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Interface Practices Subcommittee

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SCTE 109 2019

Test Procedure for Common Path Distortion (CPD)

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1. Introduction

1.1. Executive Summary

Reliable operation of today's two-way cable networks is critical, especially considering that upstream transmission in the return path includes telephone, high-speed data, and various telemetry and other signals. Common path distortion (CPD) is a type of impairment that can affect the quality of those upstream signals. This document describes test procedures for the characterization of CPD in lab and field environments.

1.2. Scope

The purpose of this document is to establish the standard methodology used to measure CPD in both a lab and in a live cable network.

The lab procedure is a very unique procedure for measuring common path distortion and distinguishes itself from other similar procedures in the following ways:

- Single port measurement, measures reflected energy

- Inject two forward carriers separated by 6 MHz and measure return beat at 6 MHz

- Used to verify performance of single port passives such as terminators or passives with all other ports terminated. Designed to be consistent with the mechanisms that cause common path distortion in outside plant.

A procedure also is included to adapt and extend the lab test method to a live cable network, involving the injection of downstream carriers at certain frequencies in the headend or hub, and measuring an upstream beat (or beats) at a headend/hub upstream test point.

The examples in this document focus on a 5 MHz to 42 MHz upstream spectrum, although other upstream bandwidths can be used (e.g., 5 MHz to 85 MHz). The methods described in this document can be adapted to any choice of upstream spectrum bandwidths without materially impacting the results.

1.3. Benefits

This document describes standard methodology that can be used for characterizing CPD in a lab and field environment. In particular, the lab method is unique in that it supports CPD characterization of single-port devices. An extension of the lab method intended for use in a live cable network can be thought of as treating the entire network as a single-port "black box" of sorts. The procedures in this document can augment other CPD test and measurement techniques used by the cable industry.

1.4. Intended Audience

The intended audience for this document includes technicians, engineers, and others with an interest in measuring CPD in a lab environment and/or in a live cable network.

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

One suggested area for further investigation is follow-up field evaluation of the method described in Section 9.3 Live Plant Third Order CPD Test.

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

- ANSI/SCTE 144 2017: Test Procedure for Measuring Transmission and Reflection

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.

Each of these procedures targets a different measurement for a unique purpose. They are independent, are specifically applicable to the device being measured, use the test equipment commonly available at the manufacturing sites used to make the device being tested, and directly measure the impairment that must be controlled. The key differences are whether they are designed for actives or passives and whether they are single port or two port measurements. Other differences are the types of distortion products being measured and the filters required to do so.

3.1. SCTE References

- ANSI/SCTE 115 2019: Test Method for Reverse Path (Upstream) Intermodulation Using Two Carriers
- ANSI/SCTE 126 2019: Test Method for Distortion of 2-way Active Amplifier Caused by Insufficient Isolation of Built in Diplex Filter
- ANSI/SCTE 145 2015: Test Method for Second Harmonic Distortion of Passives Using a Single Carrier

3.2. Standards from Other Organizations

- No informative references are applicable.

3.3. Published Materials

- Williams, T., Rupe, J., "Common Path Distortion (CPD) in Digital Cable Networks." SCTE·ISBE *Journal of Network Operations*, Volume 4, Number 1 December 2018

- Williams, T., Hamzeh B., Hranac, R., "Field Measurements of Nonlinear Distortion in Digital Cable Plants." 2014 NCTA Technical Papers
- Large, D., Farmer, J., *Broadband Cable Access Networks*. © 2009 Morgan Kaufmann Publishers
- Ciciora, W., Farmer J., Large D., Adams, M., *Modern Cable Television Technology, 2nd Ed*. © 2004, Morgan Kaufmann Publishers
- Raskin, D., Stoneback, D., *Broadband Return Systems for Hybrid Fiber/Coax Cable TV Networks*. © 1998, Prentice Hall PTR
- Patel, B. "Report on Common Path Distortions." February 1998
- Reichert, Jr., H., "CATV System Return Path Interference." 1982 NCTA Technical Papers

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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.
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5. Abbreviations and Definitions

5.1. Abbreviations

AC	alternating current
ANSI	American National Standards Institute
°C	degree Celsius
CPD	common path distortion
CSO	composite second order
CTB	composite triple beat
CW	continuous wave
dB	decibel
dBc	decibel carrier
dBmV	decibel millivolt
DC	direct current
DUT	device under test
ISBE	International Society of Broadband Experts

kHz	kilohertz
MHz	megahertz
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
TV	television

5.2. Definitions

common path distortion (CPD)	Common path distortion is intermodulation distortion of downstream signals due to nonlinearities found at metallic junctions. The distortions are manifest as a series of beats (caused by analog downstream channels) or a band(s) of noise (caused by digital downstream channels) most noticeably in the upstream path. CPD may also be present in the downstream path, but since it adds with other downstream distortions (i.e., CTB and CSO), caused by active components, it is difficult to differentiate between the two. The nonlinear behavior found at passive junctions may be due to a number of reasons including corrosion, typically from exposure to the elements, dissimilar metals, improper contact pressure, and junctions involving connectors contaminated with carbonaceous materials.

6. CPD Overview

Common path distortion is a well-known impairment that affects a cable network's return path. CPD comprises nonlinear distortions other than those generated in active devices, and which appear in the upstream spectrum. While CPD can include higher order distortions, second and third order distortions are generally the most prevalent. In operating cable networks, CPD is usually in the class of composite distortions, similar to composite second order (CSO) and composite triple beat (CTB) distortions generated in active devices.

CPD occurs when downstream RF signals pass through a diode-like nonlinearity, typically at interfaces where corrosion has formed in the signal path common to the downstream and upstream spectrums. The resulting oxide layer behaves somewhat like a semiconductor, and can be just a few molecules thick, making it fragile and susceptible to being affected by wind, vibration, temperature changes, and so on. All of the aforementioned, in addition to varying downstream RF signal levels, complicate location and troubleshooting of CPD sources.

Some of the CPD generated by the diode-like nonlinearity occurs in the downstream and some in the upstream. The downstream CPD appears on the same frequencies as existing downstream composite distortions (CSO and CTB) and cannot be easily differentiated from CSO and CTB produced by active devices.[1] What is of concern in this document is the distortions that appear in the upstream spectrum, which propagate toward the node and headend/hub. When the cause of the CPD is identified and repaired, the CPD that was occurring in both directions will be eliminated.

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[1] Experience is that downstream composite distortions falling into the upstream spectrum are effectively filtered right after the downstream actives that generate them, with no appreciable distortions observed leaking into the upstream. Also, upstream-generated composite distortions are rare, and in any case, active device-generated distortions in the upstream will quiet when there is no (or little) upstream granted modulated spectrum, but CPD will persist in the upstream (if it occurs), making separation of active device-generated distortions and CPD in the upstream simple, unlike in the downstream.

The corrosion "diode" that produces CPD doesn't always behave in a predictable manner, as one might expect from an actual diode. As such, CPD can appear as second order beats, third order beats, or a combination of second and third order beats. The amplitude of those beats across the return spectrum can vary significantly, too.

In cable networks that carry mostly analog TV signals in the downstream, the CPD beat clusters appear every 6 MHz (8 MHz in European systems). Figure 1 shows an example of second and third order CPD in an older mostly-analog system. The second order beats appear at 6 MHz and 12 MHz (both partially obscured by ingress), and 18 MHz, 24 MHz, 30 MHz, 36 MHz (partially obscured by the cable modem signal), and 42 MHz. Third order beats appear 1.25 MHz below and 1.25 MHz above each second order beat.
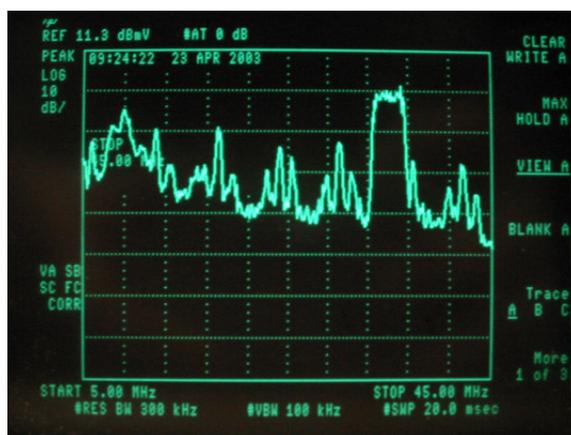
Figure 1 - CPD in a cable network carrying mostly analog TV signals in the downstream.

In a mostly- or all-digital network, CPD is noise-like, and often appears as an elevated noise floor in the upstream spectrum. Figure 2 shows an example of CPD visible in the upstream spectrum's noise floor. Note that the CPD has an appearance similar to downstream SC-QAM signals with slight gaps every 6 MHz. CPD in a digital network can also look like an elevated noise floor without the gaps.
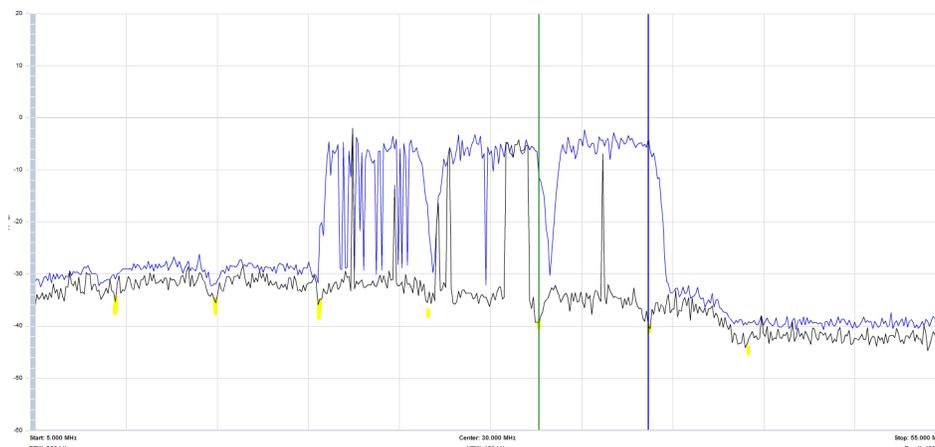
Figure 2 - CPD in a cable network carrying mostly- or all-digital signals in the downstream. (Graphic courtesy of JDSU/Viavi)

7. Equipment Requirements

The following table summarizes a list of equipment that can be used for the tests described in this document.

Qty.	Description
1	spectrum analyzer, AGILENT 8568B or equivalent
1	network analyzer, AGILENT E5071B or equivalent
1	calibration kit, network analyzer
2	RF signal generators, AGILENT 8657B or equivalent
1	current clamp, to measure current passing through active DUT
1	environmental chamber, programmable, capable of -40 °C to 60 °C, Tenney Engineering, Inc., Model TTC or equivalent
1	diplexer, low-pass ≤ 42 MHz, high-pass ≥ 54 MHz, Eagle EDPF-42/54 or equivalent
1	bi-directional amplifier, capable of amplifying signals below 42 MHz in one direction and signals above 54 MHz in the other, GI Starline 2000, BLE-86S or equivalent
1	splitter, 2-way, PCT-NGNII-2S or equivalent used for combining
1	power supply, AC (quasi-square-wave)
2	power inserters, Lindsay Electronics LHI100H or equivalent
1	power load, adjustable, to pull desired current through DUT
1	thermometer, Fluke 29 digital multimeter with Fluke 80TK thermocouple module and Fluke 80PK-1 or equivalent to measure chamber temperature
A/R*	terminators
1	torque wrench, Mitutoyo 983-201 or equivalent

A/R – as required

8. Equipment Setup and Test Procedure (Lab CPD Test)

8.1. Upstream Passband Characterization

1. Calibrate the network analyzer for a transmission path measurement, from 5 MHz to 42 MHz, per the manufacturer's instructions.
2. Set up the equipment as shown in Figure 3 and terminate any unused ports.
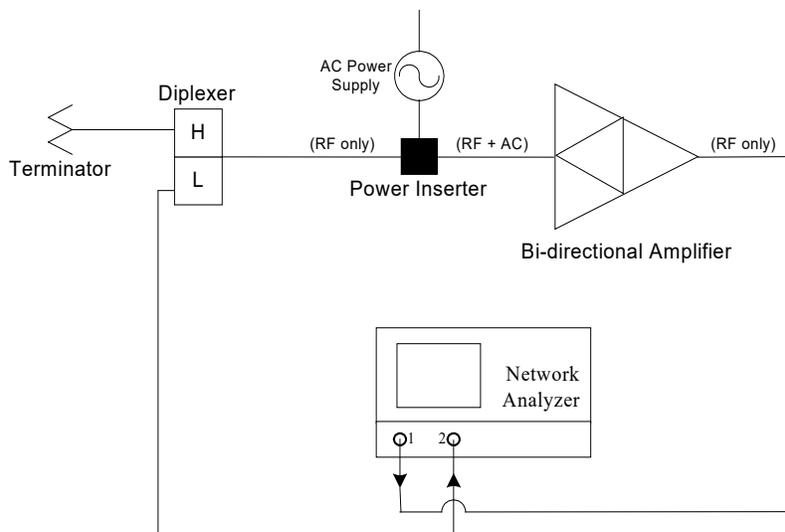
Figure 3 - Upstream Passband Characterization

Note: The bi-directional amplifier can be DC powered, eliminating the need for the AC power supply and power inserter.

3. Measure and record the frequency response and gain of the upstream passband from 5 MHz to 42 MHz. (*Reference* ANSI/SCTE 144 2012: Test Method for Insertion Gain and Loss, Frequency Response and Bandwidth.) This is defined as 'Gain.'

8.2. Stimulus Setup

1. Calibrate the spectrum analyzer per the manufacturer's instructions.
2. Set up the equipment as shown in Figure 4. Make sure to use the same cables used in Section 7, Step 2.
3. Set the resolution bandwidth of the spectrum analyzer to 30 kHz.
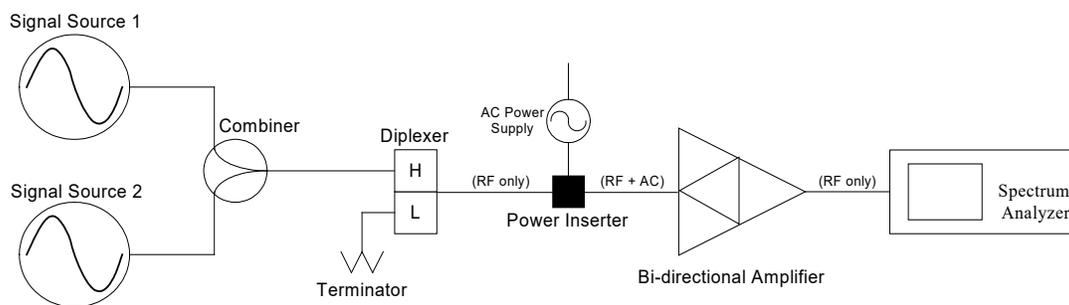
Figure 4 - Stimulus setup

4. Set Signal Source 1 and Signal Source 2 to two adjacent video carrier frequencies, 6 MHz spacing, within the downstream passband (54 MHz to 1002 MHz). Make sure to select frequencies that are within the downstream passband of the bi-directional amplifier.
5. Adjust the output of each signal source to 50 dBmV at the spectrum analyzer. This is defined as the 'Y carrier.'

8.3. Equipment Setup (Passive Device)

1. Set up the equipment as shown in Figure 5.
2. Set the spectrum analyzer as follows:

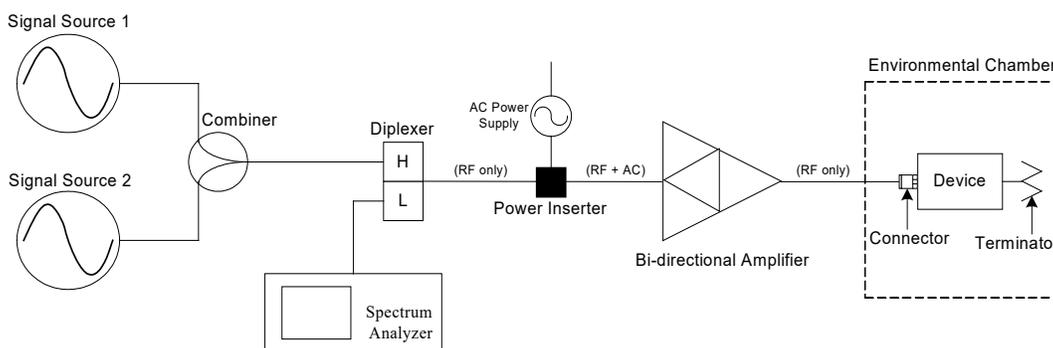|	
Start Frequency:	5 MHz
Stop Frequency:	42 MHz
RBW:	30 kHz
VBW:	1 kHz
Attenuation:	0 dB
Reference Level:	0 dBmV

Figure 5 - Test setup for passive device

8.4. Equipment Setup (Power Passing Device)

1. Set up the equipment as shown in Figure 6.

Note: To avoid damaging equipment, make sure that AC power is not present on cables going to or from RF test equipment prior to connecting the equipment.

2. Set the spectrum analyzer as follows:

|	
Start Frequency:	5 MHz
Stop Frequency:	42 MHz
RBW:	30 kHz
VBW:	1 kHz
Attenuation:	0 dB
Reference Level:	0 dBmV
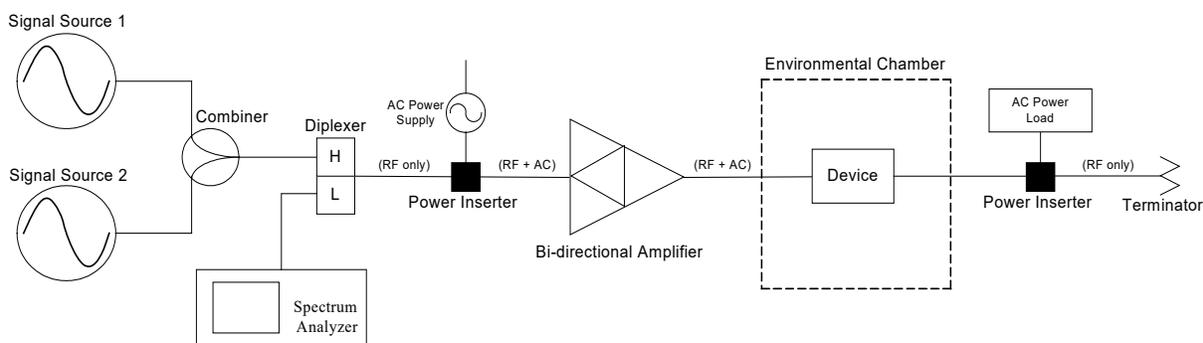
Figure 6 - Test setup for power passing device

Note: The bi-directional amplifier *may* be DC powered, allowing the AC power supply and power inserter to be placed between the bi-directional amplifier and the device under test (DUT), if desired.

3. Adjust the AC Power Load for the desired current.

8.5. Lab test Procedure

1. Measure and record the spectral response from 5 MHz to 42 MHz. If available, use a software program to capture the spectrum analyzer trace point by point.
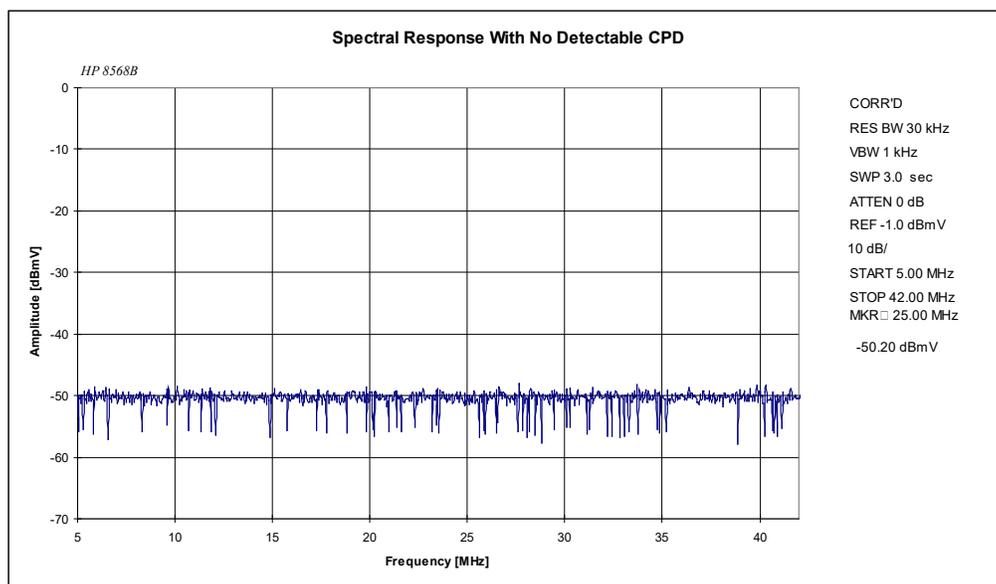
Figure 7 - Spectral response with no apparent CPD

2. Program the environmental chamber to cycle from -40 °C (±1 °C) or mfr. specified minimum operating temperature to 60 °C (±1 °C) or mfr. specified maximum operating temperature, with two hour dwell times at each temperature extreme and one hour ramp times between temperature extremes, for a period of 14 days.
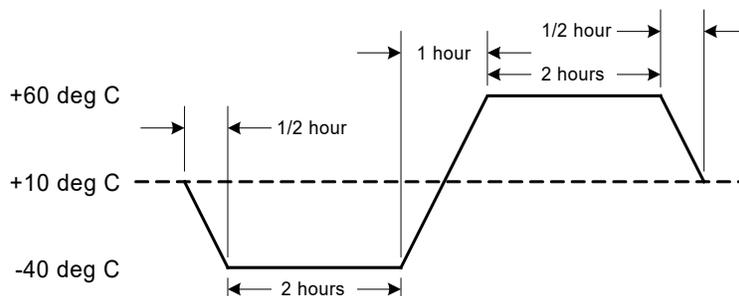
Figure 8 - Thermal cycle profile

3. Measure and record the spectral response from 5 MHz to 42 MHz twice daily for 14 days of thermal exposure. Make one measurement at minimum and one measurement at maximum temperatures. Use spectrum analyzer "peak hold" function to capture worse case data.

9. Equipment Setup and Test Procedure (Live Plant CPD Test)

9.1. Discussion

The test method described in this document also can be used (with slight modification) to test for CPD in a live cable network. Two CW carriers injected into the downstream RF spectrum at the headend or hub site can, if a CPD "corrosion diode" exists in the outside plant, produce CPD visible in the upstream spectrum. By choosing suitable frequencies for the two downstream CW carriers, second and third order CPD can appear in the upstream and be viewed/measured on a spectrum analyzer connected to a return path test point. Figure 9 shows an example of second order CPD created using this method.
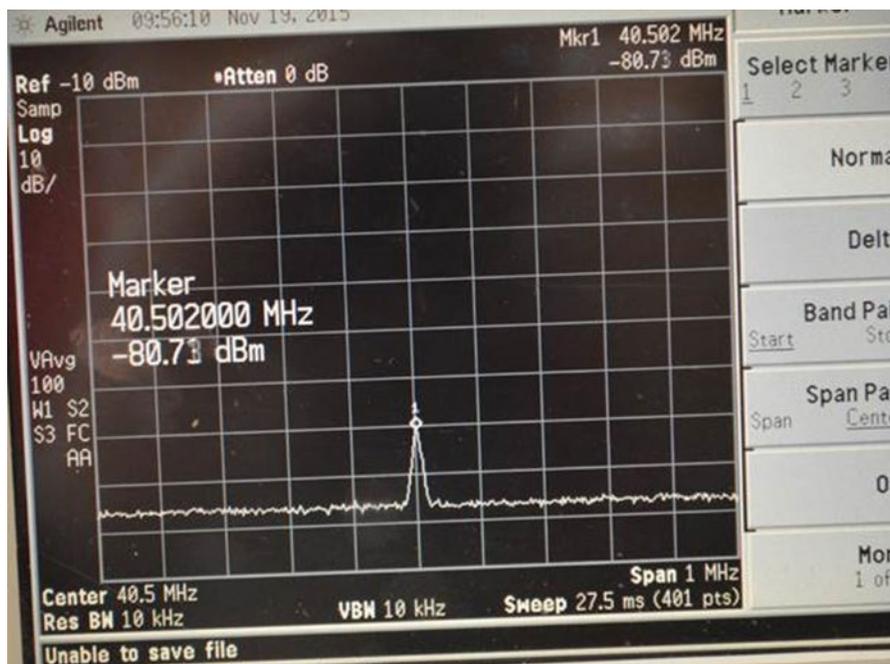
Figure 9 - A CW second order distortion beat product observed at a cable system's headend upstream test point. The beat was created as a difference product between two downstream test CW carriers at 840.5 MHz and 800 MHz.

In some cases the method described here can result in a CPD second order beat that is amplitude modulated at a 120 Hz rate (twice the 60 Hz AC mains frequency), as seen in Figure 10. One possible cause of the amplitude modulated CPD beat is believed to be the result of a loose seizure screw somewhere in the distribution network, through which several amperes of AC line powering are passing. The loose screw results in both a resistive connection and a corrosion diode.

The amplitude of the observed CPD beat can be measured, and compared to the received RF signal level (e.g., SC-QAM digital channel power) of desired upstream signals to determine the carrier-to-CPD ratio.
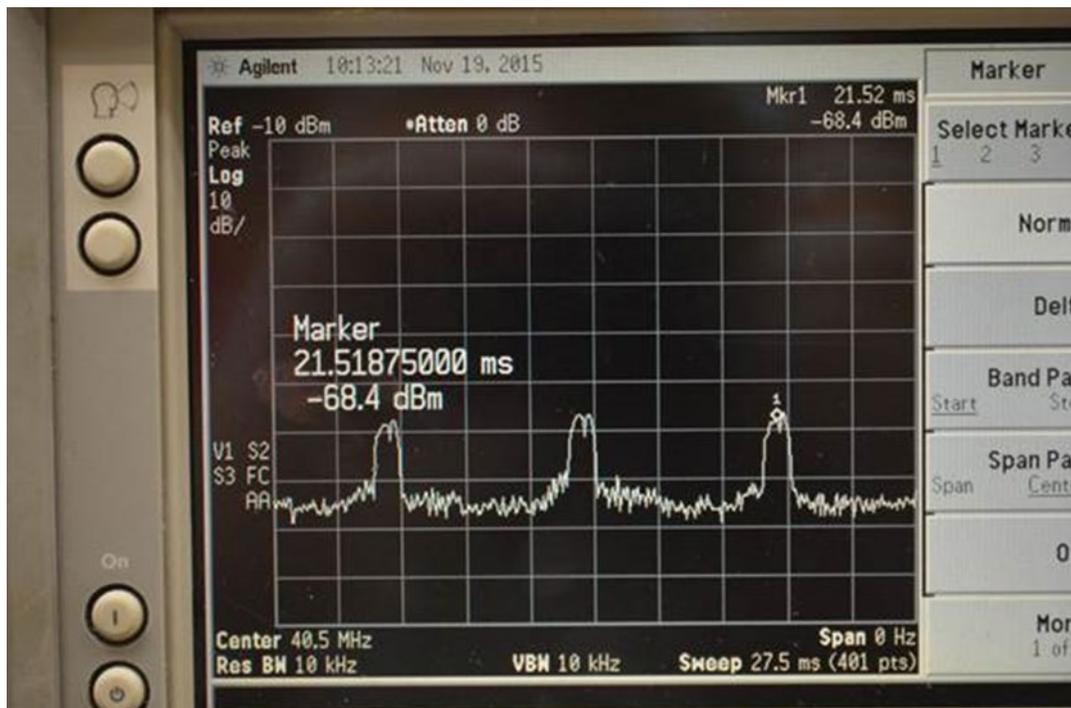
Figure 10 - A second order distortion beat (40.5 MHz) observed at a cable system's headend upstream test point. The beat, shown with the analyzer in zero span mode, is amplitude modulated at a 120 Hz rate.

9.2. Live Plant Second Order CPD Test

Set up the equipment as shown in Figure 11.

Configure Signal Source 1 to generate a downstream CW carrier on frequency F1, for example, 800 MHz; configure Signal Source 2 to generate a downstream CW carrier on frequency F2, for example, 840.5 MHz. (Note: The frequencies of F1 and F2 should be chosen such that F2 – F1 equals a second order frequency that falls within a clear spot in the upstream spectrum, in this example 840.5 MHz – 800 MHz = 40.5 MHz. As well, F1 and F2 should occupy unused downstream spectrum, although one of the CW carriers could be an existing legacy CW AGC pilot carrier.)

Set the amplitude of each CW carrier to be equal to analog visual carrier peak envelope power (e.g., 6 dB higher than SC-QAM digital channel power).

Set the spectrum analyzer as follows

Start frequency: 5 MHz

Stop frequency: 42 MHz

RBW: 30 kHz

VBW: 1 kHz

Attenuation: 0 dB

If, when the two test carriers F1 and F2 are present in the downstream spectrum, CPD is observed at the upstream second order beat frequency (F2 – F1), measure the amplitude of the difference beat and compare it to the amplitude of desired upstream signals (e.g., cable modem upstream SC-QAM signals).

9.3. Live Plant Third Order CPD Test

Note: A method similar to the second order test can be used to measure third order CPD. The third order test method has not been validated in the field, but in a plant where third order CPD is problematic, the test method should work as described in this section.

Set up the equipment as shown in Figure 11.

Configure Signal Source 1 to generate a downstream CW carrier on frequency F1, for example, 420 MHz; configure Signal Source 2 to generate a downstream CW carrier on frequency F2, for example, 800 MHz. (Note: The frequencies of F1 and F2 should be chosen such that the 2F1 – F2 equals a third order frequency that falls within clear spot in the upstream spectrum, in this example 2(420 MHz) – 800 MHz = 40 MHz. As well, F1 and F2 should occupy unused downstream spectrum, although one of the CW carriers could be an existing legacy CW AGC pilot carrier.)

Set the amplitude of each CW carrier to be equal to analog visual carrier peak envelope power (e.g., 6 dB higher than SC-QAM digital channel power).

Set the spectrum analyzer as follows

Start frequency: 5 MHz

Stop frequency: 42 MHz

RBW: 30 kHz

VBW: 1 kHz

Attenuation: 0 dB

If, when the two test carriers F1 and F2 are present in the downstream spectrum, CPD is observed at the upstream third order beat frequency (2F1 – F2), measure the amplitude of the beat and compare it to the amplitude of desired upstream signals (e.g., cable modem upstream SC-QAM signals).
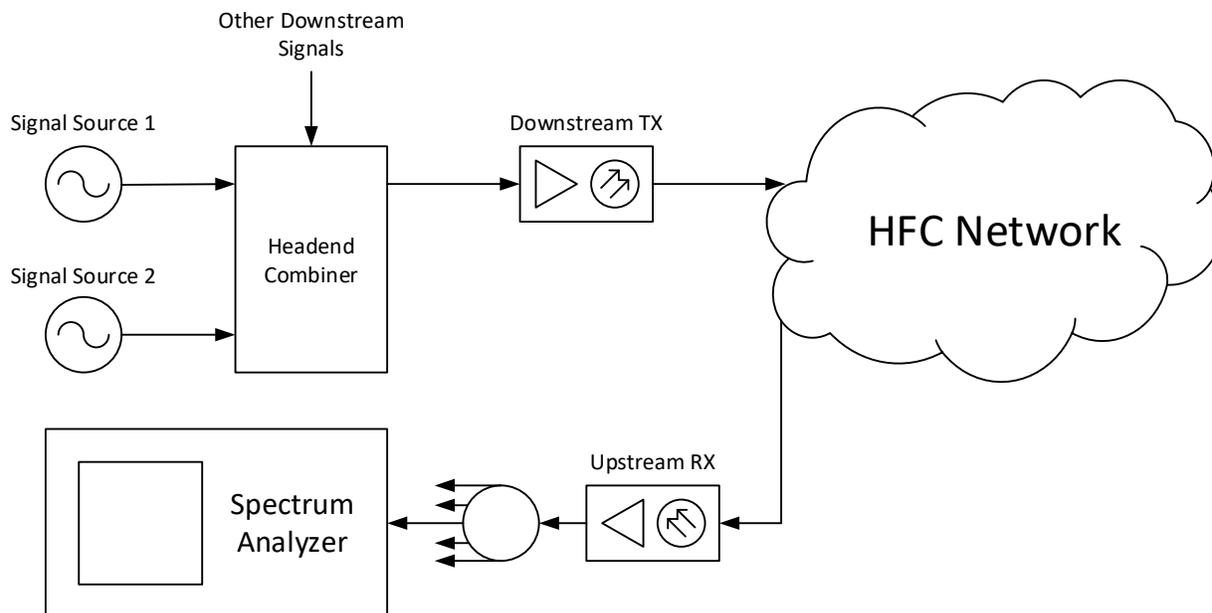
Figure 11 - Test setup for live cable plant test.

10.   Calculating CPD

1.   Use the following formula to calculate CPD.

$$\mathbf{CPD = X_{CPD} - Gain - Y_{Carrier}} \qquad \mathbf{(1)}$$
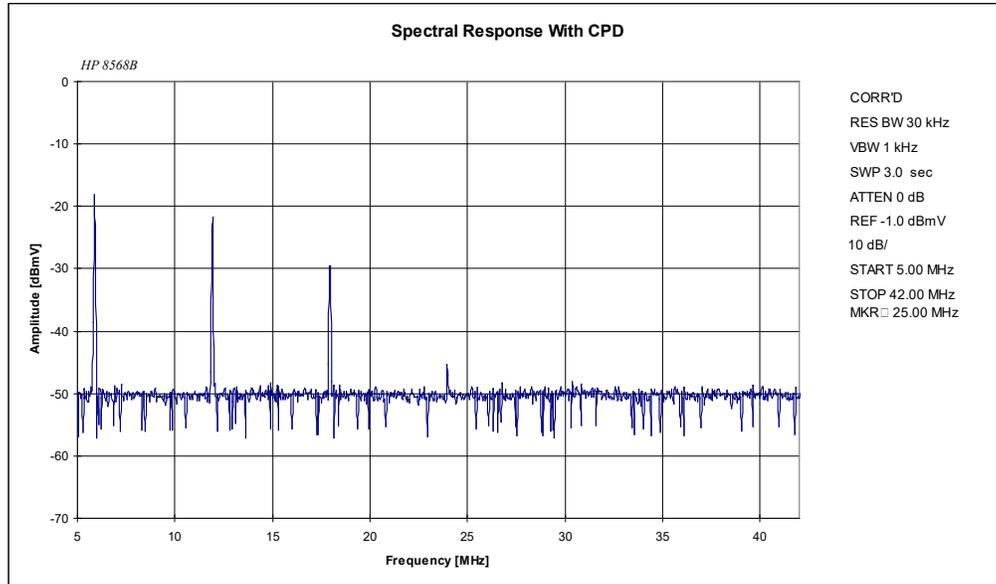
Where:

CPD – common path distortion [dBc]
X_{CPD} – signal level of CPD [dBmV]
Gain – return path gain [dB]
$Y_{Carrier}$ – signal level of carrier at input to DUT [dBmV]

Note: If common path distortion (CPD) is less than 10 dB above the noise floor of the analyzer, additional adjustments *may* be needed to compensate for the noise floor of the analyzer.

2.   Example calculation

Figure 12 - Spectral response with CPD.

Consider the plot with CPD in Figure 12. The level of X_{CPD} is indicated by the highest level in the spectral response.

signal level of Signal Source 1 and 2 at DUT = 50 dBmV

signal level of X_{CPD} at 6 MHz = -18 dBmV

return path gain at 6 MHz = 14 dB

CPD at 6 MHz [dBc] = -18 [dBmV] – 14 [dB] – 50 [dBmV]

$$= -82 \text{ dBc}$$

11. Appendix A: Data recording Template

Signal Source 1: Frequency [MHz] = _____, Amplitude [dBmV] = _____

Signal Source 2: Frequency [MHz] = _____, Amplitude [dBmV] = _____

Date	DUT	Chamber Temperature [°C]	CPD Frequency [MHz]	Level of CPD [dBc]