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STANDARDS

Network Operations Subcommittee

SCTE OPERATIONAL PRACTICE

SCTE 257 2019

Techniques for Accurate Measurement of Cable TV Network Downstream RF Signal Levels

NOTICE

Table of Contents

List of Figures

Title **Page Number**

List of Tables

Title **Page Number**

1. Introduction

1.1. Executive Summary

Measurement of a cable network's downstream radio frequency (RF) signal levels is often taken for granted. The procedure is straightforward: Connect a signal level meter (SLM), spectrum analyzer, or similar instrument to the device or signal source being measured and read the reported signal level (see

Figure *1*). But is the reported value the actual value? Not necessarily. There are several factors that affect the accuracy of measured and reported RF signal levels. This Operational Practice discusses those factors, and how to achieve more accurate and repeatable results.[1]

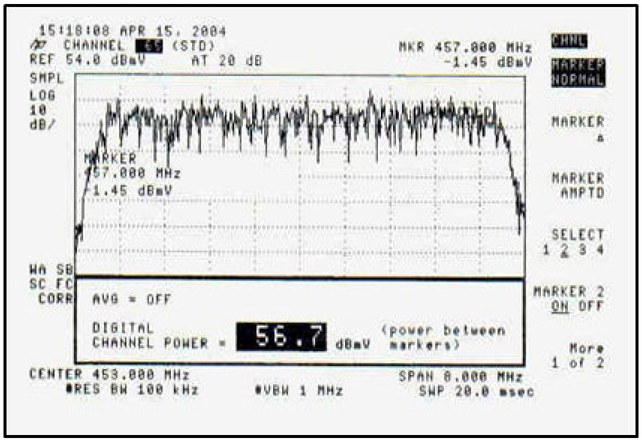

Figure 1. Is the reported digital channel power of 56.7 dBmV the actual digital channel power?

1.2. Scope

Proper cable network operation relies upon RF signal levels being within specification. RF signals are just about everywhere in modern cable systems: antenna sites, headends, hub sites, nodes, coax distribution networks, and subscriber drops. While ensuring that signal levels are what they're supposed to be won't fix or avoid every problem, correct signal levels are an important part of optimizing overall RF performance.

1.3. Benefits

Optimum cable network downstream performance requires that RF signal levels be measured and set correctly. RF signal levels affect nearly every part of a cable network's operation: headend/hub site, optical fiber links, coax distribution, subscriber drops, and customer premises equipment (CPE). This Operational Practice discusses measurement of downstream signal levels, factors that can affect the accuracy of those measurements, and provides recommendations to ensure correct RF signal levels.

[1] The content of this Operational Practice is based upon a three-part article written by Ron Hranac, which appeared in the Fall 2017, Winter 2017, and Spring 2018 issues of *Broadband Library* magazine (https://broadbandlibrary.com/). The material is used with the permission of the author.

1.4. Intended Audience

This document is intended for cable system technical personnel such as installers, service and maintenance technicians, headend and hub site technicians, and others who have to measure signal levels as part of their daily jobs, or are interested in the measurement of signal levels.

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

Future versions of this Operational Practice (or a new and separate Operational Practice) could include information about the measurement of upstream RF signal levels.

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

- No normative references are applicable.

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

- SCTE Measurement Recommended Practices for Cable Systems, Fourth Edition.

3.2. Standards from Other Organizations

- [1] ISO 5725-1:1994 "Accuracy (trueness and precision) of measurement methods and results -- Part 1: General principles and definitions"

3.3. Published Materials

- [2] Data-Over-Cable Service Interface Specifications Downstream RF Interface Specification CM-SP-DRFI-I15-160602 (http://www.cablelabs.com/wp-content/uploads/specdocs/CM-SP-DRFI-I15-160602.pdf)

- [3] "Fundamentals of RF & Microwave Power Measurements," Agilent Application Note 64-1C (http://cp.literature.agilent.com/litweb/pdf/5965-6630E.pdf)

- [4] "Power Measurement Basics," Agilent PowerPoint presentation (http://www.keysight.com/upload/cmc_upload/All/BTB_PowerBasics_2005.pdf)

- [5] "Spectrum Analyzer Basics," Agilent Application Note 150 (https://www.keysight.com/upload/cmc_upload/All/5952-0292EN.pdf)

4. Compliance Notation

shall	This word or the adjective "***required***" means that the item is an absolute requirement of this document.
shall not	This phrase means that the item is an absolute prohibition of this document.
forbidden	This word means the value specified shall never be used.
should	This word or the adjective "*recommended*" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
should not	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
may	This word or the adjective "*optional*" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.
deprecated	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

AC	alternating current
AGC	automatic gain control
CMTS	cable modem termination system
CPE	customer premises equipment
dB	decibel
dBmV	decibel millivolt
dBµV	decibel microvolt
DOCSIS®	Data-Over-Cable Service Interface Specifications
DRFI	[Data-Over-Cable Service Interface Specifications] Downstream RF Interface [Specification]
e.g.	for example (*exempli gratia*)
ESD	electrostatic discharge
ft.	foot or feet
ISBE	International Society of Broadband Experts

MHz	megahertz
N/A	not applicable
PEP	peak envelope power
QAM	quadrature amplitude modulation
RF	radio frequency
RSS	root sum of squares
SCTE	Society of Cable Telecommunications Engineers
SLM	signal level meter
TV	television

5.2. Definitions

attenuation	A decrease in the power of a signal or signals, usually measured in decibels. Expressed mathematically, $L_{dB} = 10log_{10}(P_{in}/P_{out})$, where L_{dB} is loss in decibels, P_{in} is input power in watts, P_{out} is output power in watts, and $P_{out} < P_{in}$. When signal power is stated in dBmV, $L_{dB} = P_{in(dBmV)} – P_{out(dBmV)}$.
decibel (dB)	A logarithmic-based expression of the ratio between two values of a physical quantity such as power. Mathematically, the ratio of two power levels P_1 and P_2 in decibels is $dB = 10log_{1}0(P_1/P_2)$. The decibel is used to express gain, loss or attenuation, return loss, structural return loss, isolation, carrier-to-noise ratio, signal-to-noise ratio, modulation error ratio, and similar parameters.
decibel microvolt (dBμV)	Unit of RF power expressed in terms of voltage, defined as decibels relative to 1 microvolt, where 1 microvolt equals 13.33 femtowatts in a 75 ohm impedance. Mathematically, $dB\mu V = 20log_{10}$(value in μV/1 μV). The decibel microvolt is used to express RF signal level, more commonly outside of North America.
decibel millivolt (dBmV)	Unit of RF power expressed in terms of voltage, defined as decibels relative to 1 millivolt, where 1 millivolt equals 13.33 nanowatts in a 75 ohm impedance. Mathematically, $dBmV = 20log_{10}$(value in mV/1 mV). The decibel millivolt is used to express RF signal level.
digital channel power	The average power of a digitally modulated signal as measured by a power meter which uses a thermocouple as a transducer. The average power measurement is integrated over the occupied bandwidth of that signal.
digital signal power	See *digital channel power*
loss	See *attenuation*
peak envelope power (PEP)	The average power during one cycle of an RF signal at the crest of the modulation envelope. The crest of an analog TV signal's visual carrier modulation envelope occurs during synchronizing pulses.
power	The rate at which work is done, or energy per unit of time, expressed in watts. 1 watt of power is equal to 1 volt causing a current of 1 ampere. Mathematically, $P_{AVG} = I_{RMS}*E_{RMS}*cos\theta$, where P_{AVG} is average power, I_{RMS} is root mean square current, E_{RMS} is root mean square voltage, and $cos\theta$ is the cosine of the phase angle difference in degrees between the current and voltage.
radio frequency (RF)	That portion of the electromagnetic spectrum from a few kilohertz to just below the frequency of infrared light.

signal level	The amplitude of an RF signal, specifically the power of that signal. In the case of an analog TV signal's visual carrier, signal level is the carrier's peak envelope power. The signal level of a digitally modulated signal is its average power, also called digital channel power or digital signal power.

6. Downstream Signal Level Measurements

What is signal level? As stated in **5.2 Definitions**, signal level is "The amplitude of an RF signal, specifically the power of that signal." In the case of an analog TV signal's visual carrier, signal level is the carrier's peak envelope power (PEP). The signal level of a quadrature amplitude modulation (QAM) signal or other digital signal is its average power (integrated over the signal's occupied bandwidth), also called digital channel power or digital signal power. Orthogonal frequency division multiplexing (OFDM) power is expressed in average power per CTA channel (that is, power per 6 MHz) as well as total power.[2]

Signal level in cable networks is expressed using decibel millivolt (dBmV), where dBmV is a unit of power expressed in terms of voltage.[3] It is incorrect to state signal level using just decibel (dB), because by itself dB is a "logarithmic-based expression of the ratio between two values of a physical quantity such as power." For example, one can correctly say that a two-way splitter's nominal insertion loss is 3.5 dB, or the gain of an amplifier is 20 dB, but not something like "the per-channel input to the modem is 2 dB." For the latter, the correct expression is "the per-channel input to the modem is 2 dBmV."

6.1. General RF Signal Level Measurements

Measurement of RF signal level in general involves taking into account three major components, shown in **Figure 2**.

Figure 2. Basic signal level measurement setup

The first component, the signal source, provides an RF signal (or signals) whose level is an assumed or perhaps unknown value. The second component, the interconnection, could be something as simple as a short length of coaxial cable, or may be more complex (e.g., headend combining/splitting network) and include a combination of gain and loss. The third component is the measurement device, the test instrument used to measure the RF signal level.

All three components shown in the figure have an impact in one or more ways on the outcome of signal level measurement. Among the major factors that affect the measurement results are the signal source's accuracy and stability, and depending on the nature of the source, its calibration; the net attenuation in the interconnection; and the measurement device's accuracy and calibration. Other factors such as impedance

[2] For more information, see the SCTE Operational Practice "DOCSIS 3.1 Downstream OFDM Power Definition, Calculation, and Measurement Techniques."
[3] In some locations outside of North America, the decibel microvolt (dBµV) is used instead of dBmV for RF signal levels.

mismatches, frequency response flatness, and temperature also have an effect. Indeed, the latter factors can have a significant impact on the measurement results.

The signal level present at the measurement device is the net signal level, which is the difference between the signal source output signal level and the net attenuation through the interconnection. In the following sections, RF power is intended to mean the same thing as RF signal level.

The following table summarizes typical ranges of downstream per-channel RF signal levels that can be expected in various parts of a cable network. The actual values in any given cable network can be different from what is shown here.

Table 1. Example signal levels in a cable network

Measurement location	RF signal level range
CMTS or QAM modulator output	+39 dBmV to +60 dBmV
Downstream laser transmitter input	+9 dBmV to +24 dBmV
Fiber node output	+38 dBmV to +56 dBmV
Amplifier input	+10 dBmV to +20 dBmV
Amplifier output	+38 dBmV to +60 dBmV
Tap spigot output	+10 dBmV to +20 dBmV
CPE input (analog)	0 dBmV to +10 dBmV
CPE input (digital)	-15 dBmV to +15 dBmV

6.2. Accuracy Versus Precision

Characterizing signal level measurements requires an understanding of related terminology. In particular, the terms *accuracy* and *precision* can cause confusion. While related, they do not mean the same thing. The following definitions are from ISO 5725-1 [1].

- accuracy – the closeness of agreement between a test result and the accepted reference value
- precision – the closeness of agreement between independent test results obtained under stipulated conditions

When measuring RF signal levels, it is possible for measurement results to be precise but not accurate; to be both precise and accurate; and to be neither precise nor accurate. Clearly, the desired goal is measurement results that are both precise and accurate.

To help understand the concepts of accuracy and precision, consider an analogy in which an archer shoots arrows at a target. The placement of where the archer's arrows hit the target can be described in terms of accuracy and precision, as illustrated in **Figure 3**, **Figure 4**, and **Figure 5**. The small black dots on each target represent where the arrows hit the target. Refer to the table in Section 5.2 for definitions of additional terms.

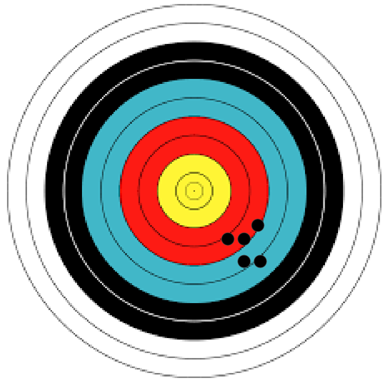

Figure 3. This five-shot target grouping is precise but not accurate.

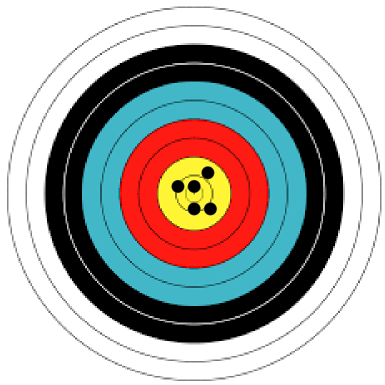

Figure 4. This five-shot target grouping is both precise and accurate.

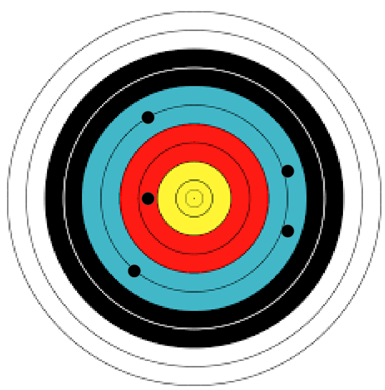

Figure 5. This five-shot target grouping is neither precise nor accurate.

Applying the archery analogies to RF signal level measurements, assume a QAM modulator whose per-channel output power is +50 dBmV.

For the example in **Figure 3**, five successive signal level measurements using the same test instrument might report +46.9 dBmV, +47.2 dBmV, +47.0 dBmV, +46.8 dBmV, and +47.1 dBmV. These five measurement results are precise but not accurate.

For the example in **Figure 4**, five successive signal level measurements using the same test instrument might report +49.8 dBmV, +50.3 dBmV, +49.6 dBmV, +49.9 dBmV, and +50.2 dBmV. These five measurement results are both precise and accurate.

For the example in **Figure 5**, five successive signal level measurements using the same test instrument might report +46.7 dBmV, +53.1 dBmV, +53.9 dBmV, +47.1 dBmV, and +54.0 dBmV. These five measurements are neither precise nor accurate.

6.3. Lab-Grade versus Field-Grade Measurement Devices

It is important to choose the proper device for measuring RF signal levels. For instance, field-grade instruments are ideal for checking signal levels at the tap, ground block and input to CPE; measuring amplifier and node signal levels, and for routine signal level checks and adjustments in a headend or hub.

Manufacturers of headend and hub site signal sources such as CMTSs and QAM modulators use specialized lab-grade test equipment to ensure that their products comply with published specifications. During manufacture, the signal sources are calibrated such that their configured RF output signal level and their measured RF output signal level meet or exceed the specified power per channel absolute accuracy. In order to ensure the latter, the absolute measurement accuracy of the test equipment used by the manufacturer must be better than the signal source's specified power per channel absolute accuracy.

For example, if the signal source's specified power per channel absolute accuracy is ±2 dB relative to the configured value, the test equipment used to calibrate the signal source must have an absolutely accuracy better than ±2 dB. Lab-grade instruments have accuracy specs on the order of ±1 dB or less.

Field-grade measurement devices used by cable technical personnel have published absolute accuracy specs that typically range from about ±1.5 dB to ±2.5 dB, depending on make/model. A measurement device with ±1.5 dB absolute accuracy might be suitable for confirming whether a CMTS or QAM modulator with ±2 dB accuracy meets its own published spec, but instruments with ±2 dB or ±2.5 dB absolute accuracy would not be suitable in this example.

Some instruments support user-selectable detectors, and other instruments select the detector type automatically without the need for user intervention.[4] Incorrect detector type could impact the accuracy of the measurement results. Refer to the test equipment manufacturer's instructions for recommendations on detector selection (if applicable) for a given measurement and signal type.

6.4. A Closer Look at Factors Contributing to Measurement Inaccuracy

6.4.1. Signal source output signal level tolerance

The purpose of measuring a signal source's output RF signal level or power is to confirm that it meets a desired value or perhaps some other specified value (e.g., meets the manufacturer's published spec). Modern QAM modulators, for instance, are required to comply with the technical parameters in the *Data-Over-Cable Service Interface Specifications Downstream RF Interface Specification*, also known as DRFI [2]. In particular, "Table 6–4 - DRFI Device Output Power," requires power per channel absolute accuracy to be ±2 dB. That is, a DRFI-compliant modulator's actual output power must be within ±2 dB of the configured value. Equipment manufacturers often state compliance with DOCSIS® or DRFI specifications[5] in published headend product data sheets. Amplifier and other active devices usually have published specs based upon typical intended use. Those specs can be adjusted by end users for specific deployment scenarios (different channel loading, tilt, cascade depth, etc., compared to the assumptions used in the manufacturer's published specs).

[4] Six common detector types discussed in [5] include average, negative peak, normal, positive peak (also known as peak), quasi-peak, and sample.
[5] DOCSIS is a trademark owned by Cable Television Laboratories, Inc.

6.4.2. Signal source RF signal level stability

Once a device's RF output power has been configured and initially measured, one might assume that the signal level will remain at the set value going forward. However, several things can affect signal level output stability. For example, in the outside coax plant, ambient temperature changes will cause the attenuation of the coaxial cable to change[6], which in turn causes RF levels in the plant to change. Absent automatic gain control (AGC), the output of an amplifier will vary as the RF input signal level from a span of coaxial cable changes over temperature. A headend modulator or other signal source might have an amplitude stability problem that causes the output signal level to vary. Amplitude variation can occur slowly over time, or it can occur quickly over a relatively short period of time. Loose or intermittent connections, cold solder joints, loose center conductor seizure screws, loose modules in nodes and amplifiers (and in headend chassis), are examples of factors that can contribute to RF output signal level instability.

6.4.3. Signal source calibration (if applicable)

As mentioned previously, manufacturers of QAM modulators and similar signal sources calibrate the actual output power versus the configured value, using specialized test equipment. Calibration ensures that the signal source meets its published specifications, and if applicable, a specification such as DRFI. If the calibration was incorrect for some reason, the device's actual output power might not meet published specifications.

6.4.4. Interconnection net attenuation

The interconnection between a signal source and the measurement device can be as simple as a short length of coaxial cable to as complex as an active headend combing network. The interconnection might exhibit only attenuation – say, coaxial cable, or a combination of coaxial cable and passive devices such as splitters, directional couplers, and in-line attenuators. As well, the interconnection might include a mix of attenuation and gain, the latter from an isolation amplifier or similar.

Net attenuation includes the effects of all attenuation and gain (if applicable) in the signal path. For example, if the interconnection includes an amplifier with 10 dB of gain, and cable and passive attenuation that totals 25 dB, the net attenuation is 15 dB. In any case, interconnection net attenuation must be measured, not assumed.

6.4.5. Measurement device accuracy

This is arguably a major source, if not the biggest source, of confusion when making RF power measurements. Often the assumption is that if a piece of test equipment reports, say, +15.2 dBmV, that value must be the actual RF power. Test equipment manufacturers specify absolute measurement accuracy for their products. As mentioned earlier, cable TV handheld and portable field instruments have published accuracy specs ranging from about ±1.5 dB to ±2.5 dB, depending on make/model. Laboratory-grade instruments might have a published accuracy spec of something like ±(0.24 dB + frequency response), where the frequency response is, say, ±0.35 dB.

An instrument's specified accuracy means that the reported RF power can be anywhere within the stated accuracy range. For example, if the published accuracy spec is ±2.5 dB and the actual net input power to that instrument is +15 dBmV, the instrument's reported value can be anywhere in the +12.5 to +17.5 dBmV range *and be considered within spec for that instrument*.

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[6] Coaxial cable attenuation in dB varies about 1 percent per 10 ˚F of temperature change.

6.4.6. Measurement device calibration

One often overlooked point is that an instrument's published accuracy specs depend upon the instrument being periodically calibrated by the factory or a factory-authorized service center. Recommended calibration cycles vary among manufacturers and equipment types, but typically range from every six months to every two years or so. The reason is that instrument calibration can and does change over time.

6.4.7. Impedance mismatches

Cable TV networks and their components are designed to have a nominal impedance of 75 ohms. The key here is "nominal," since the actual impedance is seldom exactly 75 ohms at all frequencies. Every connector, adapter, splitter, amplifier, etc., and even the coaxial cable itself represents an impedance mismatch to some degree. This is normal and is generally not a problem unless the impedance mismatches are significant. Impedance mismatches can cause standing waves (see next section) as well as additional mismatch-related attenuation in the signal path[7].

6.4.8. Frequency response

Ideally the frequency response of the interconnection between a signal source and measurement device should be flat, but this is rarely the case. Coaxial cable has greater attenuation at higher frequencies than at lower frequencies, resulting in non-flat frequency response. The latter can be an issue when measuring signal power over a wide range of frequencies. If impedance mismatches exist in the signal path being measured, standing waves (amplitude ripple) can degrade the frequency response and impact measured signal levels. Standing waves could affect signal levels on channels across the spectrum, as shown in **Figure 6**. Check signal levels on several adjacent channels or observe on a spectrum analyzer to see if standing waves are present in the spectrum.

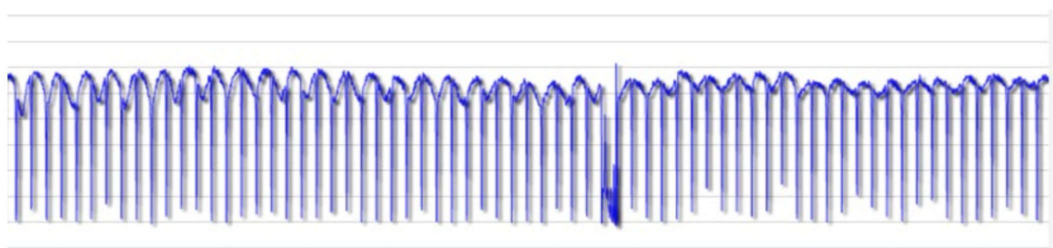

Figure 6. Standing waves can affect levels from channel to channel.

6.4.9. Temperature

Temperature can have a significant effect on the accuracy of RF signal power measurements. As discussed previously, ambient temperature affects the attenuation of coaxial cable, which in turn can affect amplifier input and output RF power. Temperature can affect test equipment calibration and measurement accuracy. Indeed, many test equipment manufacturers provide absolute accuracy specifications for both a fixed temperature and over a range of temperatures. For example, here is the published accuracy specification for a popular handheld cable field instrument:

@ 25 ˚C (77 ˚F): ±0.75 dB
Over temp -18 ˚C to +50 ˚C (0 ˚F to 122 ˚F): ±2.0 dB (analog), ±2.5 dB (digital)

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[7] For example, the published attenuation values for coaxial cable are known as matched loss values – that is, the values assume the cable is connected to a load impedance equal to the cable's characteristic impedance. If the cable is connected to a load impedance that is not equal to the cable's characteristic impedance, the attenuation of the cable will be higher than its matched loss by an amount that depends on the severity of the impedance mismatch. See https://en.wikipedia.org/wiki/Mismatch_loss

Note the wider accuracy windows for analog and digital measurements over temperature compared to the specified accuracy at 25 °C (77 °F).

6.4.10. Single channel per port versus multiple channels per port

If a QAM modulator supports multiple channels per RF port, it is important to keep in mind that per-channel maximum output power decreases when the modulator is operating in multiple-channel mode compared to operation in single-channel mode. **Figure 7** is excerpted from Table 6.4 of the DRFI Specification.

Required power per channel for *N* channels combined onto a single RF port. for *N* < 8, where *N* ≡ maximum number of combined channels per port and *N'* ≡ number of active combined channels per port (*N'* =< *N*):	Required power in dBmV per channel
N' = 1	60 dBmV
N' = 2	56 dBmV
N' = 3	54 dBmV
N' = 4	52 dBmV
4<N'=<8	60 – ceil [3.6*log2(*N'*)] dBmV
Required power per channel for *N'* channels combined onto a single RF port for *N'* >= *N* /4 and *N* >= 9:	Required power in dBmV per channel
N' >= *N* /4	60 – ceil [$3.6*\log_2(N')$] dBmV
Required power per channel for ***N'*** channels combined onto a single RF port for ***N'* < *N*** /4 and ***N*** >= 9:	Required power in dBmV per channel, where N" ≡ min [4*N'*,ceil [*N* /4]]
1 =< *N'* < *N /4*	60 – ceil [3.6*log2(N")] dBmV

Figure 7. Excerpt from DRFI

If a DRFI-compliant QAM modulator is configured for one channel per port, the maximum RF power for that channel is +60 dBmV. If the same modulator is configured for four channels per port, the maximum per-channel power is +52 dBmV. If the channel count per port is greater than four, the maximum per-channel power is defined by the formula[8]

$60 – \mathrm{ceil}[3.6*\log_2(N')]$

where
ceil is the mathematical ceiling function
N' is the number of active channels per port

Note that the logarithm in the formula is base 2, not the more common base 10. See the **Appendix** for an explanation of how to calculate base 2 logarithms.

The following two examples illustrate the change in maximum per-channel power with different numbers of channels per port.

[8] A multiple-channel-per-port QAM modulator operates with the functional equivalent of a built-in headend combiner, reducing the per-channel signal level as the number of channels increases (much like an actual combiner does). The $3.6*\log_2$ term in the formula is intended to represent the QAM modulator's equivalent internal splitter/combiner loss.

Example 1: If the modulator is configured for eight channels per port, the maximum per-channel power is

$60 - \text{ceil}[3.6*\log_2(8)]$
60 – ceil[3.6 * 3]
60 – ceil[10.80]
60 – [11]
49 dBmV

Example 2: If the modulator is configured for 32 channels per port, the maximum per-channel power is

$60 - \text{ceil}[3.6*\log_2(32)]$
60 – ceil[3.6 * 5]
60 – ceil[18]
60 – [18]
42 dBmV

6.5. Assumption Errors

Don't assume or estimate the amount of loss in cables, passives, etc., MEASURE IT. If RF power on multiple frequencies or channels is being measured, be sure to measure the attenuation through cables and other components between the signal source and measurement device at those frequencies. Consider ALL losses in the signal path: coaxial cables (mini-coax and conventional-size coax), connectors and adapters, passives such as splitters and directional couplers, in-line attenuators, and test points. If gain is present in the signal path between the source and measurement device, that must be accounted for, too.

Even though passive devices such as splitters are often said to have flat insertion loss across a wide frequency range, in reality passive device insertion loss at higher frequencies is usually at least slightly greater than it is at lower frequencies. The following table summarizes one vendor's published insertion loss specifications for two-way drop splitters. While the attenuation versus frequency differences aren't significant, they have to be taken into account. Here, too, don't assume; measure the actual insertion loss at the frequencies of interest.

Table 2. Two-way splitter insertion loss

Frequency range	Insertion loss
5 MHz to 65 MHz	3.5 dB
65 MHz to 470 MHz	3.6 dB
470 MHz to 862 MHz	3.8 dB
862 MHz to 1 GHz	3.9 dB
1 GHz to 1.2 GHz	4.2 dB

Coaxial cable attenuation is not uniform across frequency, either – its attenuation is greater at higher frequencies than it is at lower frequencies.

Figure 8 shows an example of the maximum attenuation in dB/100 feet versus frequency for 75-ohm impedance mini-coax.[9] **Figure 9** shows an example of the maximum attenuation versus frequency for Series 59 headend coax. The graphs in the two figures illustrate how coaxial cable attenuation increases

[9] The graph in Figure 8 is derived from attenuation data in ANSI/SCTE 117 2018 "Specification for Braided 75 Ω, Mini-Series Quad Shield Coaxial Cable for CMTS and SDI cables." See https://www.scte.org/SCTEDocs/Standards/ANSI_SCTE%20117%202018.pdf

with frequency, as well as the difference between mini-coax and a larger diameter coax such as Series 59. Be sure to measure the actual attenuation of the cable in use on the frequency or frequencies of interest.

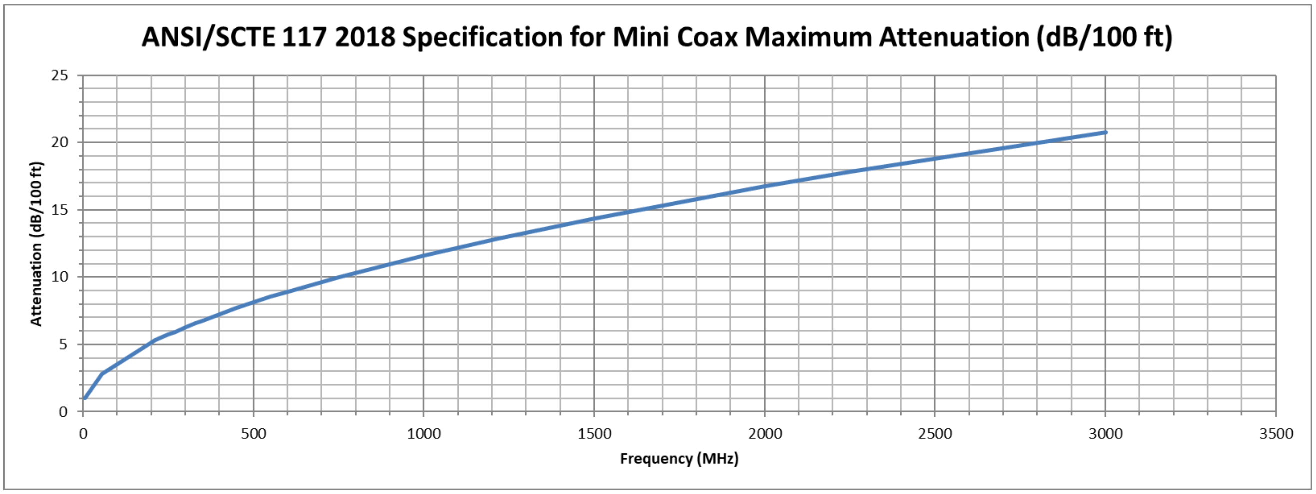

Figure 8. 75 ohm mini-coax maximum cable attenuation versus frequency (data derived from ANSI/SCTE 117 2018)

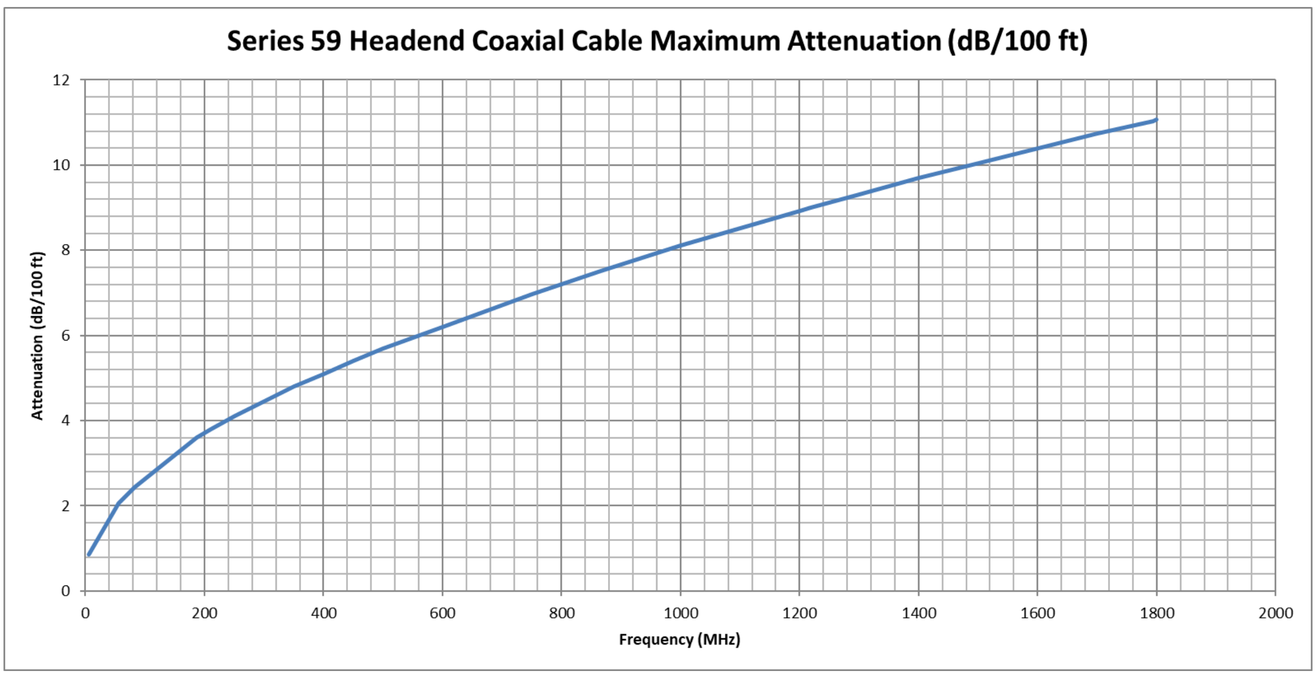

Figure 9. Example of maximum attenuation versus frequency for Series 59 headend coaxial cable

6.6. Tips for More Accurate Measurements

The following recommendations are provided to help ensure more accurate results when measuring downstream RF power.

Note: Take appropriate precautions for electrostatic discharge (ESD) protection when performing the measurements described in this document. If the test equipment is powered from an alternating current (AC) mains connection, if possible connect the test equipment to the same AC circuit as the equipment being measured.

- ✓ In scenarios where highly accurate RF power measurement results are required, be aware that some instruments may not have the required accuracy. For instance, typical handheld field instruments have absolute accuracy specifications in the ±1.5 to ±2.5 dB range.
- ✓ Use test equipment that has been calibrated by the factory or a factory-authorized service center at intervals recommended by the manufacturer.
- ✓ Ensure that the measurement device has sufficient dynamic range to support the desired measurement. In some cases it might be necessary to use an external attenuator connected to the input of the measurement device to prevent instrument overload. If so, be sure to take into account the impact of the additional attenuation on the measurement results.
- ✓ Follow the signal source and measurement device manufacturers' recommendations for adequate equipment warmup time prior to making RF signal level measurements.
- ✓ If the test equipment has a built-in calibration routine available, be sure to use it prior to performing measurements.
- ✓ Some instruments may require additional configuration steps for measurement of different types of signals (e.g., analog TV signal visual carrier levels versus QAM signals). In all cases, follow the test equipment manufacturer's instructions for setup and operation.
- ✓ Ensure that battery-operated test equipment is fully charged prior to use.
- ✓ To the extent possible, minimize the use of adapters, which can degrade measurement accuracy.
- ✓ Ensure that all connectors have been properly installed on test cables, and are adequately tightened on mating interfaces.
- ✓ Check all connectors between the signal source and measurement device (e.g., signal source output, patch panel(s), headend combiner, etc.), and ensure that all are properly tightened.
- ✓ Unused RF ports on combining networks, splitters, couplers, and other devices should be properly terminated using suitable 75-ohm impedance terminators.
- ✓ When checking amplifiers, nodes, and headend or hub site equipment, ensure that all modules, line cards, and plug-in components and accessories are properly seated in their respective chassis slots, housings, and sockets.
- ✓ Where applicable, confirm that the configuration of the signal source (e.g., CMTS or QAM modulator) is correct prior to performing RF power measurements.
- ✓ For signal sources that support multiple channels per port, take into account the reduced power-per-channel with multiple-channel operation compared to single-channel operation.
- ✓ Be sure to add the net attenuation of the interconnection to the measurement device's displayed power reading to determine the source output power. Be aware that the net attenuation of the interconnection might not be uniform across frequency.
- ✓ Do not assume or estimate the amount of attenuation in cables, passives, etc., MEASURE IT at the frequency or frequencies of interest.

Note: To reduce the possibility of damaging the MCX connectors on CMTS line cards, headend combiners, and other MCX-equipped devices, avoid connecting the test equipment directly to the connector. Instead, connect the test equipment to the end of a downstream cable that is already connected to the line card, to a convenient test point, or the output of an external RF switch (if used). Be sure to account for attenuation between the device's MCX connector and test equipment input (if possible, measure the actual loss). In scenarios where a direct connection must be made to a device's MCX connector (e.g., when troubleshooting possible connector or mini-coax problems), carefully connect an MCX connector-equipped test cable to the port in question, ensuring that the test cable's MCX connector is properly mated to the device's MCX connector.

6.7. Signal Source Configuration

Before measuring CMTS or QAM modulator downstream RF signal level, ensure that the signal source's configuration is correct. Consult the respective manufacturer's documentation for configuration and monitoring commands and data access.

7. Signal Level Measurement Examples

The following two examples illustrate the impact of various factors on the accuracy of signal level measurements.

7.1. Example 1

Assume that a QAM modulator is configured via its setup menu to generate a single QAM signal whose frequency is 750 MHz at an output level of +50 dBmV (digital channel power). The desire is to measure the output power to confirm the modulator's configuration. The following table summarizes the various factors affecting the measurement. What is the worst-case measurement error?

Table 3. Parameters for Example 1

Parameter	Tolerance
Modulator output +50 dBmV @ 750 MHz	±2 dB
10 ft. mini-coax jumper loss (0.92 dB/10 ft. @ 750 MHz)	N/A
Test equipment measurement accuracy	±2 dB

Figure 10 illustrates this example.

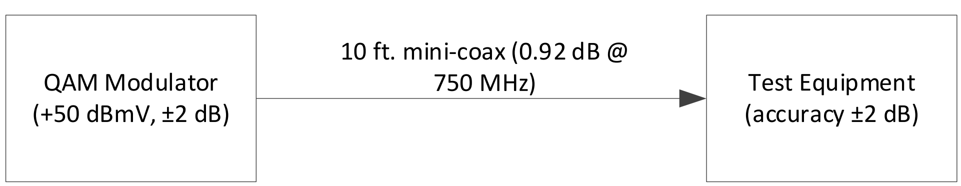

Figure 10. Block diagram for Example 1

In a perfect world, the modulator output would be exactly +50 dBmV, the coax loss exactly 0.92 dB, and the net input power to the test equipment exactly +49.08 dBmV. The instrument would display the net input power, or +49.08 dBmV. Adding back the loss of the 10 ft. length of coax, 0.92 dB, to the reported power would yield the modulator's +50 dBmV output power.

In reality, the following factors will affect the test equipment's reported power. First, the modulator's ±2 dB calibration accuracy means the actual output power could be anywhere in the +48 dBmV to +52 dBmV range when the device is configured for +50 dBmV. The test equipment's reported power could be as much as 2 dB below or above its net input power.

In a worst-case scenario, all of the measurement errors would be at their extremes in the same direction and add constructively. For example, the modulator's actual output power might be +48 dBmV and the test equipment accuracy at the -2 dB point. Thus, the net input power to the test equipment would be +48 dBmV – 0.92 dB = +47.08 dBmV. However, instead of reporting +47.08 dBmV, the instrument would report 2 dB low, or +45.08 dBmV.

Practically speaking, the measurement errors are unlikely to be at their extremes, and even if they were, the errors probably would not all be in the same direction. There is a method known as root sum of squares, or RSS, that can be used to combine measurement uncertainties/errors and provide a more realistic total uncertainty. However, RSS is beyond the scope of this paper. See [3] and [4] in **3.3 Published Materials** for more information on RSS.

7.2. Example 2

Assume that a QAM modulator is configured via its setup menu to generate a single QAM signal whose frequency is 750 MHz at an output level of +50 dBmV (digital channel power). The desire is to measure the output to confirm the modulator's configuration. The following table summarizes the various factors affecting the measurement. What is the worst-case measurement uncertainty?

Table 4. Parameters for Example 2

Parameter	Tolerance
Modulator output +50 dBmV @ 750 MHz	±2 dB
10 ft. mini-coax jumper loss (0.92 dB/10 ft. @ 750 MHz)	N/A
Directional coupler test point loss (20 dB)	±0.5 dB
Second 10 ft. mini-coax jumper loss (0.92 dB/10 ft. @ 750 MHz)	N/A
Test equipment measurement accuracy	±2 dB

Figure 11 illustrates this example.

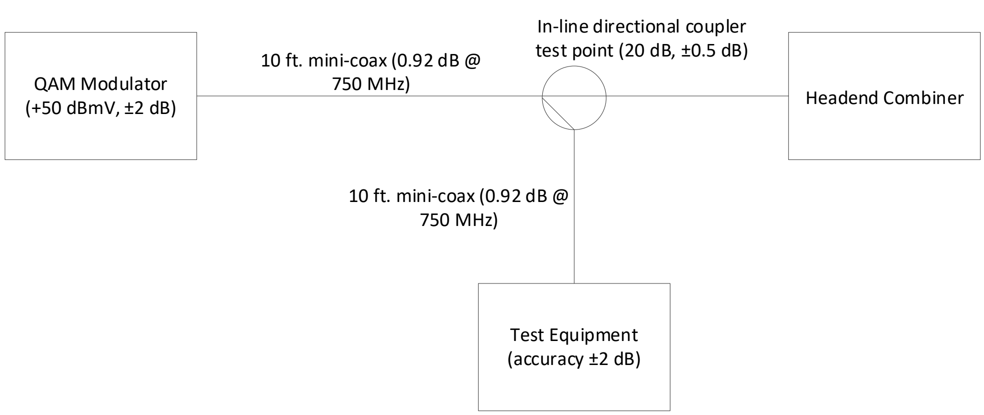

Figure 11. Block diagram for Example 2

As was the case in Example 1, if there were no measurement tolerance or error to worry about, the modulator output would be exactly +50 dBmV, the first 10 ft. length of coax loss would be exactly 0.92 dB, the directional coupler insertion (tap) loss exactly 20 dB, the second 10 ft. length of coax loss exactly 0.92 dB, and the net input power to the test equipment exactly +28.16 dBmV. The instrument would display the net input power, or +28.16 dBmV. Adding back the total interconnection loss, 21.84 dB, to the reported power would yield the modulator's +50 dBmV output power.

In a worst-case scenario, all of the measurement tolerances/errors would be at their extremes in the same direction and add constructively. For example, the modulator's actual output power might be +48 dBmV, the directional coupler tap loss 20.5 dB, and the test equipment accuracy at the -2 dB point. The net input power to the test equipment would be +48 dBmV – (0.92 dB + 20.5 dB + 0.92 dB) = +25.66 dBmV. However, instead of reporting +25.66 dBmV, the instrument would report 2 dB low, or +23.66 dBmV. Adding back the assumed interconnection loss (0.92 dB + 20 dB + 0.92 dB) would mean the assumed modulator output power is +45.5 dBmV, or 4.5 dB below the configured output. If the actual interconnection loss (0.92 dB + 20.5 dB + 0.92 dB) were known, the assumed modulator output power would be +23.66 dBmV + 0.92 dB + 20.5 dB + 0.92 dB = +46 dBmV, or 4 dB below the configured output.

Here, too, the measurement tolerances/errors are unlikely to be at their extremes, and even if they were, they probably would not all be in the same direction.

8. Conclusion

Measurement of a cable network's downstream RF signal levels is often taken for granted and assumed to be fairly straightforward. Rarely, however, is signal level measurement as simple as connecting a piece of test equipment to a test point or signal source output connector.

Some important factors must be taken into consideration, such as measurement device absolute measurement accuracy compared to the accuracy of the signal source. Typical handheld field instruments are fine for most routine plant and subscriber drop measurements, but generally don't have the necessary accuracy to confirm whether a CMTS or QAM modulator meets published specifications. For example, one cannot use a measurement device with a published accuracy spec of ±2.5 dB to accurately measure a signal source whose published RF output level accuracy is, say, ±1.5 dB.

Other factors discussed in this Operational Practice must be accounted for when performing RF signal level measurements, all of which will affect a measurement device's reported signal level. For more in-depth information about measurement of RF signal levels, the reader is encouraged to review some or all of the material listed in **3. Informative References**.

9. Appendix

9.1. How to Calculate Base 2 Logarithms

The equation in Table 6.4 of the DRFI specification that is used to calculate required power in dBmV per channel for multiple channels per port is 60 – ceil[3.6*$\log_2$(N')]. Note that the logarithm function in the equation is base 2 ($\log_2$), not the more common base 10 ($\log_{10}$).

Scientific calculators have a base 10 logarithm function. Some scientific calculators also have a natural logarithm (ln) – also called base e or $\log_e$ – function. How can one calculate the base 2 logarithm of a given quantity? The following examples illustrate two ways to do so using base 10 and natural logarithm functions.

9.1.1. Base 10 logarithm method

To find the base 2 logarithm of a quantity x, use the formula

$\log_2(x) = \log_{10}(x)/\log_{10}(2)$

For example, calculate the base 2 logarithm of the number 24.

$\log_2(24) = \log_{10}(24)/\log_{10}(2)$
$\log_2(24) = 1.380211/0.301030$
$\log_2(24) = 4.584963$

9.1.2. Natural logarithm method

To find the base 2 logarithm of a quantity x, use the formula

$\log_2(x) = \ln(x)/\ln(2)$

For example, calculate the base 2 logarithm of the number 24.

$\log_2(24) = \ln(24)/\ln(2)$
$\log_2(24) = 3.178054/0.693147$
$\log_2(24) = 4.584963$