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Test Method for Downstream Bit Error Ratio

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1. Introduction

1.1. Executive Summary

Test method for downstream bit error ratio.

1.2. Scope

The purpose of this test is to measure bit error ratio (BER) of downstream (forward path) broadband telecommunications QAM signals. This procedure will address mainly pre-forward error correction BER results for 64- and 256-QAM.

It is important to rely upon both the pre-FEC and post-FEC BER results. In North America, most 64- and 256-QAM signals incorporate ITU-T J.83 Annex B FEC encoding. It is therefore important to reference the post-FEC result, but extremely dangerous to rely solely upon it. BER suffers from what is commonly known as a “cliff effect” in which the post-FEC BER remains error free up to a point and then begins to rapidly decline. Referring to the pre-FEC BER result can yield insight as to how much margin is available prior to reaching the cliff.

Although ITU-T J.83 Annex B is the standard of choice for forward error correction in North America, it can lead to an overoptimistic pre-FEC BER result. When utilizing ITU-T J.83 Annex B, the pre-FEC measurement is after the Trellis decoder, but before the Reed Solomon decoder. Therefore, the Annex B pre-FEC test results will include the improvements of the Trellis coding.

ITU-T J.83 Annex C is similar to Annex B in that it relies on Reed Solomon error correction and occupies a 6 MHz-wide channel; however, Annex C does not incorporate Trellis coding. Since Annex C does not contain Trellis coding, it allows the test to yield a result closer to the true pre-FEC BER performance. Annex C is however, not likely to be the FEC encoding used in the field in North America.

This test is a static measurement at a single, specified device under test (DUT) input level. It does not provide performance over an input operating range. Also, the user will have the option of either testing with Annex B or Annex C. The final test results must clearly indicate which Annex was utilized.

In addition to a bit error ratio measurement, Appendix B refers to the parameters errored and error-free seconds, which can be a useful tool in determining the impairments resulting in the bit errors.

Since the introduction of Cablelabs DOCSIS 3.1 specifications, QAM channels have been sharing the downstream spectrum with OFDM channels. Through Proactive Network Maintenance (PNM), DOCSIS 3.1 specifications leverage CMTS and cable modem features and capabilities to enable measurement and reporting of network conditions and their effects. These measurements include FEC statistics (BER) as measured by cable modems on downstream OFDM channels. Accordingly, the scope of this test was not broadened to cover OFDM channels. Instead, the reader is referred to the DOCSIS 3.1 specifications.

1.3. Benefits

Uniform test method to determine bit error ratio of downstream signals.

1.4. Intended Audience

Equipment manufacturers and technical operations.

1.5. Areas for Further Investigation or to be Added in Future Versions

As bandwidth usage changes additional testing parameters may be added.

2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this document. At the time of Subcommittee approval, the editions indicated were valid. All documents are subject to revision; and while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

- No normative references are applicable.

2.2. Standards from Other Organizations

- No normative references are applicable.

2.3. Published Materials

- ITU-T Recommendation J.83 (1997), Series J: Transmission of Television, Sound Programme and other Multimedia Signals. Digital Transmission of Television Signals.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

- ANSI/SCTE 96 2013: Cable Telecommunications Testing Guidelines
- SCTE Measurement Recommended Practices for Cable Systems, Fourth Edition, March 2012.

3.2. Standards from Other Organizations

- NCTA Engineering Committee's Subcommittee for Standards of Good Engineering Practices, 2002.
- DOCSIS 3.1, Physical Layer Specification, CM-SP-PHYv3.1-I13-171220, December 20, 2017, Cable Television Laboratories, Inc.

3.3. Published Materials

- Edgington, Francis and Thomas, Jeffrey. Digital Basics For Cable Television Systems. Upper Saddle River: Prentice Hall PTR, 1999.

4. Compliance Notation

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<i>deprecated</i>	Use is permissible for legacy purposes only. Deprecated features may be removed from future versions of this document. Implementations should avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

AWGN	additive white Gaussian noise
BER	bit error ratio
CSO	composite second order
CTB	composite triple beat
CW	continuous wave
dB	decibel
DUT	device under test
FEC	forward error correction
Hz	hertz
i.e.	that is (<i>id est</i>)
ISBE	International Society of Broadband Experts
ITU-T	International Telecommunication Union - Telecommunication Standardization Sector
kHz	kilohertz
Mbps	megabits per second
MHz	megahertz
Msp/s	megasymbols per second
QAM	quadrature amplitude modulation
RF	radio frequency
SCTE	Society of Cable Telecommunications Engineers
SDL	simulated digital loading

5.2. Definitions

adaptive equalizer	A circuit in a digital receiver that compensates for a digitally modulated signal's in-channel complex frequency response impairments..
bit error ratio (BER)	The number of errored bits divided by the total number of bits transmitted, received, or processed over some stipulated period.
errored second	A one second period with one or more errored blocks.
forward error correction (FEC)	A combination of techniques and algorithms used to identify and fix data transmission errors.
interleaving	A subset of forward error correction that provides additional immunity to noise bursts by spreading the bits or symbols in time.
International Telecommunication Union (ITU)	An agency within the United Nations that allocates global RF spectrum, assigns satellite orbits, and develops standards related to information and telecommunication technology.
ITU-T J.83	A set of technical specifications published by the International Telecommunication Union - Telecommunication Standardization Sector applicable to digital signals used in cable networks for the transmission of video, audio, and data services.
quadrature amplitude modulation (QAM)	A modulation technique in which an analog signal's amplitude and phase vary to convey information, such as digital data.
randomization	A subset of forward error correction in which the data to be transmitted is randomized using a pseudorandom binary sequence scrambler.
Reed-Solomon coding	A class of error correction techniques that is capable of detecting and correcting multiple symbol errors. As used in ITU-T J.83 Annex B, Reed-Solomon FEC can correct up to three errored Reed-Solomon symbols per Reed-Solomon codeword, and up to eight errored RS symbols per RS codeword in ITU-T J.83 Annex C. p
symbol rate	The number of symbols transmitted over a given period of time, typically per second.
Trellis coding	A subset of forward error correction in which the symbol constellation (redundancy) is increased without increasing the symbol rate or power spectrum. The redundancy allows for an improved signal-to-noise ratio threshold.

6. Test Setup

6.1. Test Equipment List

- Digital modulator(s). Quantity to be determined by the amount of channel loading being tested.
 - 64- and/or 256-QAM
 - ITU-T J.83(B) and/or ITU-T J.83(C)
 - Variable interleaver controls
- RF upconverter(s). Quantity to be determined by the amount of channel loading being tested. May not be needed if signal source is able to directly generate desired signals on-channel.
 - Frequency range variable from 54 MHz to 860 MHz, minimum
 - Above 860 MHz desirable
- Simulated digital loading (optional)
Aside from the QAM channels under test, the remaining digital loading may be simulated digital loading vs. actual QAM channels
- AWGN generator
 - Variable output power or incorporate an external variable attenuator
- Appropriate bandpass (high/low pass) filter to shape the noise loading in accordance with the specified channel plan
 - 16 dB minimum return loss, 75 ohm nominal impedance
 - +/- 10 MHz from edge frequency, >40 dB rejection
 - +/- 0.25 dB flatness
 - < 1.5 dB insertion loss
- Notch filters (channel deletion filters)
 - Center frequency = center frequency of test channel
 - 16 dB minimum return loss, 75 ohm nominal impedance
 - 6 MHz wide, >50 dB in-band rejection
 - +/- 2 MHz from bandedge, <3.0 dB insertion loss
 - +/- 0.25 dB flatness in the passband
 - < 1.5 dB insertion loss
- One lab amplifier (optional)
 - Gain as needed in order to meet the DUT specified input, minimal distortion or noise contribution
 - 75 ohm nominal impedance
- One variable RF attenuator
 - 16 dB minimum return loss, 75 ohm nominal impedance
- One multi-channel signal generator
 - Capability to produce signals on all the nominal visual carrier frequencies for all the channels in the frequency band to be tested
 - Ability to adjust the power of each individual channel
 - Ability to turn individual channels on/off.
 - CSO, CTB, or spurious signals generated within the signal source(s) should be at least 20 dB below those of the DUT
 - For testing with non-coherent carrier frequencies, the capability to maintain individual non-coherent frequencies to within +/- 5 kHz of the nominal carrier frequencies.
- Two RF combiners, may be RF splitter/combiner or a directional coupler.
 - Minimum isolation of 20 dB, 75 ohm nominal impedance
- One 6 MHz wide bandpass filter with the center frequency set to that of the channel under test
 - +/- 10 MHz from center frequency, > 25 dB rejection
 - 75 ohm nominal impedance, 18 dB minimum return loss

- May not be required depending on the model of demodulator/analyzer used.
- One QAM analyzer.
 - 64- and 256-QAM capabilities
 - ITU-T J.83(B) and/or ITU-T J.83(C)
 - QAM analyzer should be able to display pre-FEC and post-FEC BER results
Note: The QAM analyzer pre-FEC results are to be strictly based on an errored bit count relative to the total number of transmitted bits. It is not to be derived based on a theoretical value relative to a signal-to-noise measurement.
- Spectrum analyzer (optional)

Follow all calibration requirements recommended by the manufacturers of the test equipment, including adequate warm-up and stabilization time.

6.2. Setup Verification

Connect the equipment as depicted in Figure 1. Bypass the DUT with a straight coaxial connection from the combined analog and digital to the input of the bandpass filter.

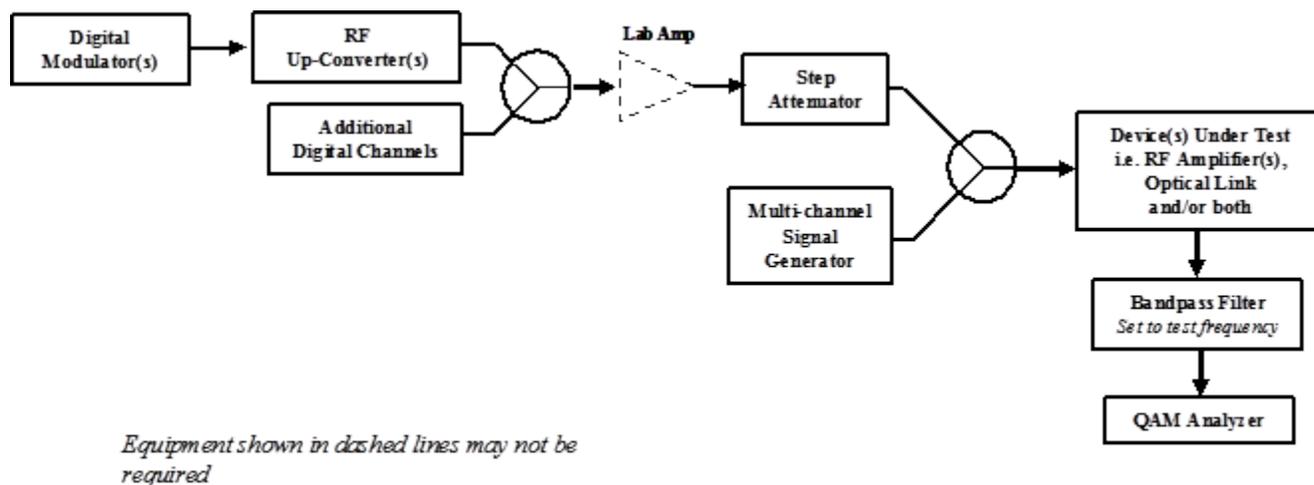


Figure 1 - Downstream BER Test Diagram

6.2.1. Digital Modulator

- Set the modulation to the proper format (i.e., 64- or 256-QAM)
- Set the symbol rate accordingly
 - Annex B
 - 64-QAM – 5.056941 Msps
 - 256-QAM – 5.360537 Msps
 - Annex C
 - 64-QAM – 5.309734 Msps
 - 256-QAM – 5.309734 Msps
- Information bit rate / transmitted bit rate
 - Annex B
 - 64-QAM – 26.97035 Mbps / 30.342 Mbps
 - 256-QAM – 38.81070 Mbps / 42.8843 Mbps
 - Annex C

- 64-QAM – 29.359708 Mbps / 31.644 Mbps
 - 256-QAM – 39.146278 Mbps / 42.192 Mbps
- Set the interleaver accordingly
 - Annex B
 - 64-QAM – I=128, J=4
 - 256-QAM – I=128, J=4
 - Annex C
 - 64-QAM – I=12, J=17
 - 256-QAM – I=12, J=17
- Set the roll-off factor accordingly
 - Annex B
 - 64-QAM – 18%
 - 256-QAM – 12%
 - Annex C
 - 64-QAM – 13%
 - 256-QAM – 13%

6.2.2. RF Upconverter

- Set the RF center frequency as required per the channel plan
 - As a minimum, the first and last digital channel performance should be verified for BER performance.
- The RF output level should be adjusted such that all digital channels are at an equal level as indicated in Figure 2.

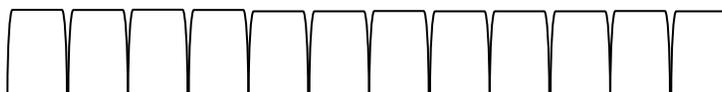


Figure 2 - QAM only Display

6.2.3. Simulated Digital Loading (optional)

When using a combination of simulated digital loading (SDL) comprising additive white Gaussian noise (AWGN) and QAM channels, the actual QAM channel will appear to be higher in level than the SDL when viewed on a spectrum analyzer. This is due to the fact that most of the total channel power is within a 5.06 MHz (64-QAM, Annex B) or 5.36 MHz (256-QAM, Annex B) spectrum versus the 6 MHz of the SDL. The total power within a 6 MHz channel is to be equal. This may be accomplished by setting the spectrum analyzer to measure power per 6 MHz channel or measuring in power per Hz.

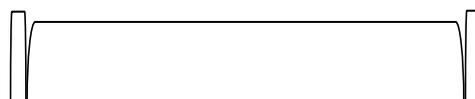


Figure 3 - QAM & AWGN Display

6.2.4. Step Attenuator

Adjust the step attenuator in order to achieve the DUT specified input for the digital channel loading relative to the analog input.

6.2.5. Multi-channel generator

Each channel to be operated as a continuous wave (CW) tone at its specified operating level.

Set the output to provide all of the signals need for the applicable frequency plan.

The analog carrier frequencies for noncoherent frequency plans should be randomly dispersed within +/-5 kHz about the nominal visual carrier frequency, in order to obtain the most stable, repeatable result.

Input the combined analog and digital channel loading to the 6 MHz bandpass filter. Tune or select the center frequency of the filter to the center frequency of the channel under test.

Input the filtered test channel to the QAM analyzer.

Ensure that the input of the QAM analyzer is at the proper RF level. Refer to the manufacturer's specification sheet.

6.2.6. QAM Analyzer

- Mode
 - ITU-T J.83, Annex B or ITU-T J.83, Annex C
- Modulation format
 - 64- or 256-QAM
- Set the symbol rate accordingly
 - Annex B
 - 64-QAM – 5.056941 Msps
 - 256-QAM – 5.360537 Msps
 - Annex C
 - 64-QAM – 5.309734 Msps
 - 256-QAM – 5.309734 Msps
- SAW filter
 - 6 MHz
- Set the roll-off factor accordingly
 - Annex B
 - 64-QAM – 18%
 - 256-QAM – 12%
 - Annex C
 - 64-QAM – 13%
 - 256-QAM – 13%
- Adaptive equalizer
 - On
- Center frequency tuned to the channel under test

Set the QAM analyzer for a 1 minute averaged BER test. Enable the modulator forward error correction (Annex B or Annex C).

Per the test equipment manual, reset the BER results and begin the 1 minute averaged BER test. Ensure that both the post-FEC and pre-FEC BER are error free.

If the test fails to meet error free performance, verify the setup connections, the tuning of the bandpass filter, proper RF levels, modulator/demodulator settings, as well as the QAM analyzer settings. If pre-FEC error free performance is unobtainable, ensure that the setup has sufficient performance margin (at

least two orders of magnitude) such that it will not impact the measurement of the DUT. Refer to the equipment manufacturers manuals as needed.

7. Procedure

1. Connect the DUT into the test setup as indicated in Figure 1. Verify that the DUT input is per specification.
2. Adjust the levels of the DUT {optical link and/or RF amplifier(s)} as specified.
3. Ensure that the input of the QAM analyzer is at the proper RF level. Refer to the manufacturer's specification sheet.
4. Set the QAM analyzer for a 1 minute averaged BER test. Enable the modulator forward error correction (Annex B or Annex C).

Note: A sequential grouping of the individual 1-minute tests will be performed in order to complete the overall test. See Appendix A for a detailed explanation of the overall integration time.

Per the test equipment manual, reset the BER results and begin the 1 minute averaged BER test.

At the conclusion of the 1-minute test, record the pre-FEC BER results and immediately reset the BER measurement in order to begin the next series of the data compilation.

Note: The accuracy of the pre-FEC BER results have been compromised once any post-FEC bit errors have occurred. If any post-FEC errors are recorded, disregard the pre-FEC BER results.

Repeat 6.4.2 until the entire data set is completed. The final results must clearly indicate whether Annex B or Annex C FEC encoding was utilized.

Note: Some test instruments can be set up to achieve minute by minute average BER results during a multiple minute test. Provided the BER test sample period is less than or equal to one minute, any 'sub-minute' test period BER results can be averaged in order to determine the average BER per each one minute time period. For example, if BER is measured in one second samples, the average of 60 contiguous samples would equal the average BER for a one minute period. In this case, the analyzer test duration is set for the total, desired test time. The one second samples are extracted and the individual 1-minute results are created at the conclusion of the entire test.

Consult the test equipment manufacturer's procedures for information on setting up the instrument.

Appendix A: Test Integration Time

The BER test integration time is merely the length of time that the test is allowed to run before taking a measurement or considering the test complete.

Determining the test integration time (length of the test) involves a couple of parameters. First, the length of the test is directly related to how small of a BER value is attempting to be measured. For example:

Assuming that the desired measurement is $1e-12$ with a 256-QAM signal

$$1 / (1e-12) = 1e12 \text{ bits}$$

$$1e12 \text{ bits} / 42.8843 \text{ Mbps (transmitted bit rate)} = 23.3186e3 \text{ seconds}$$

$$23.3186e3 \text{ seconds} = 6.4774 \text{ hours}$$

Assuming that the desired measurement is $1e-9$ with a 256-QAM signal

$$1 / (1e-9) = 1e9 \text{ bits}$$

$$1e9 \text{ bits} / 42.8843 \text{ Mbps} = 23.3186 \text{ seconds}$$

The next parameter to consider is an averaged BER measurement over 15 minutes, or longer, can mask a short duration anomaly by averaging its affects across the entire 15+ minute test. Linking several shorter tests together in order to complete one whole test can overcome this issue. For example:

Transmitted bit rate = 42.8843 Mbps (256-QAM)

Assuming a 1-minute test in which 100 randomly dispersed errors occur.

$$42.8843 \text{ Mbps} * 60 \text{ seconds} = 2.5731e9 \text{ bits}$$

$$100 \text{ errors} / 2.5731e9 \text{ bits} = 3.8864e-8 \text{ BER}$$

Assuming a 15-minute test in which each 1-minute block yields the same $3.8864e-8$ result, the end result would of course be identical. In this case the 15-minute test would not produce any issues.

Now assume that one of the 1-minute blocks has an additional burst of 3000 errors.

Averaging all errors across 15 minutes:

$$42.8843 \text{ Mbps} * 60 \text{ seconds} * 15 \text{ minutes} = 38.5959e9 \text{ bits}$$

$$(1400+3100 \text{ errors}) / 38.5959e9 \text{ bits} = 1.1659e-7 \text{ BER}$$

Using individual 1 minute tests:

$$42.8843 \text{ Mbps} * 60 \text{ seconds} = 2.5731e9 \text{ bits}$$

$$3100 \text{ errors} / 2.5731e9 \text{ bits} = 1.2048e-6 \text{ BER}$$

This particular 1-minute block would indicate a BER of $1.2048e-6$, while the remaining 14 blocks would each show $3.8864e-8$

The end result of the averaged, 15-minute test produces a result which can lead to a misconception of an acceptable margin. By looking at 15 separate 1-minute blocks, the potential issue of less BER margin is identified.

In determining the total test integration time or the time to complete the entire test, it is suggested that the test be allowed to run such that at least 100 errored seconds are incurred.

Appendix B: Errored and Error-Free Seconds

In addition to bit error ratio, another important parameter, which can be recorded during the BER test, is errored and error-free seconds. By comparing the ratio of errored and error-free seconds to the total test time, the clustering/distribution of errors can be identified. The clustering/distribution of the errors will illustrate whether the errors are most likely the result of clipping/compression or noise.

Errors caused by laser clipping tend to be bursty in nature and will not be evenly distributed across the entire test. Conversely, errors produced as a result of Gaussian noise will be more uniformly dispersed and of a shorter duration.

Typically the overall bit error ratio result will be comprised of both types of errors (burst and non-burst). By establishing the dominant error type during the total peak BER, the main contributor can be identified.

The importance of identifying burst errors vs. non-burst errors further manifests itself into determining the amount of performance margin that is available. In an AWGN channel, the ratio between pre-FEC and post-FEC BER will be much greater than that of a laser clipped channel. In other words, a change to the pre-FEC BER within a laser clipped channel will have a larger impact to the post-FEC BER than it would in an AWGN channel.