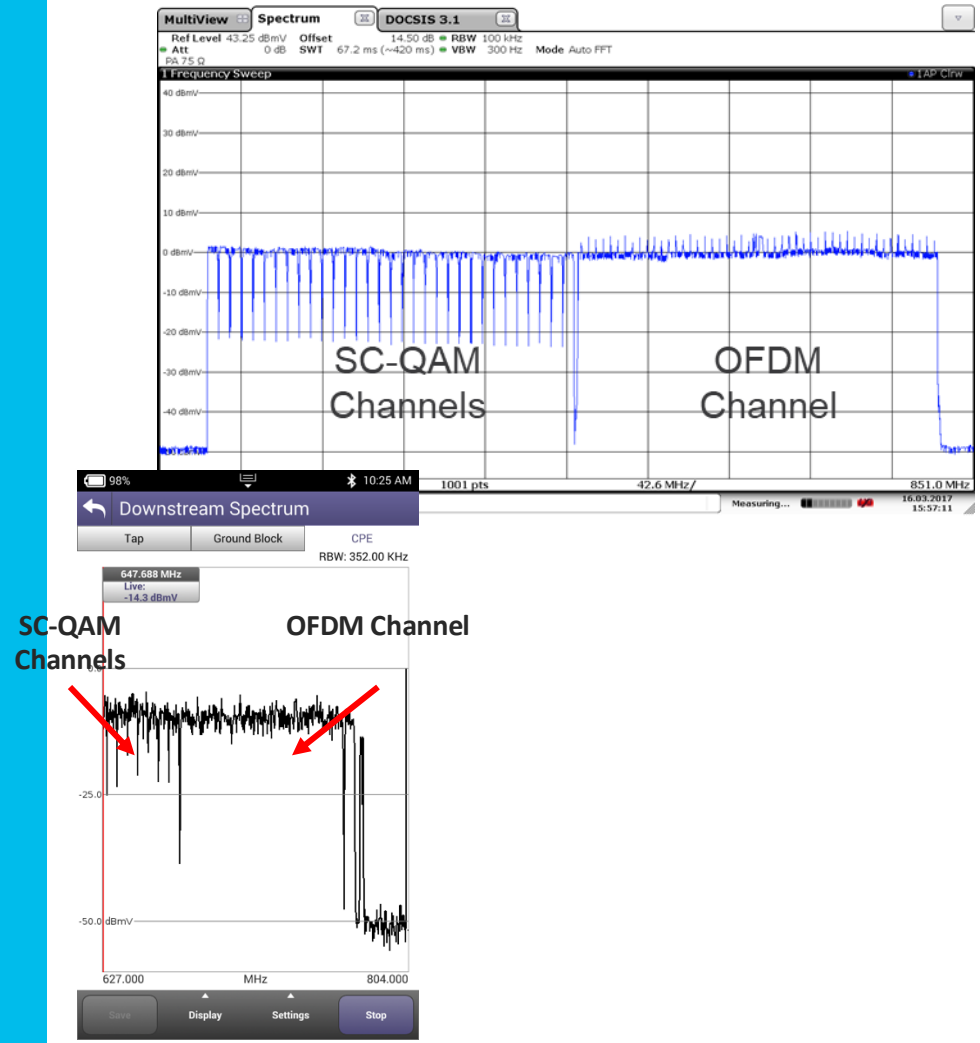


- **Average:** -3.3 dBmV
- **Minimum:** -5.3 dBmV
- **Maximum:** -2.7 dBmV

Per the DOCSIS 3.1 PHY Spec, the OFDM signal level at the cable modem input is supposed to be in the -15 dBmV to +15 dBmV range (power per 6 MHz).

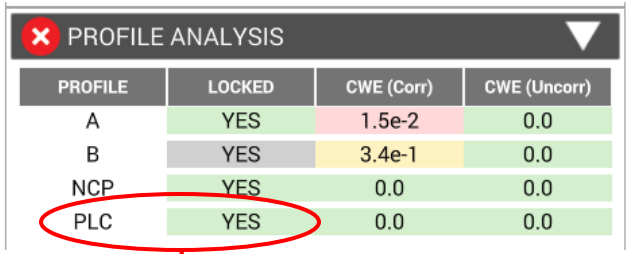
OFDM channel power (signal level)

In most cases, OFDM channel power should be set to the same power spectral density (PSD) as SC-QAM channels. In other words, the heights of the OFDM and SC-QAM “haystacks” as seen on a spectrum analyzer should be the same.



PHY link channel (PLC)

The test equipment must be locked to the PLC. If lock to the PLC cannot be achieved, then DOCSIS 3.1 operation won't be possible.

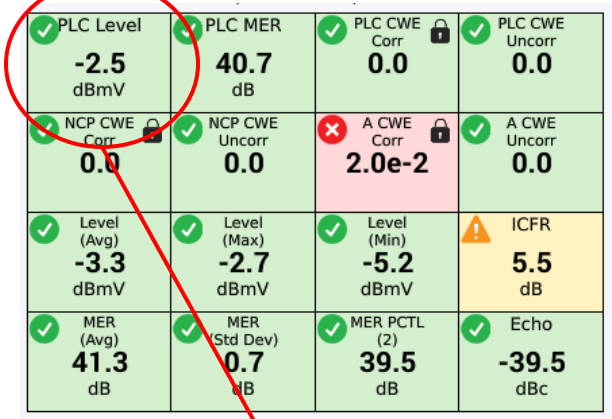


PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	1.5e-2	0.0
B	YES	3.4e-1	0.0
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

- **PLC locked** Yes

PHY link channel (PLC)

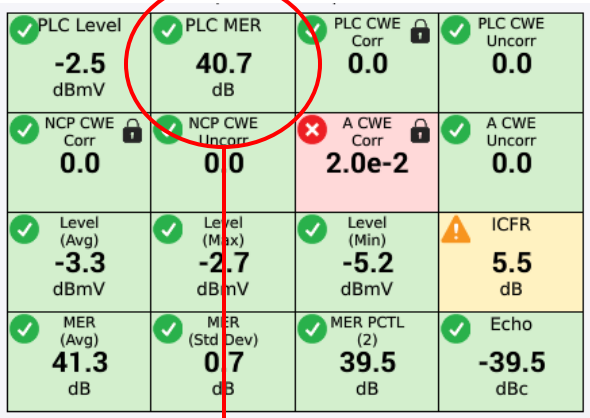
The PLC signal level should be ≥ -15 dBmV.



- **PLC level:** -2.5 dBmV

PHY link channel (PLC)

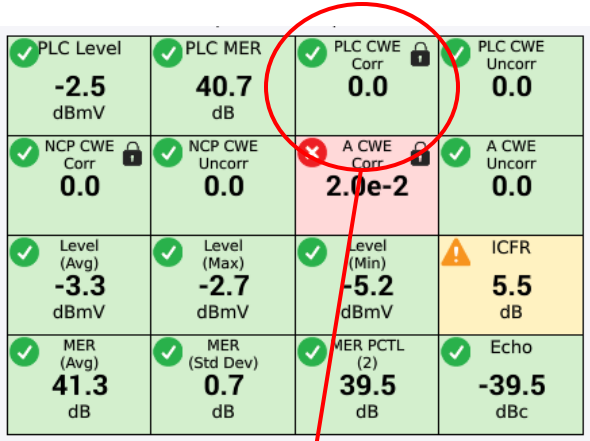
The PLC, which is 16-QAM, should have a reported RxMER that is 15 dB or higher. Practically speaking, the PLC's RxMER likely will be similar to the OFDM signal's average per-subcarrier RxMER.



- **PLC level:** -2.5 dBmV
- **PLC RxMER:** 40.7 dB

PHY link channel (PLC)

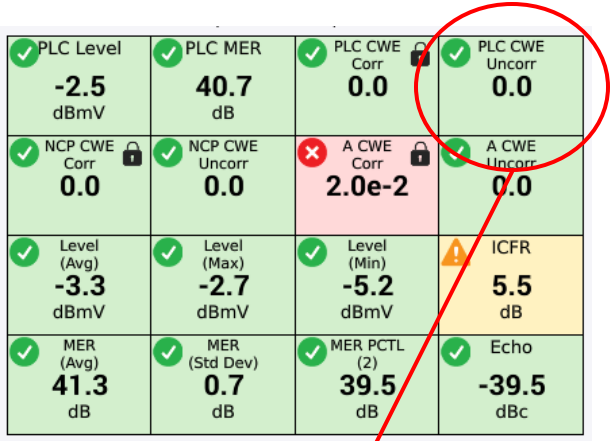
If the instrument reports any **correctable codeword errors**, they can be ignored.



- **PLC level:** -2.5 dBmV
- **PLC RxMER:** 40.7 dB
- **PLC correctable codeword errors:** 0

PHY link channel (PLC)

There should not be any **uncorrectable codeword errors**.

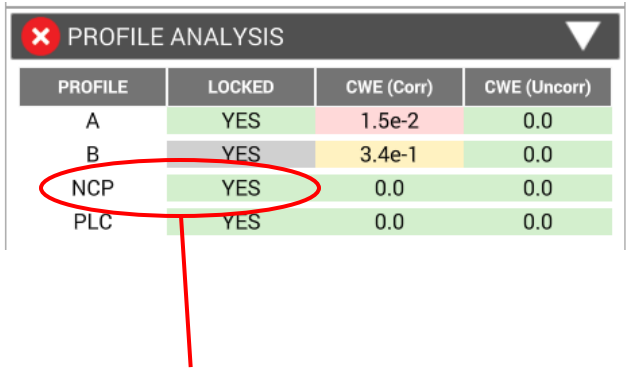


- **PLC level:** -2.5 dBmV
- **PLC RxMER:** 40.7 dB
- **PLC correctable codeword errors:** 0
- **PLC uncorrectable codeword errors:** 0

Next codeword pointer (NCP)

The test equipment must be locked to the NCP.

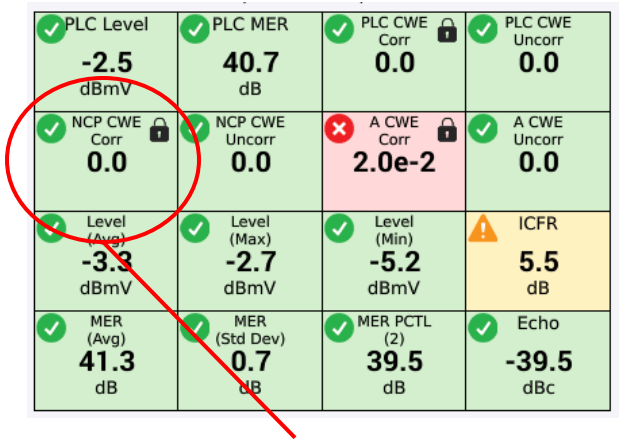
- The NCP points to the start of a codeword
- NCPs are necessary because an OFDM symbol can contain codewords for several profiles; codewords can continue from one symbol to the next; profiles can have different – and variable – QAM values



- **NCP locked:** Yes

Next codeword pointer (NCP)

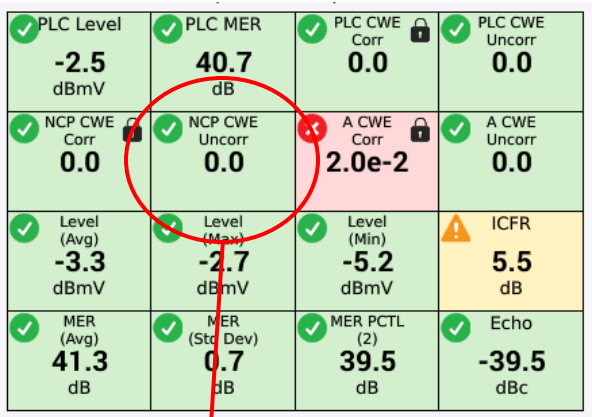
If the instrument reports any **correctable codeword errors**, they can be ignored.



- **NCP correctable codeword errors:** 0

Next codeword pointer (NCP)

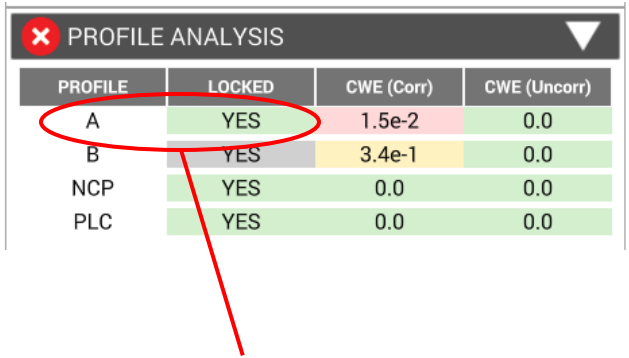
There should not be any **uncorrectable codeword errors**.



- NCP correctable codeword errors: 0
- **NCP uncorrectable codeword errors:** 0

Profile A

- The test equipment must be locked to Profile A
- This is the boot profile; all modems must be able to receive Profile A. This profile typically uses a lower, more robust modulation order such as 256-QAM.

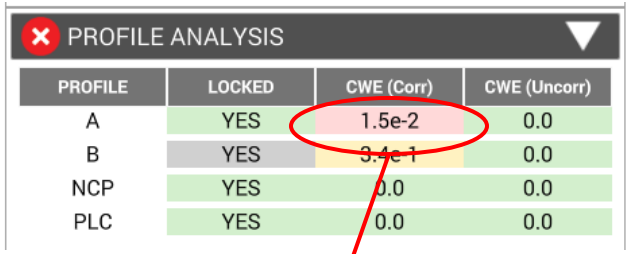


PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	1.5e-2	0.0
B	YES	3.4e-1	0.0
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

- **Profile A locked:** Yes

Profile A

If the instrument reports any **correctable codeword errors**, they can be ignored.



- **Profile A locked:** Yes
- **Profile A correctable codeword errors:** 1.5e-2

Profile A

There should not be any **uncorrectable codeword errors**.

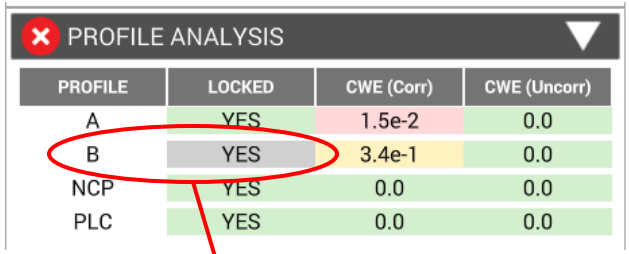
PROFILE ANALYSIS

PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	1.5e-2	0.0
B	YES	3.4e-1	0.0
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

- **Profile A locked:** Yes
- **Profile A correctable codeword errors:** 1.5e-2
- **Profile A uncorrectable codeword errors:** 0

Profile B

- If higher profiles are used, the test equipment must lock to them, too.
- Profiles other than Profile A use a higher modulation order, such as 1024-QAM or 4096-QAM.



- **Profile B locked:** Yes

Profile B

If the instrument reports any **correctable codeword errors**, they can be ignored.

PROFILE ANALYSIS

PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	1.5e-2	0.0
B	YES	3.4e-1	0.0
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

- **Profile B locked:** Yes
- **Profile B correctable codeword errors:** 3.4e-1

Profile B

There should not be any **uncorrectable codeword errors**.

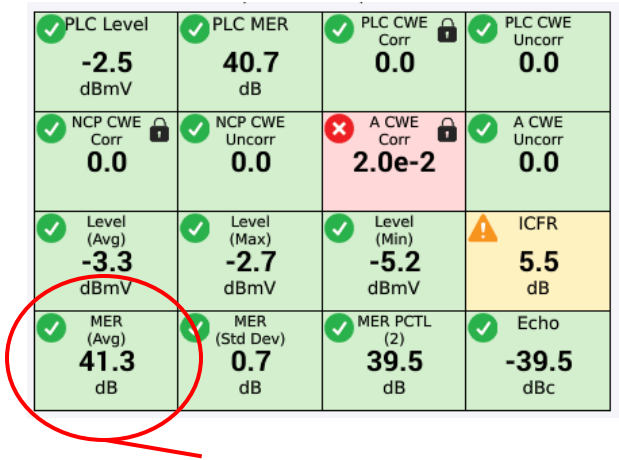
PROFILE ANALYSIS

PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	1.5e-2	0.0
B	YES	3.4e-1	0.0
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

- **Profile B locked:** Yes
- **Profile B correctable codeword errors:** 3.4e-1
- **Profile B uncorrectable codeword errors:** 0

Receive modulation error ratio

Average RxMER per subcarrier should meet or exceed the recommended minimum value for the desired modulation orders (see next slide).



- **Average RxMER per subcarrier:** 41.3 dB

RxMER: What does it take?

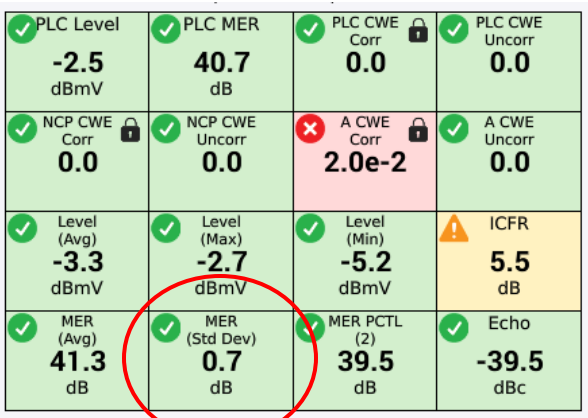
The values shown in this table include 5 dB to 6 dB or so of operational headroom above the respective RxMER failure thresholds.

Example DOCSIS 3.1 recommended RxMER

Modulation order	RxMER
256-QAM	≥ 29~30 dB
512-QAM	≥ 31~33 dB
1024-QAM	≥ 34~36 dB
2048-QAM	≥ 37~39 dB
4096-QAM	≥ 40~42 dB

Receive modulation error ratio

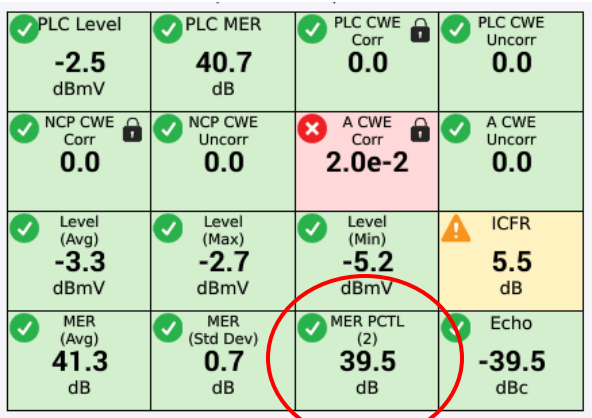
The standard deviation should be less than 2 dB, but 1 dB or less is even better.



- Average RxMER per subcarrier: 41.3 dB
- **RxMER standard deviation:** 0.7 dB

Receive modulation error ratio

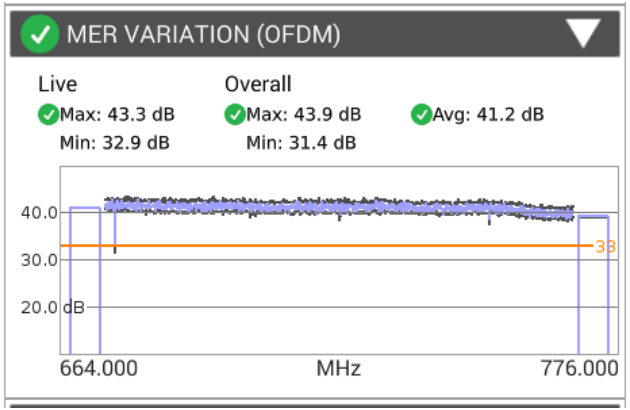
- Good engineering practice suggests that this value be greater than 35 dB.
- "RxMER 2nd percentile" means that 98% of the subcarriers have higher RxMER than what is shown.



- **Average RxMER per subcarrier:** 41.3 dB
- **RxMER standard deviation:** 0.7 dB
- **RxMER 2nd percentile:** 39.5 dB

Receive modulation error ratio

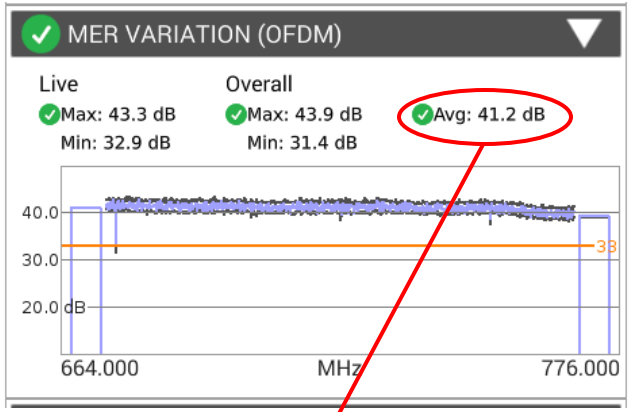
This graph shows RxMER (in dB) on the vertical axis, and frequency (in MHz) on the horizontal axis, for the OFDM channel being measured.



- **Graphical view of RxMER per subcarrier**

Receive modulation error ratio

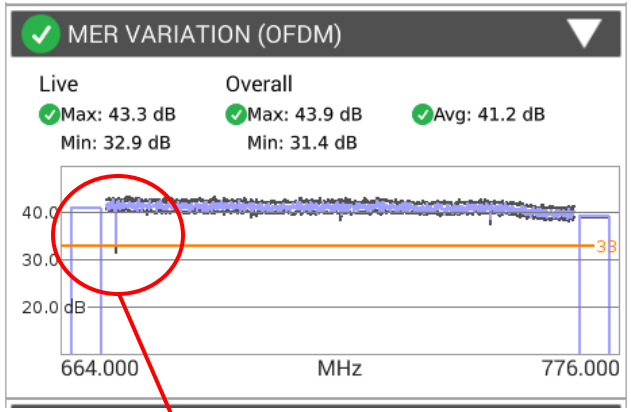
As before, the average RxMER per-subcarrier should meet or exceed the recommended minimum value for the desired modulation orders.



- Graphical view of RxMER per subcarrier
- **Average RxMER per subcarrier:** 41.2 dB

Receive modulation error ratio

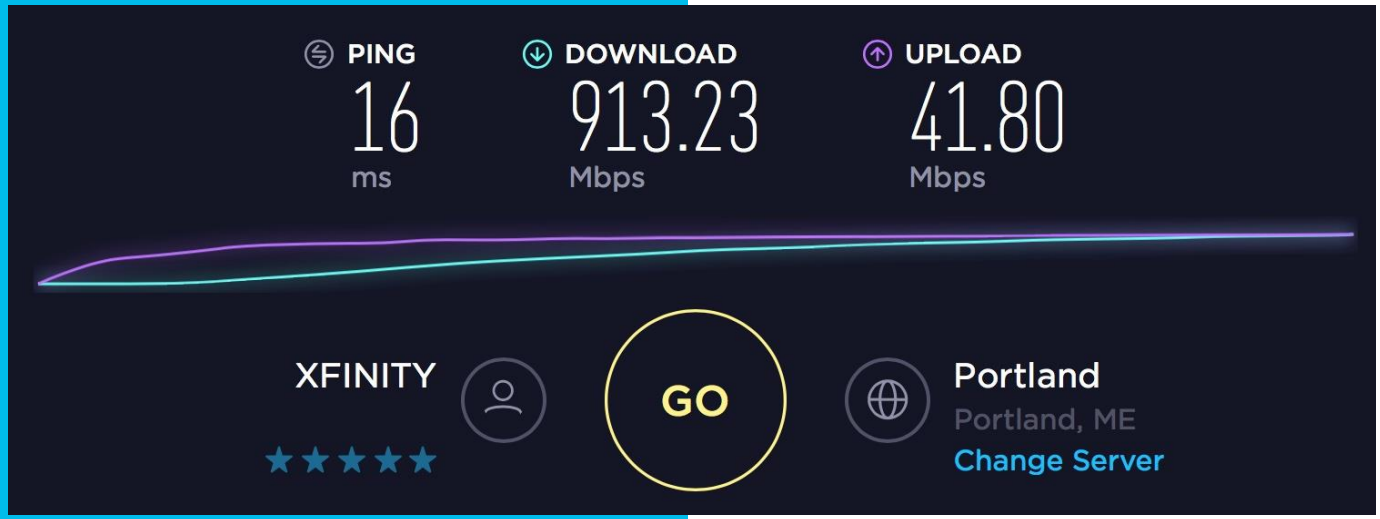
Here the graph shows the RxMER in a small part of the OFDM signal's lower frequency range is about 32 dB, indicating the possible presence of some kind of narrowband interference.



- Graphical view of RxMER per subcarrier
- Average RxMER per subcarrier: 41.2 dB
- **Note lower than average RxMER in this part of OFDM signal; possible ingress**

The measurement results highlighted in this presentation indicate a healthy DOCSIS 3.1 OFDM signal

A successful speed test is the frosting on the cake!*



*Note: A 96 MHz-wide DOCSIS 3.1 OFDM channel bonded with 24 DOCSIS 3.0 SC-QAM channels provides a gross data speed of about 1.6 Gbps to 1.7 Gbps, which can be used as the basis for gigabit-class service.

Summary

- DOCSIS 3.1-compatible field test equipment is now readily available
- The test equipment must be locked to the PLC, NCP, Profile A (and higher profiles, if used)
- Because of how LDPC FEC works, correctable codeword errors can be ignored
- There should not be any uncorrectable codeword errors
- PLC RxMER should be 15 dB or higher, and the PLC ideally should be on a frequency free from interference
- Average RxMER per-subcarrier should be at or above the recommended values for the modulation orders in use
- OFDM channel power (the RF power per 6 MHz) should be about the same as digital channel power on SC-QAM channels: -15 dBmV to +15 dBmV at the modem input

Resources

- Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer Specification – www.cablelabs.com
- Downey, J., “DOCSIS 3.1 Downstream Early Lessons Learned.” 2017 SCTE Cable-Tec Expo Proceedings
- Druse, S., Miller, J., “DOCSIS 3.1 Leaves The Lab And Hits The Field With Midco.” 2016 SCTE Cable-Tec Expo proceedings
- Flask, R., “Testing and turn-up of DOCSIS 3.1 services in the HFC network from a field and maintenance technician perspective.” 2016 SCTE Cable-Tec Expo proceedings
- Salinger, J., “DOCSIS® 3.1 – Experiences from Early Deployments.” 2016 SCTE Cable-Tec Expo proceedings
- SCTE – Society for Broadband Professionals, Autumn Lecture 2016 video: “DOCSIS 3.1: An Overview, by Ron Hranac, Cisco” https://www.youtube.com/watch?v=ZwKuPZVh19Y