DOCSIS 3.1
Application Note

Products:

- R&S®CLGD
- R&S®FSW

For cable TV, the "last mile" to the connection at the home is the bottleneck that prevents higher data rates. The last mile is made up of optical fiber and coaxial cables, amplifiers and electrical/optical converters. This mix of optical fiber and coaxial cables is known as a hybrid fiber coax (HFC) network. One option for cable network providers to maximize both the downstream (DS) and upstream (US) data throughput using the existing cable TV network, but without making expensive changes to the HFC network infrastructure, is to employ the data over cable service interface specification (DOCSIS) 3.1.

This Application Note discusses the fundamental technological advances of DOCSIS 3.1 and presents measurement solutions from Rohde & Schwarz.

Application Note

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1 Introduction

1.1 Background

Many cable providers have expanded their offering over the past few years. They now offer telephone and Internet in addition to conventional cable TV. These are called "triple play services".

The expanding markets for cloud computing, IP-TV, time-shifted TV using media libraries and video-on-demand via streaming platforms (e.g. Netflix) have fed the rapid rise in demand for more bandwidth. This is compounded by customer demand for viewing videos in high definition (HD). And with 4K we are seeing a new trend toward even higher picture resolution, requiring even more bandwidth.

For cable TV, the "last mile" to the connection at the home is the bottleneck that prevents higher data rates. The last mile is made up of optical fiber and coaxial cables, amplifiers and electrical/optical converters. This mix of optical fiber and coaxial cables is known as a hybrid fiber coax (HFC) network. One option for cable network providers to maximize both the downstream (DS) and upstream (US) data throughput using the existing cable TV network, but without making expensive changes to the HFC network infrastructure, is to employ the data over cable service interface specification (DOCSIS) 3.1.

The DOCSIS standard was developed by the non-profit consortium Cable Labs and ratified in mid-1997. DOCSIS specifications include the complete communications infrastructure for IP connections, various layers and bidirectional data transmission over the cable TV network. Development on the standard has continued since its publication. Features such as the improvement of the upstream performance, channel aggregation and the dynamic quality of service for Internet telephony (voice over cable) have been introduced.

In October 2013, Cable Labs published the latest version, DOCSIS 3.1. DOCSIS 3.1 offers significant technological advances over its predecessors. However, these previous versions remain as part of the DOCSIS 3.1 specification, which means that network components must remain backward compatible. This Application Note discusses the fundamental technological advances and provides a first look at measurements.

1.2 Components of the Cable TV Network

All available signals in the cable TV network are fed in at the headend of the cable network provider. The television signal modulator as well as the cable modem termination system (CMTS) are located there.

The CMTS enables the high-speed data services and provides coverage to several thousand end customers, depending on the configuration. The cable modems (CM) found in homes serve as the counterpoint to the CMTS in the headend.

The CMTS forms the interface to the IP-based network over the Internet. It modulates the data from the Internet (downstream modulator) for transmission to homes and receives the upstream data from homes (upstream demodulator). The CMTS additionally manages the load balancing, error correction parameters and the class of service (CoS). The CoS management makes it possible to assign higher priority to specific CMs.

Signals from the headend are distributed optically to within the vicinity of individual homes, where the optical signals are converted to electrical signals at the terminating points. The electrical signals are then distributed to the various homes via the existing 75 ohm coaxial cables. The frequency-based attenuation on these coaxial cables causes the signal-to-noise ratio (SNR) to decrease as the frequency increases. As a result, the maximum data rate is limited. Electrical signals transmitted over coaxial cables must be amplified. The amplifiers used for this purpose are suited to a specific frequency range. In addition, the upstream and downstream must occur over the same physical connection. Optical fiber cables use separate fibers for the upstream and the downstream. The coaxial connection between the CMTS and the CMs branches off in a tree structure. Each CM's reception conditions depend in part on its position in the cable TV network.

A CMTS transmits the same data to all CMs located along the same section of cable (one-to-many communications). A CM needing to transmit data must first send a request to the CMTS, after which it can transmit at the time assigned to it. A request/grant mechanism exists between the CMTS and the CMs. No direct communications is possible between the individual CMs.

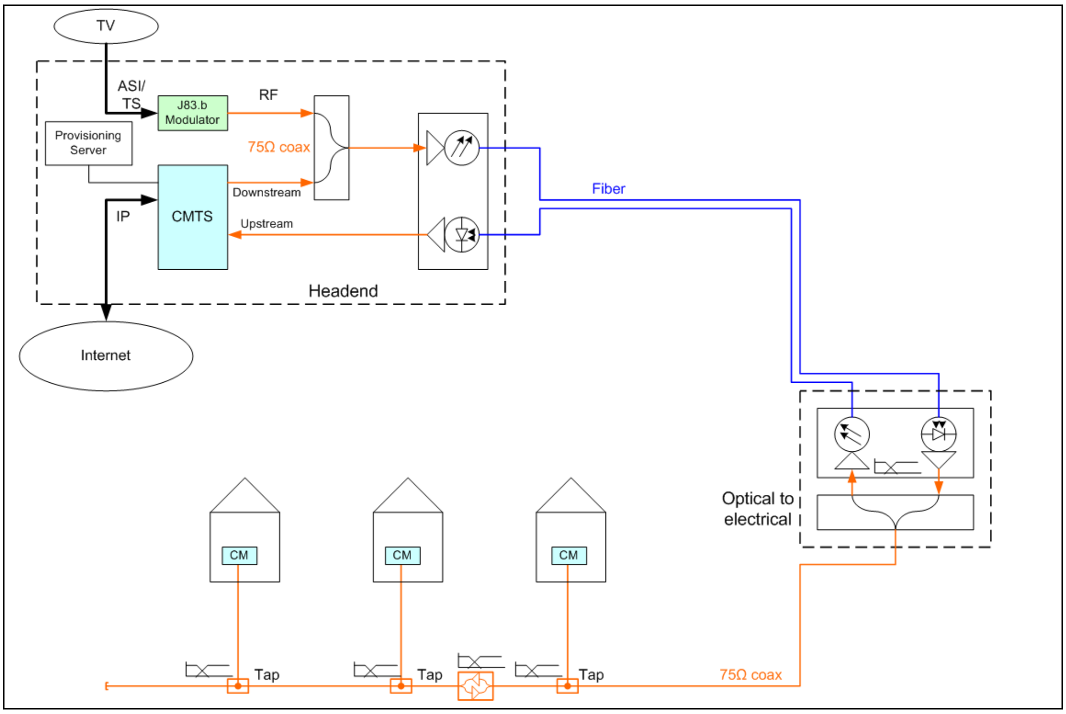


Fig. 1: Schematic diagram of the cable TV network.

2 DOCSIS 3.1 – Technical Foundation

2.1 Frequency Range and Bandwidth

With DOCSIS 3.1, the frequency range for the downstream is expanded to 1218 MHz in the initial phase and to 1794 MHz in the final phase. The channel bandwidth in the downstream can be between 24 MHz and 192 MHz. At a channel bandwidth of 192 MHz, the actual transmission is limited to 190 MHz in order to protect the adjacent channels. This 190 MHz is known as the encompassed spectrum. The DOCSIS 3.1 specification requires cable modems to cover the frequency range of 258 MHz to 1218 MHz for the downstream as well as to receive two 192 MHz channels in parallel. Support to 1794 MHz is optional.

The upstream lies in the lower frequency range and extends to a maximum of 204 MHz. The channel bandwidth of the upstream is scalable between 6.4 MHz and 96 MHz. At a channel bandwidth of 96 MHz, the encompassed spectrum is 95 MHz.

The split between downstream and upstream cannot simply be changed in an existing network because the network components being used must be configured appropriately.

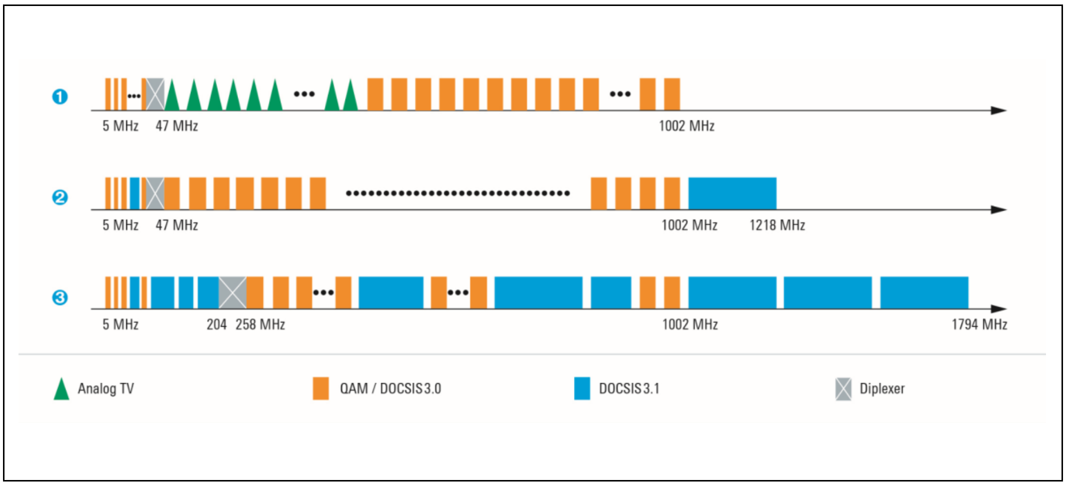


Fig. 2: ❶ Current channel assignment, ❷ channel assignment with initial phase of DOCSIS 3.1, ❸ channel assignment with final phase of DOCSIS 3.1.

2.2 Orthogonal Frequency Division Multiplex (OFDM)

DOCSIS 3.1 uses OFDM to provide an optimal adjustment to the transmission channel characteristics in spite of the high bandwidths. Frequent mention is also made of COFDM, where C stands for "coded" and refers to the use of a forward error correction (FEC).

OFDM is a complex modulation method that uses a number of narrowband subcarriers. All subcarriers are transmitted simultaneously, called the OFDM symbol. The OFDM symbols are broken up with a guard interval, known as the cyclic prefix (see Section 2.3). OFDM is used by most modern terrestrial transmission methods (mobile radio and terrestrial TV). The transmit signal is the sum of a number of digitally modulated carriers. Compared to the single carrier modulation, the subcarriers are transmitted with a relatively long symbol duration (FFT duration).

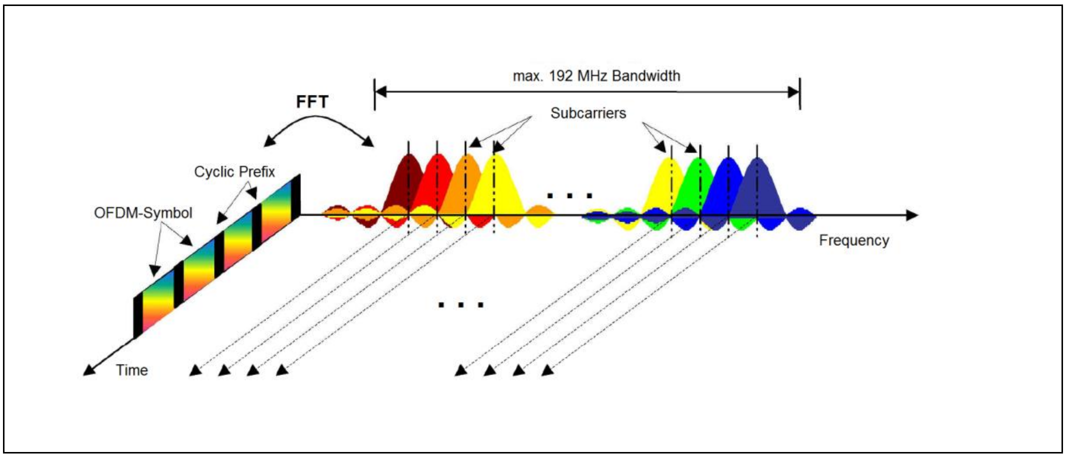


Fig. 3: Frequency-time relationship for OFDM.

Each transmission channel uses up to 8192 (8K) orthogonal subcarriers, depending on the selected FFT mode. By orthogonal is meant that all other subcarriers have a zero crossing at the peak of a given subcarrier (see Fig. 4).

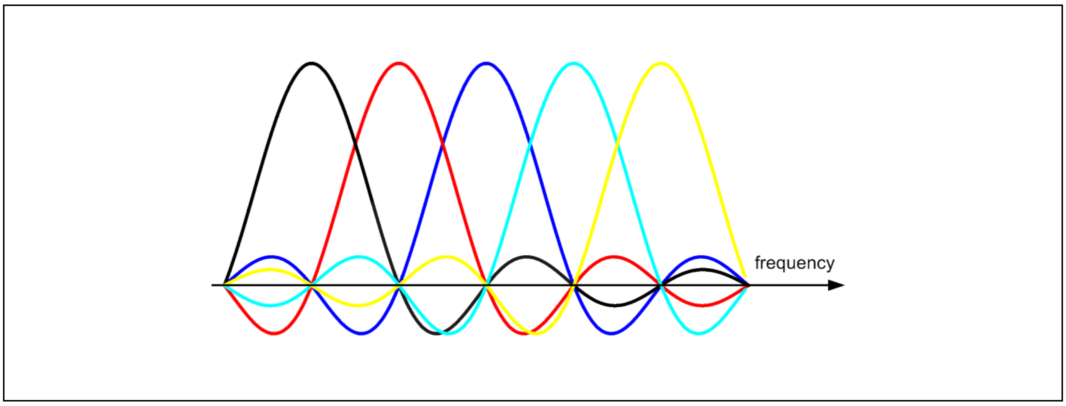


Fig. 4: Orthogonal carriers.

The high number of carriers makes it possible to investigate interference in the transmission channel selectively. As a result, subcarriers are either modulated differently or completely excluded from the data transmission, depending on the interference. Excluded carriers are called either exclusion subcarriers or exclusion bands (minimum 1 MHz bandwidth). They are used when carriers are heavily disturbed or noisy. Other requirements apply for exclusion bands. As a result, each modulated segment in a channel must have a minimum width of 2 MHz and must include a continuously modulated range that is at least 22 MHz wide.

DOCSIS 3.1 does not use all theoretically possible carriers even under ideal transmission conditions. Along the edge of the channel lie exclusion bands with unused OFDM carriers. These serve as a guard band.

192 MHz downstream channel bandwidth				
FFT mode	**Theoretically available subcarriers**	**Maximum subcarriers in use**	**Carrier spacing**	**Sampling rate**
4K	4096	3800	50 kHz	204.8 MHz
8K	8192	7600	25 kHz	

96 MHz upstream channel bandwidth				
FFT mode	**Theoretically available subcarriers**	**Maximum subcarriers in use**	**Carrier spacing**	**Sampling rate**
2K	2048	1900	50 kHz	102.4 MHz
4K	4096	3800	25 kHz	

The variously modulated single carriers make it possible to achieve a higher data throughput than with single-carrier modulation. The number of subcarriers and the symbol duration correspond to a sampling rate (f_s) of 204.8 MHz for the downstream and 102.4 MHz for the upstream.

Digital signal processing means that it is not necessary to have a modulator at the transmitter end or a demodulator and a channel filter at the receiver end for each single carrier. Instead, the subcarriers are orthogonally generated in the transmitter by means of an inverse fast Fourier transform (IFFT) and received by the receiver without filtering by means of a fast Fourier transform (FFT).

For the DS, all OFDM subcarriers in a channel are generated in a single transmitter, which makes the generation of orthogonal subcarriers relatively simple. For the US, different CMs serving as transmitters each generate a subset of the subcarriers for an OFDM symbol. The subsets are not combined into a complete OFDM until they reach the receiver input at the CMTS. This is known as orthogonal frequency division multiple access (OFDMA). The individual CMs must be frequency synchronized, as the individual carriers would otherwise lose their orthogonality. The DOCSIS 3.1 specification limits carriers generated by a CM to a maximum frequency deviation of ± 30 Hz.

2.3 Cyclic Prefix and Windowing

The mutual influence from the sequentially transmitted OFDM symbols is known as intersymbol interference (ISI). As a result of this ISI, the OFDM symbols coming into the receiver can also be faulty. ISI originates from reflections that cause an additional signal component to come into the receiver after a delay of several ns to a few µs.

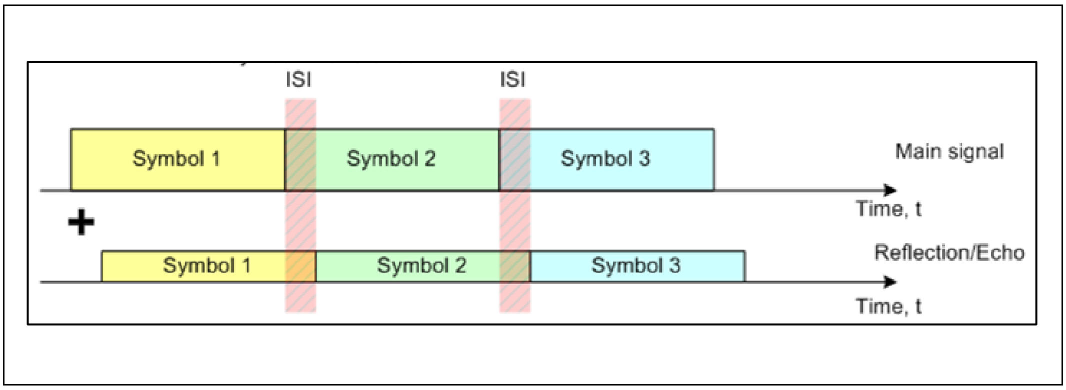


Fig. 5: Intersymbol interference.

To counteract this problem, a protective interval is inserted into the transition between two sequential symbols. In DOCSIS 3.1, this interval is known as the cyclic prefix (CP). In other transmission methods using OFDM, it is typically known as the guard interval (GI). A receiver must receive a continuous signal without a phase jump. The end of the symbol is therefore copied to the start in the place of a blank CP. By selecting the interference-free samples at the receiver, the CP makes it possible to receive symbols without ISI.

DOCSIS 3.1 defines windowing for signal filtering in order to minimize the influence on adjacent channels. A Tukey raised cosine window is used for this purpose. The steepness of the filter is defined by the roll-off period. The roll-off period is integrated into the CP and must be smaller than the CP.

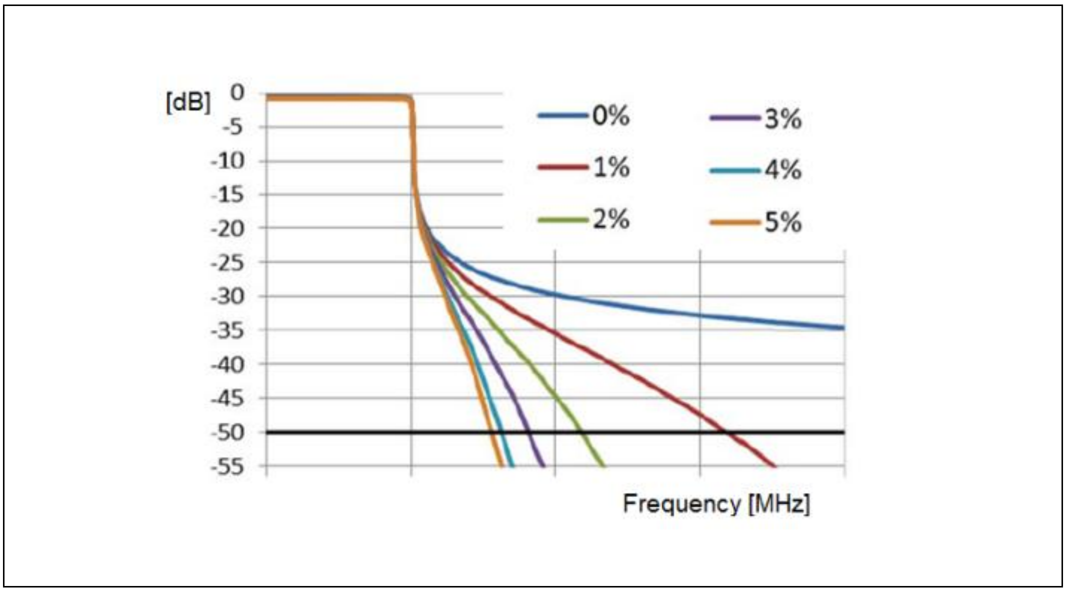


Fig. 6: Tukey raised cosine windowing with differing values.

The larger the CP and the smaller the roll-off period, the longer the maximum occurring echoes can be present without ISI resulting. However, larger CPs will decrease the net data transmission rate accordingly. The adjacent channel influence also increases with smaller roll-off periods. The length of the CP must be selected based on the current cable network conditions and can lie between 0.9375 µs and 5 µs for the downstream and between 0.9375 µs and 6.25 µs for the upstream. The roll-off period can be between 0 µs and 1.25 µs for the downstream and between 0 µs and 2.1875 µs for the upstream.

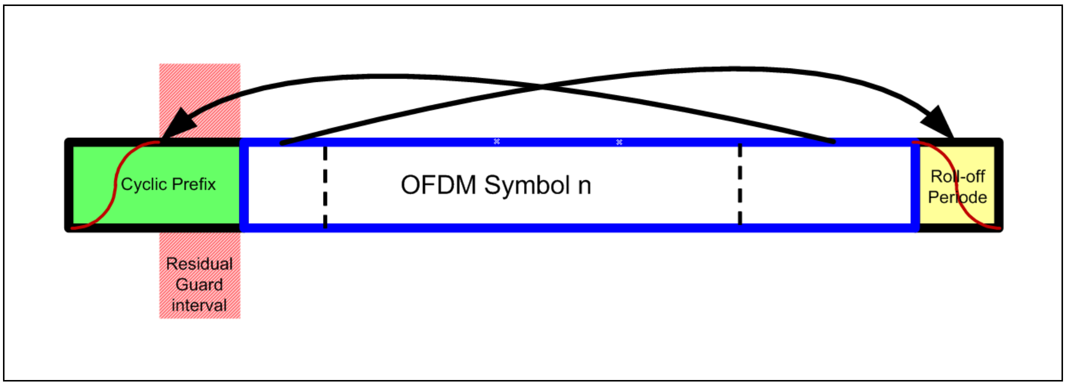


Fig. 7: Cyclic prefix and roll-off period of an OFDM symbol.

2.4 PLC, Exclusion Band and 0th Carrier

A small portion of the transmission channel (8 or 16 subcarriers) is excluded from the normal data transmission and instead carries basic information about the signal. This basic information is transmitted in the physical layer link channel (PLC) and is used by the receiver for synchronization purposes. The PLC is therefore placed in the spectrum so that it is subject to as little interference as possible, and the PLC data carriers are modulated with 16QAM for extra protection against errors. The PLC lies in the middle of a specially defined, 6 MHz wide range (without exclusion subcarriers or exclusion band). This 6 MHz contains the PLC as well as pilot carriers (see 2.5). To make it easier for receivers to find the PLC, the first carrier in the 6 MHz range must lie at a full MHz frequency.

Unlike many other standards, the position of the RF spectrum is not defined over the center frequency. Due to the use of exclusion bands and exclusion subcarriers, the center frequency cannot necessarily be read from the visible spectrum. The first FFT subcarrier with the lowest frequency is defined as the OFDM spectrum location (0th carrier). An active carrier is never present at this location because of the guard interval.

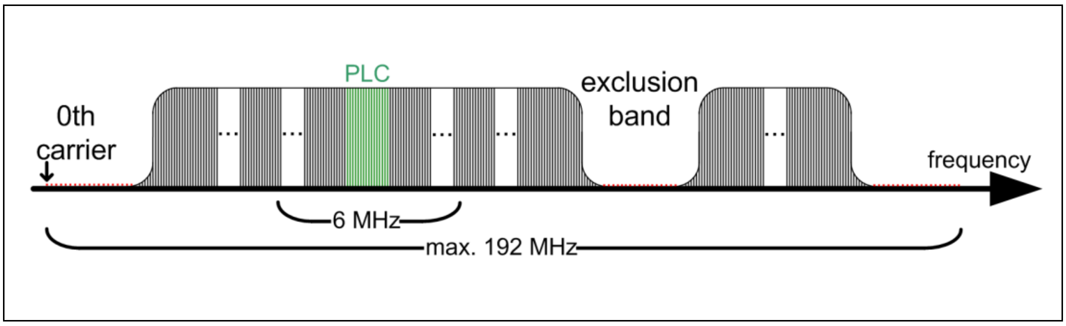


Fig. 8: Downstream signal with the 0th carrier, PLC and exclusion band.

2.5 Pilot Carriers

OFDM signals include pilot carriers that have an amplitude that is a factor of two greater than the data carrier. There are two types of pilot carriers in the downstream:

- Continuous Pilots (CP): These are transmitted without modulation at fixed positions and permit the receiver to synchronize the frequency and phase. There are always 8 CPs arranged next to the PLC; these are known as predefined continuous pilots around the PLC. The number of additional CPs can be configured in the continuous pilot parameter to a value between 8 and 120. The positions of all remaining 8 to 120 CPs are signaled in the PLC.
- Scattered Pilots (SP): These have no fixed positions, but rather are scattered throughout the subcarriers so that every subcarrier is eventually used for transmission. The advantage of transmitting these pilots at varying times is that they have very little effect on the net data rate. Scattered pilots are needed so that the receiver can perform a channel estimation (determining latency, attenuations and phase shifts). Many pilot values are needed for an accurate channel estimation.

2.6 Profiles and NCP

Different signal configurations are used depending on the reception conditions at a CM. There are different profiles for these configurations. Each profile defines the modulation order for all subcarriers. Profiles make it possible to achieve the maximum possible channel capacity at various reception points with the defined reception conditions. The CMTS determines the profile to be used at any given time based on the transmission conditions and reports the profile to the CMs in the next codeword pointer (NCP). The subcarriers that transmit the NCP must be robust against interference, and are therefore modulated at a maximum of 64QAM.

Downstream profile A is very robust (low modulation order) and is designed so that it can be received by every CM connected to the network. Profile A is also called the boot profile, and it is used for transmitting signaling information such as the upstream channel information and the profile descriptors for all other profiles.

The CMTS defines up to 16 optimization profiles, and each CM must at least be capable of receiving profile A plus four additional profiles.

The reception conditions and thus the profile being used at a reception point depend on the position in the cable TV network, i.e. the length of the coaxial cable leading to the reception point (see Fig. 9).

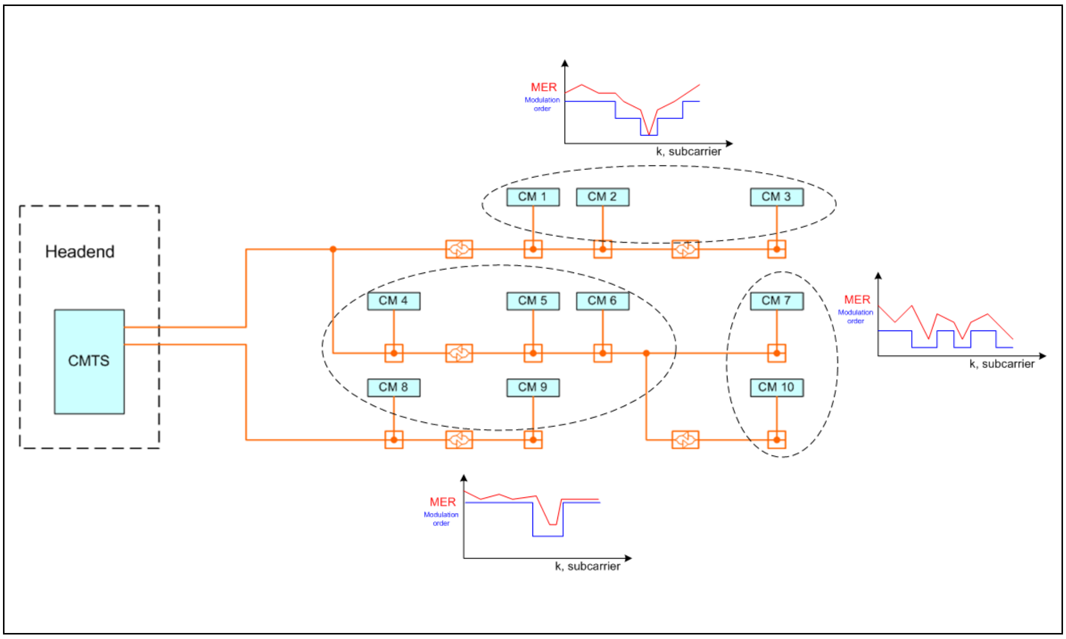


Fig. 9: Simplified schematic of an HFC network with varied MER values.

2.7 Forward Error Correction (FEC) and Interleaving

In order to improve the clearing of any errors that might occur, the FEC for DOCSIS 3.1 consists of a combination of the low density parity check (LDPC) and Bose-Chaudhuri-Hocquenghem (BCH) code. LDPC was developed in the 1960s. The calculation required in the receiver for this iterative algorithm is very processor intensive and requires significantly more computational power than the Reed-Solomon (RS) code FEC used up to DOCSIS 3.0. LDPC has therefore gained in practical use only in the last few years and is used in second-generation TV standards (DVB-C2/S2/T2), for example.

LDPC is an iterative block code method that iteratively reduces the number of faulty bits. The transition between the point at which the received and corrected signal is error free and the point at which the signal can no longer be reconstructed (fall-of-the-cliff effect) is very narrow. With LDPC, data rates near the maximum channel capacity (Shannon limit) are achieved. Of course, there is a limit to the number of errors that can be corrected per packet with LDPC. The more time allotted to the LDPC algorithm increases the number of iterations, thereby increasing the number of errors that can be corrected. The LDPC algorithm stops as soon as all errors are corrected. The number of iterations required to correct all errors provides a method to assess the signal quality. It must be noted that the number of iterations is dependent on the implementation, and therefore values measured for different receivers cannot be compared to one another.

BCH is capable of correcting any residual errors arising as a result of the LDPC principle.

The FEC requires a certain amount of data redundancy, and so reduces the net data rate. In DOCSIS 3.1, the BCH error protection consists of 14232 user bits located 14400 bits before the LDPC error protection. The LDPC code rate is always 8/9, and 1800 check bits are added to the 14400 bits. The resulting codeword length is 16200 bits.

In order to keep the overhead for error correction as low as possible while remaining as resistant to errors as possible, an interleaving is performed after the FEC. To do this, the data bits are interleaved so that related data and the associated error protection are not transmitted contiguously. This is done because interference usually either affects only a narrow frequency range or occurs very briefly (burst errors).

DOCSIS uses several types of interleaving, including:

- Frequency domain interleaving (FDI): The positions of the I/Q values within the OFDM symbol are interleaved, which minimizes frequency-selective influences.
- Time domain interleaving (TDI): The I/Q values of a symbol are distributed among up to 32 sequential OFDM symbols. Short-term faults that affect a complete OFDM symbol can be distributed over multiple codewords so that the FEC can then eliminate the faults.

The use of TDI causes delays in the data transmission. As a result, DOCSIS makes it possible to configure the interleaving depth, which specifies the number of packets that will carry the data.

2.8 Modulation Order

Until DOCSIS 3.0, modulation orders of up to 256QAM were defined for the downstream. With its improved FEC, DOCSIS 3.1 can use higher modulation orders for the same transmit conditions and thus increase the maximum data throughput. The LDPC error protection is so robust that DOCSIS 3.1 can use previously unheard-of constellations. Every wireless device must support constellations up to 4096QAM in the downstream (see Fig. 10). DOCSIS 3.1 optionally permits devices to support constellation orders up to 16K QAM (16384QAM).

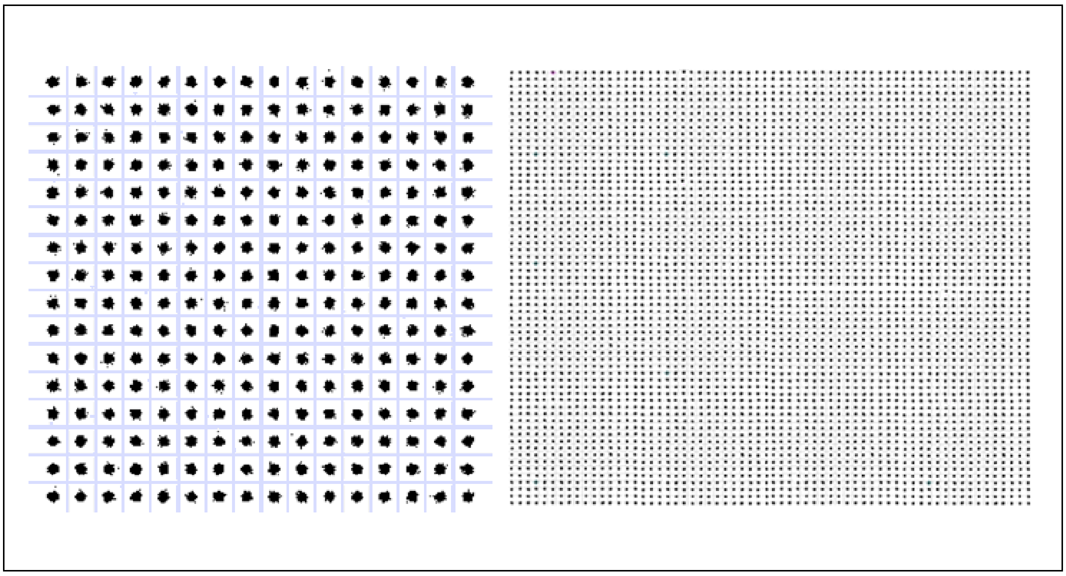


Fig. 10: Modulation order 256QAM (left) and 4096QAM (right).

3 Typical Measurement Parameters

3.1 Modulation Error Ratio and Downstream Profile

The modulation error ratio (MER) is a measure of the sum of all interference that affects a signal. The deviation of the points in the constellation diagram from their theoretical position is measured. This makes a quantitative assessment of the signal quality possible. The MER is typically expressed in dB as a logarithmic ratio between the RMS value of a data carrier and the error vector magnitude:

$$MER_{RMS} = -20log_{10}\frac{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}(|error\_vector|)^2}}{U_{RMS}} \text{ [dB]}$$

A high MER value indicates good signal quality. In previous cable TV standards, MER values of over 40 dB are typical, while for DOCSIS 3.1 MER values of over 50 dB are possible at the CMTS. To demonstrate these high MER values, a new generation of T&M equipment must be developed for DOCSIS 3.1.

To make a MER-dependent configuration possible, CMs can measure the MER progression over the OFDM carriers and transmit this information to the CMTS. The MER measurement accuracy on the CM does not need to come even close to 50 dB MER because MER values for a CM typically will not exceed 43 dB.

3.2 FEC Statistics: Codeword Error Ratio (CW) and Bit Error Ratio (BER)

The CER and BER define the ratio of faulty codewords or bits to the total number of codewords or bits. All interference in a transmission path is reflected in the CER and BER. DOCSIS 3.1 provides for an outer and inner error protection: LDPC and BCH. Three ratios apply:

- BER before LDPC
- CW error ratio after LDPC = CW error ratio before BCH
- CW error ratio after BCH

The range in which errors are visible after the FEC is limited to only about 1 dB, because the transition between the point at which the received and corrected signal is error free and the point at which the signal can no longer be reconstructed (fall-of-the-cliff effect) is very narrow. This is why the CW error ratio after LDPC or BCH is measured instead of BER after LDPC or BCH.

4 Measurement Equipment for DOCSIS 3.1

Once the standard has been defined, the industry players need to get to work. A completely new generation of broadband modulators and tuners will be needed for cable modems and CMTS. Even if the network infrastructure is left untouched, it will still be necessary to test the amplifiers and converters with the new signals. The large number of signals present on the cable is especially critical since distortion can easily occur due to intermodulation. With OFDM, signal peaks can also occur, which lead to laser clipping in electrical/optical converters, resulting in interference and loss of data. During a transition period, DOCSIS 3.1 will have to coexist in the cable with existing digital TV as well as analog TV and FM sound broadcasting to some extent. DOCSIS 3.1 and DOCSIS 3.0 will run in parallel in the upstream.

4.1 R&S®CLGD DOCSIS Cable Load Generator

For investigating load and coexistence scenarios, Rohde & Schwarz now offers a new realtime signal generator, the R&S®CLGD DOCSIS cable load generator, which has evolved from the R&S®CLG (see Fig. 11).

Fig. 11: R&S®CLGD DOCSIS cable load generator.

It permits DOCSIS 3.1 channel loading scenarios alongside digital (J.83/A/B/C) and analog TV signals in the downstream, as well as both DOCSIS 3.1 and DOCSIS 3.0 signals in the upstream. With a frequency range of 47 MHz to 1218 MHz and to 1794 MHz through optional keycode for the downstream, the R&S®CLGD can simultaneously generate six 192 MHz DOCSIS 3.1 channels or up to 160 QAM channels. A combination of DOCSIS channels and QAM channels is possible. Each channel is continuously modulated in realtime either with an internally generated MPEG-2 transport stream or PRBS content or with data fed over IP. This permits direct

BER measurements over the entire frequency range without requiring changes to the configuration.

The R&S®CLGD makes such simulations realistic by adding different types of interference such as additive white Gaussian noise (AWGN), impulsive noise, microreflections (in line with SCTE 40), narrowband ingress and 50 Hz/60 Hz AC hum.

Typical applications for the R&S®CLGD include the development of broadband tuners for the new generation of cable modems and CMTS or the qualification of amplifiers and electrical/optical converters with DOCSIS 3.1 signals.

A frequency range of 5 MHz to 204 MHz is supported in the upstream. For DOCSIS 3.0, TDMA and CDMA signals can be generated. For DOCSIS 3.1, OFDMA signals can be generated with up to 96 MHz bandwidth.

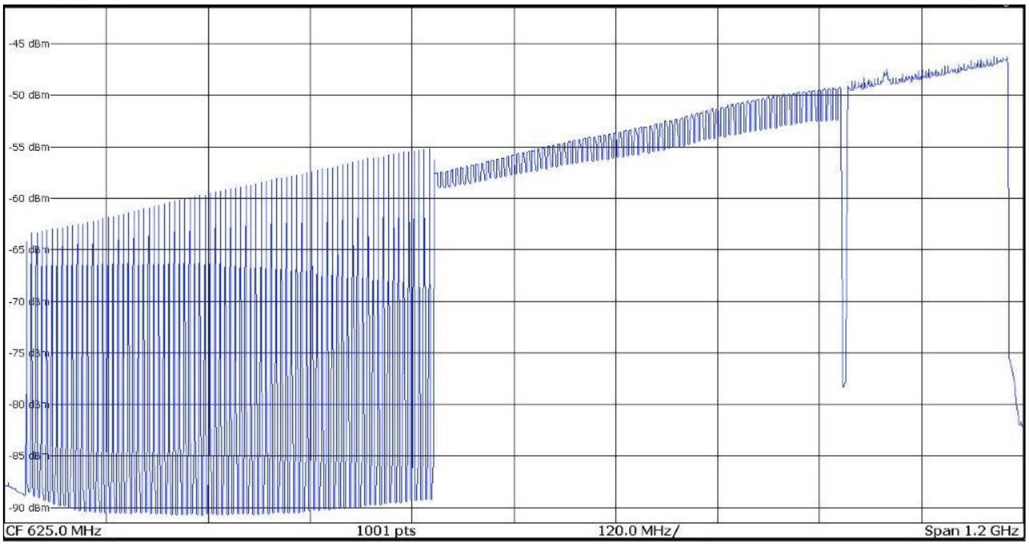


Fig. 12: Test signal for a cable TV amplifier with analog TV, QAM and a 192 MHz DOCSIS 3.1 signal with a total of 15 dB uptilt. The DOCSIS 3.1 signal contains the bulk of the power.

4.2 R&S®FSW with R&S®FSW-K192 DOCSIS 3.1 Analysis

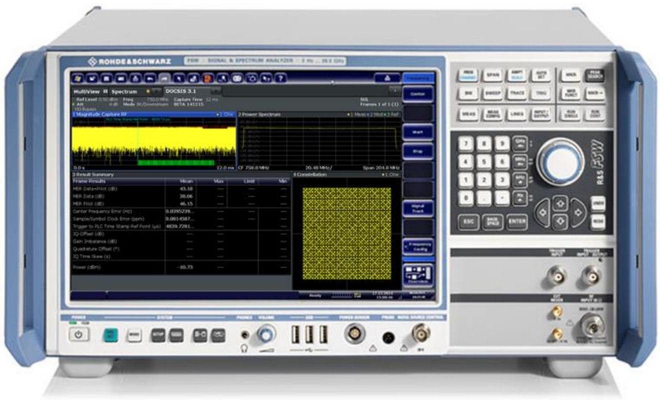


Fig. 13: R&S®FSW signal and spectrum analyzer

The R&S®FSW-K192 option is available on the R&S®FSW signal and spectrum analyzer for analyzing DOCSIS 3.1 downstream signals. This software application offers a wide range of graphical displays with detailed results as well as tables listing the key measurement parameters, greatly facilitating precise characterization and troubleshooting on the DUT.

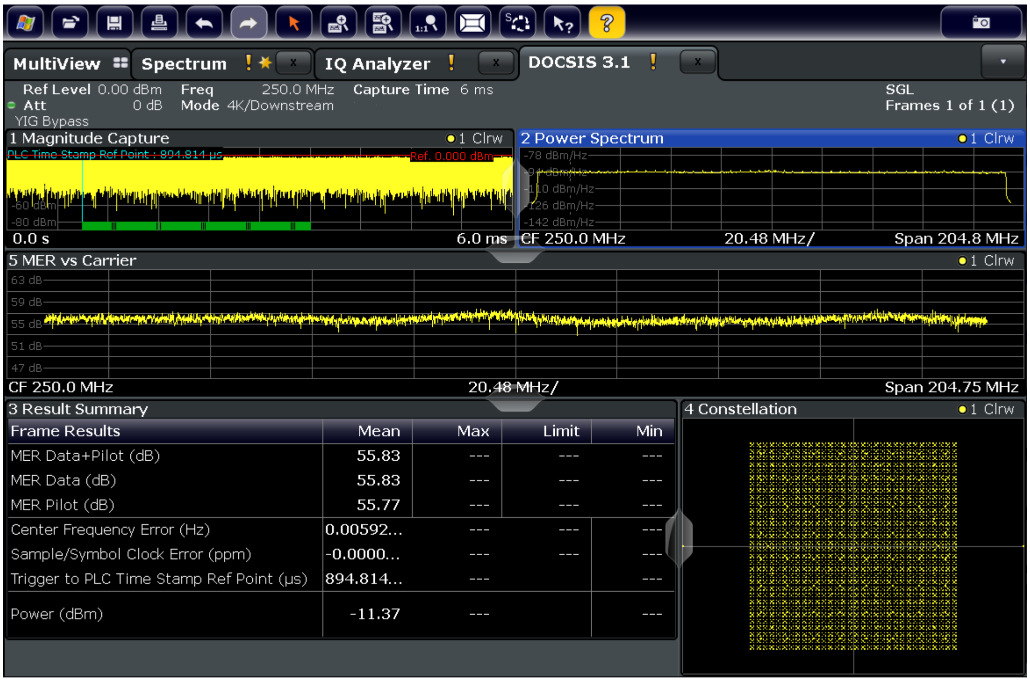


Fig. 14: R&S®FSW-K192.

In addition to manual input of signal configurations, the R&S®FSW-K192 also offers automatic detection of a variety of signal parameters. These include:

- Cyclic prefix and roll-off period
- PLC position
- Continuous pilot positions
- Codeword positions and length

These parameters can be determined automatically without reading the PLC, making it possible to perform initial measurements without precise knowledge of the signal. Automatic parameter detection can also be a benefit when the PLC is incorrectly configured or the signal does not match the expected configuration. To permit demodulation and decoding of all codewords, it is additionally important to specify the profiles being used. This can be done either manually or automatically by reading the PLC data.

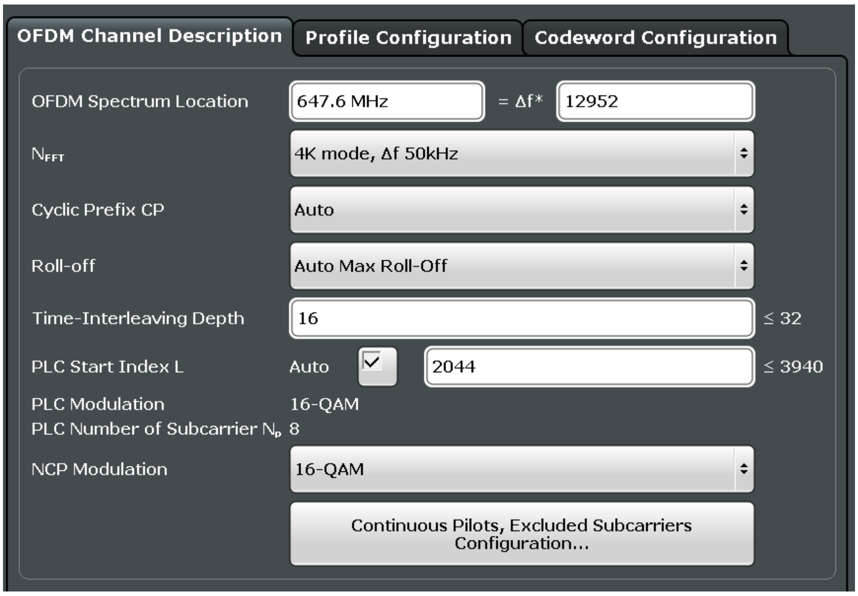
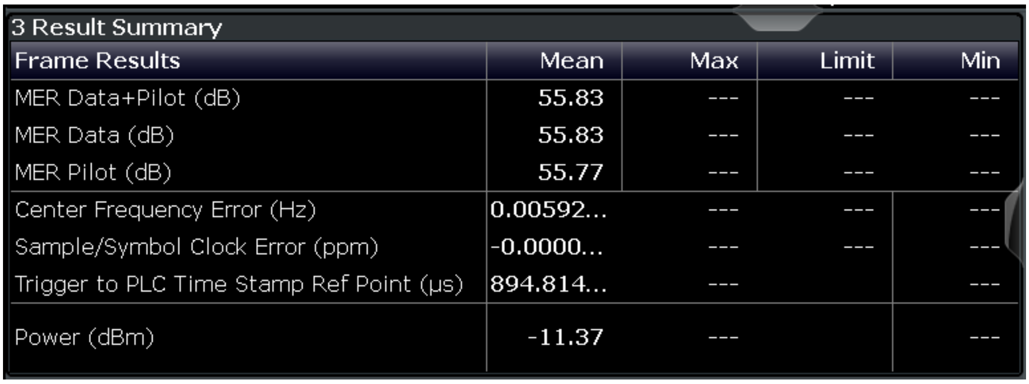


Fig. 15: Automatic detection of key OCD signal parameters.

The R&S®FSW-K192 software application determines a number of key parameters for analyzing the signal quality, e.g. for 16384QAM modulated signals, a high MER can be measured. In addition, the MER for the OFDM carriers and for the symbols can be displayed graphically. When combined with the results of the precorrection, these graphical images make it easy to identify interference and other influences in the transmission channel.



3 Result Summary				
Frame Results	Mean	Max	Limit	Min
MER Data+Pilot (dB)	55.83	---	---	---
MER Data (dB)	55.83	---	---	---
MER Pilot (dB)	55.77	---	---	---
Center Frequency Error (Hz)	0.00592...	---	---	---
Sample/Symbol Clock Error (ppm)	-0.0000...	---	---	---
Trigger to PLC Time Stamp Ref Point (µs)	894.814...	---		---
Power (dBm)	-11.37	---		---

Fig. 16: Scalar measurement results.

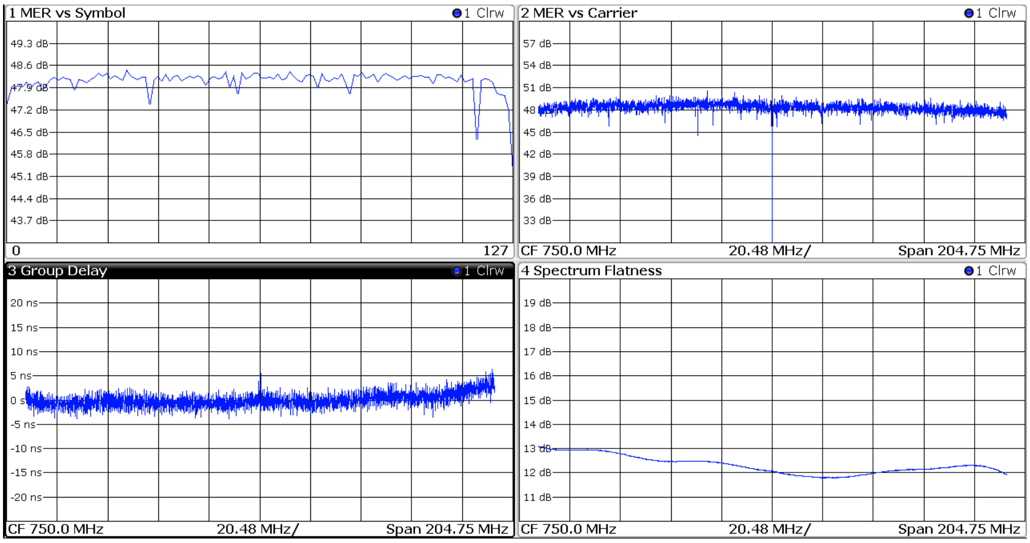


Fig. 17: Graphical measurement results facilitate troubleshooting as well as DUT characterization.

The R&S®FSW-K192 is also capable of decoding the detected symbols (LDPC and BCH decoding). This makes it possible to measure the bit error rate (BER). In practical applications, it is important to be able to measure even very small BER values. The R&S®FSW-K192 can measure a BER of 10^{-10}.

Fig. 18 shows a detailed list of detected signal components. The pilots and PLC as well as all NCPs and associated codewords are included in the list. The MER, BER and codeword errors for each component are displayed.

5 Signal Content Detailed

CW Index	Symbol Start	Object	Modulation	MER (dB)	Power (dBm)	# sc	LDPC #BitErr_Pre #BitErr_Pre/#Bit_Pr	LDPC #BitErr_Post #BitErr_Post/#Bit_Pos	LDPC #CWErr_Post #CWErr_Post/#CW_Po
---	---	Pilots	BPSK	34.3196	-40.909	---	--- ---	--- ---	--- ---
---	---	PLC Preamble	BPSK	33.292	-47.2018	---	--- ---	--- ---	--- ---
---	---	PLC Data	16 QAM	33.049	-47.1397	---	0 0	--- ---	0 0
0	0	NCP CW C	16 QAM	33.7736	-47.6364	12	0 0	--- ---	--- ---
1	0	NCP CW C	16 QAM	35.7029	-46.2152	12	0 0	--- ---	--- ---
2	0	NCP CW A	16 QAM	32.741	-47.511	12	0 0	--- ---	--- ---
0	0	NCP CRC-24	16 QAM	36.2464	-47.0561	12	0 0	--- ---	--- ---
0	0	Codeword C	1024 QAM	34.4628	-46.9749	1620	16 0.000987654	0 0	--- ---
1	0	Codeword C	1024 QAM	34.2479	-47.0432	1620	18 0.00111111	0 0	--- ---
2	0	Codeword A	64 QAM	34.2794	-46.8356	2700	0 0	0 0	--- ---
3	1	NCP CW D	16 QAM	34.3425	-47.5504	12	0 0	--- ---	--- ---
4	1	NCP CW D	16 QAM	35.4494	-45.0632	12	0 0	--- ---	--- ---
1	1	NCP CRC-24	16 QAM	34.8379	-46.8582	12	0 0	--- ---	--- ---
3	1	Codeword D	4096 QAM	36.6261	-47.1175	1350	--- ---	--- ---	--- ---

Fig. 18: List of signal components with BER analysis.

5 Abbreviations

BCH	Bose-Chaudhuri-Hocquenghem code
BER	Bit error ratio
CER	Codeword error ratio
CM	Cable modem
CMTS	Cable modem termination system
Continual pilot	CP
CoS	Class of service
CP	Cyclic prefix Continuous pilot
CW	Codeword
DOCSIS	Data over cable service interface specification
DPD	Downstream profile descriptor
DS	Downstream
FDI	Frequency domain interleaving
FEC	Forward error correction
FFT	Fast Fourier transform
GI	Guard interval
HFC	Hybrid fiber coaxial
IFFT	Inverse fast Fourier transform
ISI	Intersymbol interference
LDPC	Low density parity check
MER	Modulation error ratio
NCP	Next codeword pointer
OCD	OFDM channel descriptor
(C)OFDM	(Coded) orthogonal frequency division multiplex
(C)OFDMA	(Coded) orthogonal frequency division multiple access
PLC	Physical layer link channel
QAM	Quadrature amplitude modulation
RS	Reed-Solomon
SP	Scattered pilot
TDI	Time domain interleaving
US	Upstream

6 Auxiliary Information

Our application notes are regularly revised and updated. Check for any changes at http://www.rohde-schwarz.com.

Please send any comments or suggestions about this application note to

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7 Ordering information

7.1 R&S®CLGD

Designation	Type	Order No.
Base unit		
DOCSIS Cable Load Generator	R&S®CLGD	2118.6956.02
Software options (firmware)		
Downstream Full Channel Load Generator	R&S®CLGD-K200	2118.6962.02
Upstream Cable Modem Emulator	R&S®CLGD-K300	2118.6979.02
Signal Interference Simulation	R&S®CLGD-K1050	2118.6991.02
Downstream Frequency Range Extension to 1794 MHz	R&S®CLGD-K3018	2118.6985.02
External accessories		
Multi-TS Streaming Software	R&S®TSStream	2116.8945.02

7.2 R&S®FSW and R&S®FSW-K192

Designation	Type	Order No.
Base unit and hardware option		
Signal and Spectrum Analyzer, 2 Hz to 8 GHz	R&S®FSW8	1312.8000K08
320 MHz Analysis Bandwidth	R&S®FSW-B320	1313.7172.02
Software tools		
DOCSIS 3.1 OFDM DOWNSTR	R&S®FSW-K192	1325.4138.02

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