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Interface Practices Subcommittee

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Test Procedure for Hum Modulation

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Note: This document is a reaffirmation of SCTE 16 2018. No substantive changes have been made to this document. Information components may have been updated such as the title page, NOTICE text, headers, and footers.

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1. Introduction

1.1. Executive Summary

This test procedure provides instructions for how to measure hum modulation in active and passive broadband RF telecommunications equipment (taps, line passives, RF Amplifiers, Optical Nodes, etc.) in a laboratory environment. This procedure is not intended for field measurements.

1.2. Scope

The purpose of this test procedure is to define and measure hum modulation in active and passive broadband RF telecommunications equipment and sub-assemblies. This procedure presents two methods for measuring hum modulation in the time domain, with a sensitivity exceeding -80 dB. These methods are referred to as the 1 dB delta and the differential voltage method. A mathematical relationship between time domain and frequency domain measurement methods is also provided.

This document provides specifications or procedures for frequencies up to 1002 MHz. DOCSIS 3.1 specifications include operation at frequencies up to 1218 MHz, and optionally, to 1794 MHz. Specifications or procedures for those higher frequencies should be considered in a future revision of this document.

1.3. Benefits

In a coaxial telecommunications system, AC power and radio frequency (RF) signals can exist on the same conductor. As a result, amplitude modulation of the transmitted signals at the power line frequency (hum modulation) can occur in both active and passive equipment due to excessive ac voltage at the output of a local power pack (in the case of an active device) or from parametric modulation of magnetic components (used in circuitry to separate power and signal voltages) in active or passive devices.

In North American NTSC analog television systems, the frame repetition rate is 59.94 Hz and the commercial power frequency is 60 Hz. Amplitude modulation of the transmitted signals at the power line frequency (hum modulation) can cause picture disruption in the form of horizontal bars or brightness variation. Excessive hum modulation could also disrupt AGC circuitry commonly used in RF amplifiers, causing excessive RF level variations in the HFC plant.

The FCC (Title 47, Part 76.605) requires that hum modulation does not exceed 3% of the visual signal level.

This test procedure for hum modulation, when executed according the procedure, will yield confidence in the measured hum modulation performance of the active or passive broadband RF telecommunications equipment under test. Use of this test procedure provides a means for the user to verify acceptable performance of the unit under test.

1.4. Intended Audience

The intended audience for this test procedure includes manufacturers, corporate engineers, technical operations, and technicians.

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

None at the time of update.

Specifications or procedures for frequencies above 1002 MHz should be considered in a future revision of this document.

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 96, 2013, Cable Telecommunications Testing Guidelines

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

- ANSI/SCTE 82, 2012, Test Method for Low Frequency and Spurious Disturbances

3.2. Standards from Other Organizations

- 47eCFR76, Electronic Code of Federal Regulations (e-CFR), Title 47, Telecommunication, Part 76, Subpart K, 76.605 – Multichannel Video and Cable Television Service

3.3. Published Materials

- Ciciora, Farmer, Large, Adams. (2004) *Modern Cable Television Technology (2nd Edition)*. San Francisco: Morgan Kaufmann. P461-463, 631

4. Compliance Notation

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5. Abbreviations and Definitions

5.1. Abbreviations

AC	alternating current
AM	amplitude modulation
dB	decibel
DC	direct current
DUT	device under test
FCC	Federal Communications Commission
GHz	gigahertz
HFC	hybrid fiber-coax
Hz	hertz
kHz	kilohertz
ms	millisecond
mv	millivolt
RF	radio frequency
SCTE	Society of Cable Telecommunications Engineers
VSWR	voltage standing wave ratio

5.2. Definitions

Hum Modulation	The amplitude distortion of a signal caused by the modulation of the signal with components of the power source. It is the ratio, expressed in dB, of the peak to peak variation of the carrier level caused by AC power line frequency products (and harmonics up to 1 kHz) to the peak voltage amplitude of the carrier.
Peak Voltage Amplitude	The maximum voltage amplitude of the carrier.

Percent Hum Modulation	Hum Modulation may also be expressed as a percentage of the peak to peak variation of the carrier level to the peak voltage amplitude of the carrier. See Appendix 3 for a derivation of percent Hum.

6. Background

In a coaxial telecommunications system, where AC power and radio frequency (RF) signals exist on the same conductor, hum modulation of a television signal is measured as a comparison between the modulation envelope (created by line power distortions of the RF carriers), and the peak voltage of the sync tips of the video signal.

In a laboratory test environment, the video signal is replaced with a sine wave RF carrier. Under these conditions, the only modulation existing on the carrier is the line power related distortion (created by the device under test) of that carrier. Hum modulation is determined as a function of the line frequency current passing through the device by comparing the peak to peak modulation envelope of the power line distortion to the peak voltage of the carrier by utilizing a diode detector.

Due to the non-linear characteristics of any diode detector, it is inaccurate to simply compare the AC modulation voltage and the rectified DC carrier voltage directly due to the voltage drop across the diode. Instead, the modulation voltage is compared to a calibrated change in the rectified carrier.

There are two time-domain methods for measuring hum modulation in a laboratory environment, which are detailed in this procedure. These methods are commonly referred to as the 1 dB delta method, and the differential voltage method. These methods are described in Appendix 5.

7. Equipment

7.1. The general equipment required for this test is shown in Figure 1. ANSI/SCTE 96 (Cable Telecommunications Testing Guidelines), describes and specifies this equipment.

7.2. The signal generator for this test must have (minimum) the characteristics listed below.

7.2.1. 5 MHz – 1.002 GHz (minimum) single carrier signal generation capability.

7.2.2. 0.2% minimum AM modulation index capability.

7.2.3. < 0.01% residual hum.

7.3. Two AC/RF Power Combiners/Inserters:

7.3.1. Hum modulation < -80 dB at desired test current and voltage.

7.3.2. Return loss: > 22 dB.

7.3.3. Power Combiners/Inserters must possess RF only input/output capability, i.e. AC blocking incorporated into design.

7.3.4. Current carrying capacity of at least 50% greater than desired test currents.

Note: AC/RF Power Combiners/Inserters may not be required for certain DUT applications. Refer to Appendix 7 for special test considerations.

7.4. Resistive Load Bank: capable of dissipating desired test power.

7.5. Display Devices:

    7.5.1. Power analyzer capable of measuring rms current and voltage simultaneously.

    7.5.2. Oscilloscope must have a minimum deflection sensitivity of 2.0 mV/div.

        7.5.2.1. The oscilloscope used for the test must possess signal averaging capability.

7.6. Power supply:

    7.6.1. Ferro-resonant quasi-square wave (trapezoidal wave with < 100 V/ms slew rate).

    7.6.2. AC voltage output (50/60 Hz) at desired test voltage.

    7.6.3. Rated current output of at least 30% greater than the desired test current.

7.7. Low Pass Filter: DC – 1 kHz(minimum)

    7.7.1. Shielded.

    7.7.2. High Impedance (5 kΩ or greater).

    7.7.3. > 30 dB attenuation above 30 kHz.

    7.7.4. This filter may be contained in the differential preamplifier used in the test.

7.8. AM Detector:

    7.8.1. 75 Ω Input Impedance.

    7.8.2. Frequency Range: 200 kHz to 1.002 GHz.

    7.8.3. Maximum VSWR: 1.2:1 to 1.002 GHz.

7.9. Required inter-connect cables and connectors.

    7.9.1. Quad-shield 75Ω coaxial cable, for RF only paths.

    7.9.2. Rigid or semi-rigid 75Ω coaxial cable (1/2" diameter or greater), for RF and AC common paths, with a current carrying capacity of at least 50% greater than desired test currents.

7.10. Isolation Transformer

    7.10.1. 15 – 120 VAC Input : 115 – 120 VAC Output.

    7.10.2. 50/60 Hz.

    7.10.3. > 1,000 VA.

7.11. RF Amplifier

7.11.1.   5 MHz – 1 GHz (two amplifiers may be used to encompass this frequency range).

7.11.2.   Gain $\cong$ 25 dB.

7.11.3.   Noise Figure $\leq$ 10 dB.

7.12.   RF Attenuators

7.12.1.   4.12.1 Maximum VSWR: 1.2:1 to 1 GHz.

7.12.2.   4.12.2 75 Ω Switchable Attenuators.

7.12.2.1.   0.1 dB steps, 0 – 1 dB range, $\pm$0.05 dB tolerance.

7.12.2.2.   1.0 dB steps, 0 – 10 dB range, $\pm$0.1 dB tolerance.

7.12.2.3.   10.0 dB steps, 0 – 70 dB range, $\pm$0.2 dB tolerance.

7.12.3.   75 Ω fixed attenuators: 10 dB values, $\pm$0.05 dB tolerance.

8. Setup

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

8.2.   Connect the test equipment as shown in Figure 1.

Note: AC/RF Power Combiners/Inserters may not be required for certain DUT applications. Refer to Appendix 7 for special test considerations.

8.3.   Set the oscilloscope to the following settings:

Vertical Scale	As required for waveform display
Horizontal Scale	1 ms/div
Input Impedance	1 MΩ
AC Coupled Mode	On
Measurement Mode	V pk-pk
Signal Averaging	Off
Trigger	External

Note: A pre-amplifier is recommended to increase the vertical resolution of the oscilloscope, and extend the noise floor.

8.4. Determine RF levels:

    8.4.1. Connect DUT into test setup.

    8.4.2. Set the signal generator to a frequency within the operating range of the device.

    8.4.3. Adjust the signal generator RF output level, while monitoring the RF test point, to set the RF output level of the DUT to it's typical operating levels.

    8.4.4. Adjust the step attenuator preceding the RF post amplifier until the voltmeter displays approximately 0.9 VDC. If this voltage cannot be obtained, the gain of the RF post amp will need to be increased. This will ensure operation in the linear region of the AM detector.

Note: Section 8.4 establishes the calibration voltage while maintaining the DUT at its rated output level (achieved by monitoring the test point). This prevents possible compression of the DUT while obtaining the calibration voltage.

8.5. Calibration:

    8.5.1. Add 1.0 dB of attenuation from the input attenuator and note the voltage change on the voltmeter.

    8.5.2. Fine tune the amplitude of the signal generator until a 1.0 dB switchable attenuator change causes a 100 mVDC deflection on the voltmeter. When a 100 mVDC delta is achieved, record the DC voltage at the higher signal level as the detector dc operating point or calibration voltage.(see Appendix 2)

8.6. Calibration verification:

    8.6.1. AM modulate the signal generator at 0.5%(conventional AM index), 400 Hz.

    8.6.2. Adjust oscilloscope for maximum signal deflection, then measure Vp-p and signal period. With the pre-amplifier gain set to 100, a sinusoidal signal with a period of 2.5 ms (400 Hz) and amplitude of approximately 900 mV should appear on the oscilloscope if the setup is properly calibrated. This corresponds to a hum modulation of 1.0% or -40 dB (see section 8.7 and Appendix 2 for calculations).

    8.6.3. Turn off signal generator AM modulation.

8.7. AC Power Combiner Back-to-Back Hum Modulation Characterization:

    8.7.1. Remove the DUT and install a calibration jumper as shown in Figure 1. A cable or adapter may be used in place of the DUT, when applicable.

    8.7.2. Turn on AC power supply and adjust load bank to desired test current, as displayed on power analyzer.

    8.7.3. Set signal generator to desired test frequency.

    8.7.4. Set-up the oscilloscope:

Horizontal Scale	5 ms/div
Trigger	Line
Signal Averaging	Off

8.7.5. Adjust RF amplitude at the generator until the voltmeter displays the calibration voltage determined in section 8.5.2, above. Record this voltage in millivolts as Va.

8.7.6. Adjust the oscilloscope for maximum deflection of the non-averaged signal, making sure that none of the signal amplitude goes off-screen.

8.7.7. Set signal averaging to 64 samples or greater.

8.7.8. Record the peak-to-peak voltage of the hum modulation waveform as mVp-p in millivolts after the averaging has settled.

8.7.9. Add 1 dB of attenuation at the generator output or decrease the signal generator level by 1 dB and record the DC voltage in millivolts displayed by the voltmeter as Vb.

8.7.10. Calculate noise floor hum in dB as:

Hum (dB) = -19.27 –20log(Va-Vb) + 20log(mVp-p/100) (See Appendix 2 for derivation)

Note: The mVp-p value must be divided by 100 due to the pre-amplifier gain. If the pre-amplifier is not used, the mVp-p value is divided by 1.

8.7.11. Calculate hum in percent as:

Hum (%) = 100 * 10Hum(dB)/20 (See Appendix 3 for derivation)

8.7.12. Repeat steps 8.7.3 through 8.7.11 for all test frequencies.

8.7.13. Turn off power supply and remove calibration jumper.

8.7.14. Turn off signal generator RF output.

Note: The back-to-back hum modulation of the power combiners should be a minimum of –75 dB, with a goal of greater than –80 dB. If the noise floor is not lower than –75 dB, there may be a ground loop in the AC circuit. See Appendix 6 for ground loop trouble shooting recommendations.

9. 1 dB Delta Measurement Procedure

9.1. Connect DUT into test setup.

9.2. Turn on power supply and load to desired test current (using the resistive load bank) as measured on the power analyzer.

9.3. Operate the DUT under power until it reaches temperature stability.

9.4. Set signal generator to desired test frequency and turn RF on.

9.5. Adjust RF amplitude at the generator until the voltmeter displays the calibration voltage determined in section 8.5.2, above. Record this voltage as Va. (in mV)

9.6.   Adjust the oscilloscope for maximum deflection of the non-averaged signal, making sure that none of the signal amplitude goes off-screen.

9.7.   Set signal averaging to 64 samples or greater.

9.8.   Record the peak-to-peak voltage of the hum modulation waveform as mVp-p in millivolts after the averaging has settled.

Note: When using signal averaging, make sure that the non-averaged signal does not go off the screen when adjusting the oscilloscope for maximum deflection. This can cause severe averaging errors.

9.9.   Decrease the signal generator level by 1.0 dB and record the DC voltage displayed by the voltmeter as Vb. (in mV)

9.10.   Calculate hum in dB as:

Hum (dB) = -19.27 –20log(Va-Vb) + 20log(mVp-p/100). (See Appendix 2 for derivation)

Note: The mVp-p value must be divided by 100 due to the pre-amplifier gain. If the pre-amp is not used, the mVp-p value is divided by 1.

9.11.   Calculate hum in percent as: Hum (%) =100 * 10Hum(dB)/20.(See Appendix 3 for derivation)

9.12.   Repeat steps 9.4 through 9.11 for all test frequencies and temperatures.

10.   Differential Voltage Measurement Procedure

10.1.   Connect DUT into test setup.

10.2.   Turn on power supply and load to desired test current (using the resistive load bank) as measured on the power analyzer.

10.3.   Operate the DUT under power until it reaches temperature stability.

10.4.   Set signal generator to desired test frequency and turn RF on.

10.5.   Adjust RF amplitude at the generator until the voltmeter displays the calibration voltage determined in section 8.5.2, above.

Note: The signal generator level can be adjusted to levels less than the calibration voltage without loss of accuracy to accommodate measurements such as a sloped frequency response at the DUT output. The generator level does not need to be adjusted at each frequency if the calibration voltage is not exceeded during the test sequence.

10.6.   AM modulate the signal generator to 0.5 % (conventional AM index) at 400 Hz.

10.7.   Set the oscilloscope to the following settings:

Vertical Scale	As required for waveform display
Horizontal Scale	1 ms/div
Measurement Mode	V pk-pk
AC Coupled Mode	On
Signal Averaging	> 64 Samples
Trigger	External

Note: Reliable triggering of the oscilloscope is obtained through a direct connection between the signal generator modulation test point and the oscilloscope external trigger. Do not make a ground connection between the signal generator and oscilloscope through this cable as this will cause ground loop hum.

10.8. The oscilloscope should display the reference modulation envelope. Record the peak to peak amplitude value as Vref in mVp-p when the averaging has settled.

10.9. Turn off signal generator AM modulation.

10.10. Change the following oscilloscope settings:

Horizontal Scale	5 ms/div
Trigger	Line

Adjust the oscilloscope for maximum deflection of the displayed signal and record the peak to peak amplitude value as Vhum in mVp-p when the averaging has settled.

Note: When using signal averaging, make sure that the non-averaged signal does not go off the screen when adjusting the oscilloscope for maximum deflection. This can cause severe averaging errors.

10.11. Calculate hum in dB as: Hum (dB) = -40.04 –20log(Vref) + 20log(Vhum). (See Appendix 5 for derivation.)

10.12. Calculate hum in % as: Hum (%) = 100 * 10Hum(dB)/20. (See Appendix 3 for derivation.)

10.13. Repeat steps 10.4 through 10.13 for all test frequencies and temperatures.
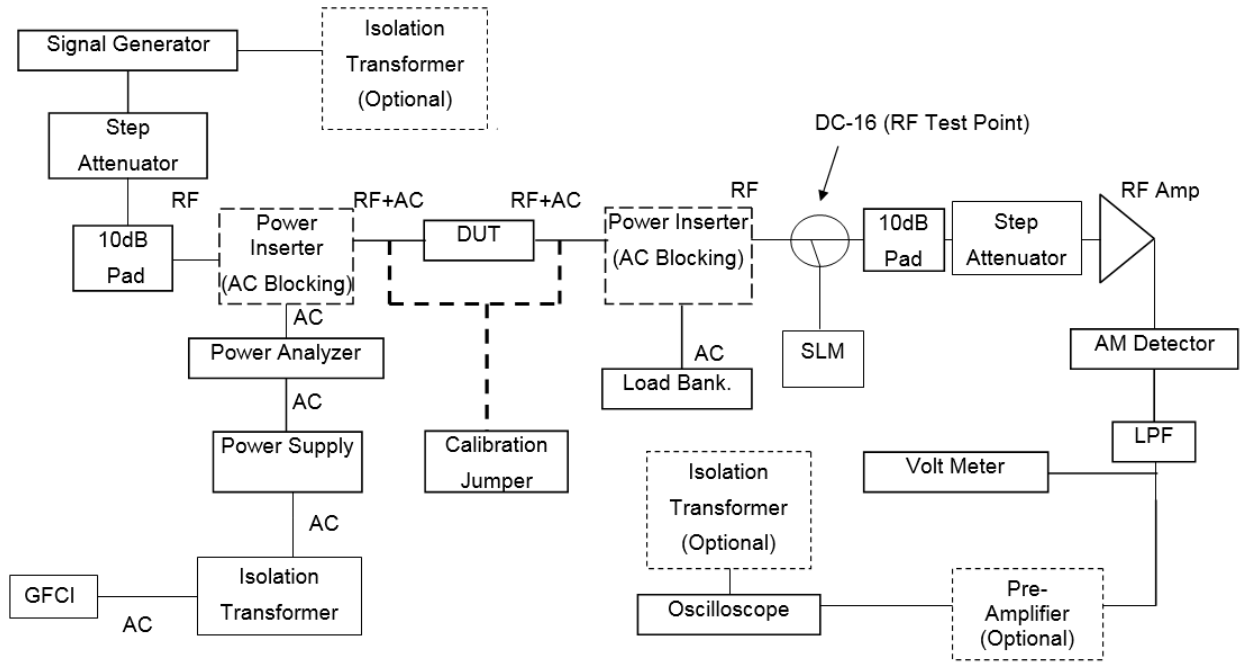
Figure 1 - Hum Modulation Test Setup

Appendix 1 – Hum Modulation Derivation

The equation for a TV sinewave amplitude modulated carrier is:

$$y(t) = B[1 - (k/2)(1 + \cos\omega_m t)]\cos\omega_c t \qquad (A\text{-}1)$$

where B is the peak amplitude of the RF carrier and k is the modulation factor which is equal to:

$$k = \frac{M_{pk-pk}}{B}, k \leq 1 \qquad (A\text{-}2)$$

and k is related to the conventional AM modulation index by the equation:

$$k = \frac{2m}{(1+m)} \quad \text{where m is the conventional AM modulation index.}$$

If the peak-to-peak amplitude variation in time is kB, and this amplitude variation is considered to be hum modulation, hum is defined as.

$$AM\,Mod(dB) = 20Log\left(kB\middle/B\right) = 20Log(k) \qquad (A\text{-}3)$$

Hum modulation is simply a measurement of k, which is the ratio of the peak-to-peak hum on the carrier to the peak of the RF carrier (B).

$$k = \frac{Hum_{pk-pk}}{B} \qquad (A\text{-}4)$$

Figure 2 shows a graphical representation of hum modulation using a continuous wave (CW) carrier as an example.
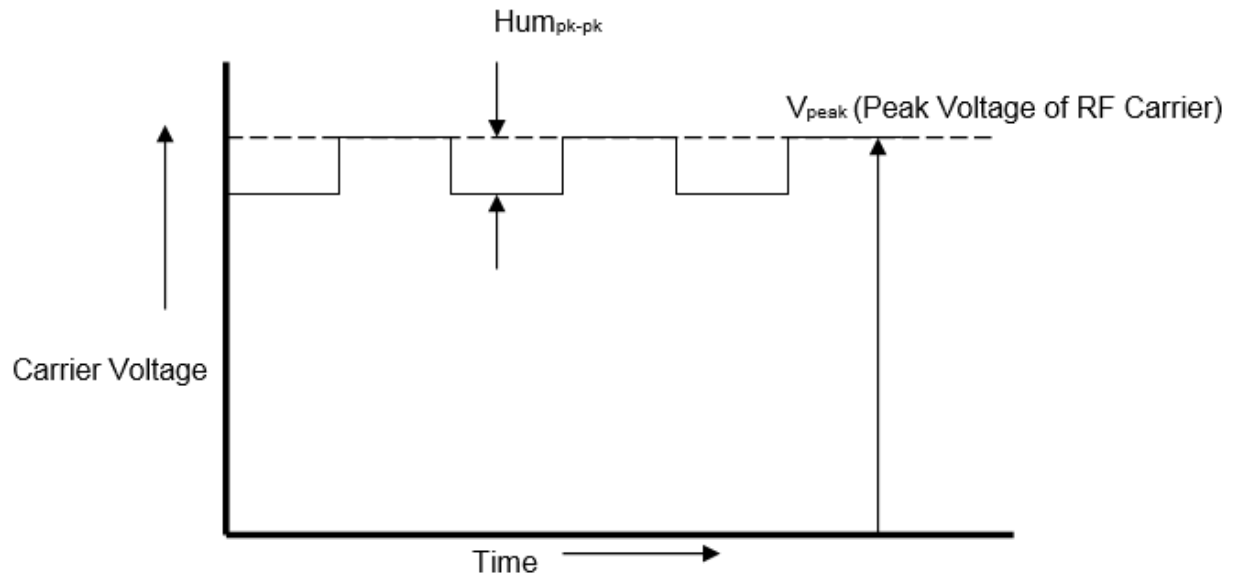
Figure 2 – Continuous Wave Hum Modulation

Appendix 2 – Derivation of the 100mVDC Delta Calibration

The 100mVDC delta hum modulation reference calibration procedure establishes, through a –1 dB RF level change, a repeatable envelope change that can be compared to the actual peak-to-peak hum voltage. From this a hum modulation ratio can be determined.

Consider the signal:

$$v(t) = B[1 - v_{hum}(t)]\cos\omega_c t \qquad \text{(A - 5)}$$

Where B is the peak amplitude of the RF carrier, $v_{hum}(t)$ is the peak-to-peak hum voltage, and B in dB is defined as $B(dB) = 20\log(B/B_o)$. If B is attenuated by 1 dB (which corresponds to a 100 mVDC delta on the voltmeter), then:

$$-1\,dB = 20Log\left(B(@-1\,dB)/B_o\right) \qquad \text{(A - 6)}$$

$$\Delta B\left(@-1\,dB, 100mV_{p-p}\right) = B_O - B_O \bullet 10^{(-1/20)} = B_O\left(1 - 10^{(-1/20)}\right)V_{p-p} \qquad \text{(A - 7)}$$

So, time domain hum modulation can be defined as:

$$Hum(dB) = 20Log\left[\frac{Env_{max} - Env_{min}}{Env_{max}}\right] \qquad \text{(A - 8)}$$

Where Env_{max} is the –1 dB delta in B (envelope change) that can be compared to the actual peak-to-peak hum voltage ($Env_{max}-Env_{min}$) to give a hum modulation ratio in dB.

$$Env_{max} = \frac{\left|\Delta B\left(@-1\,dB, 0.1V_{p-p}\right)\right|}{\left[1 - 10^{(-1/20)}\right]} \qquad \text{(A - 9)}$$

$$Env_{max} - Env_{min} = Hum_{p-p} \qquad \text{(A - 10)}$$

At the 100mVDC calibration reference (which is a 100 mV_{p-p} delta envelope reference), the equation for hum modulation is:

$$Hum(dB) = 20Log(1 - 10^{(-1/20)}) + 20Log\left[\frac{Hum_{mVp-p}}{100mV_{p-p}ref}\right] \qquad \text{(A - 11)}$$

Where Hum_{p-p} is given in millivolts, and hum modulation is given in dB.

$$\text{Hum(dB)} = -19.27 - 20\text{Log}\left(100\text{mV}_{p-p}\text{ref}\right) + 20\text{Log}(\text{Hum}_{mVp-p}) = -59.27 + 20\text{Log}\left(\text{Hum}_{mVp-p}\right) \quad \text{(A-12)}$$

Appendix 3 – Conversion of Hum Modulation from dB to percent (%)

The Federal Communications Commission (FCC) defines hum in Technical Standards part 76.605(a) as: The peak to peak variation in visual signal level caused by undesired low frequency disturbances (hum or repetitive transients) generated within the system, or by inadequate low frequency response, shall not exceed 3 percent of the visual signal level.

This appendix will detail the derivation of hum modulation in percent, and will provide a table with conversions of hum modulation from mV_{p-p} to dB and percent hum.

Hum Modulation may be expressed as a percentage of the peak to peak variation of the carrier level to the peak voltage amplitude of the carrier. From equations A-9 and A-10, located in Appendix 2, Env_{max} is defined as the -1 dB delta in B (envelope change) that can be compared to the actual peak to peak hum voltage (Env_{max} - Env_{min}, or Hum_{p-p}) to give a hum modulation ratio.

To express hum modulation as a percent:

$$\text{Hum(\%)} = \left(\frac{\text{Hum}_{mVp-p}}{\text{Env}_{max}}\right) * 100\% = \left(\frac{\text{Hum}_{mVp-p}}{919.5\text{mV}_{p-p}}\right) * 100\% = .109 * \text{Hum}_{mVp-p} \quad \text{(A-13)}$$

where,

$$\text{Env}_{max} = \frac{100\text{mV}_{p-p}}{\left[1 - 10^{(-1/20)}\right]} = \frac{100\text{mV}_{p-p}}{.1087} = 919.5\text{mV}_{p-p} \quad \text{(from A-9)}$$

The 100mV delta is shown as the standard reference. However, for hum measurements, the actual delta of voltages between the 1 dB change should be used for improved accuracy.

The conversion of hum in mV_{p-p} to dB and percent is shown in Table 1.

Table 1 - Hum Modulation Conversion Chart

mV$_{p-p}$	dB	%		mV$_{p-p}$	dB	%		mV$_{p-p}$	dB	%
0.082	81.0	0.0089		0.774	61.5	0.0843		7.303	42.0	0.7960
0.087	80.5	0.0095		0.819	61.0	0.0893		7.736	41.5	0.8432
0.092	80.0	0.0100		0.868	60.5	0.0946		8.194	41.0	0.8932
0.097	79.5	0.0106		0.919	60.0	0.1002		8.680	40.5	0.9461
0.103	79.0	0.0112		0.974	59.5	0.1062		9.194	40.0	1.0021
0.109	78.5	0.0119		1.032	59.0	0.1124		9.739	39.5	1.0615
0.116	78.0	0.0126		1.093	58.5	0.1191		10.316	39.0	1.1244
0.123	77.5	0.0134		1.157	58.0	0.1262		10.927	38.5	1.1910
0.130	77.0	0.0142		1.226	57.5	0.1336		11.574	38.0	1.2616
0.138	76.5	0.0150		1.299	57.0	0.1416		12.260	37.5	1.3364
0.146	76.0	0.0159		1.376	56.5	0.1499		12.987	37.0	1.4156
0.154	75.5	0.0168		1.457	56.0	0.1588		13.756	36.5	1.4994
0.163	75.0	0.0178		1.543	55.5	0.1682		14.571	36.0	1.5883
0.173	74.5	0.0189		1.635	55.0	0.1782		15.435	35.5	1.6824
0.183	74.0	0.0200		1.732	54.5	0.1888		16.349	35.0	1.7821
0.194	73.5	0.0212		1.834	54.0	0.2000		17.318	34.5	1.8877
0.206	73.0	0.0224		1.943	53.5	0.2118		18.344	34.0	1.9995
0.218	72.5	0.0238		2.058	53.0	0.2244		19.431	33.5	2.1180
0.231	72.0	0.0252		2.180	52.5	0.2376		20.583	33.0	2.2435
0.245	71.5	0.0267		2.309	52.0	0.2517		21.802	32.5	2.3764
0.259	71.0	0.0282		2.446	51.5	0.2666		23.094	32.0	2.5173
0.274	70.5	0.0299		2.591	51.0	0.2824				
0.291	70.0	0.0317		2.745	50.5	0.2992				
0.308	69.5	0.0336		2.907	50.0	0.3169				
0.326	69.0	0.0356		3.080	49.5	0.3357				
0.346	68.5	0.0377		3.262	49.0	0.3556				
0.366	68.0	0.0399		3.455	48.5	0.3766				
0.388	67.5	0.0423		3.660	48.0	0.3990				
0.411	67.0	0.0448		3.877	47.5	0.4226				
0.435	66.5	0.0474		4.107	47.0	0.4476				
0.461	66.0	0.0502		4.350	46.5	0.4742				
0.488	65.5	0.0532		4.608	46.0	0.5023				
0.517	65.0	0.0564		4.881	45.5	0.5320				
0.548	64.5	0.0597		5.170	45.0	0.5635				
0.580	64.0	0.0632		5.476	44.5	0.5969				
0.614	63.5	0.0670		5.801	44.0	0.6323				
0.651	63.0	0.0709		6.145	43.5	0.6698				
0.689	62.5	0.0751		6.509	43.0	0.7095				
0.730	62.0	0.0796		6.894	42.5	0.7515				

Hum (dB) = -59.27 + 20 log (Hum$_{mVp-p}$)

Hum (%) = 0.109 * Hum$_{mVp-p}$

Appendix 4 – Time Domain vs. Frequency Domain Measurements

This appendix is intended to demonstrate a mathematical correlation between the time domain measurement method (which this procedure details), and the frequency domain measurement method. The frequency domain method uses a spectrum analyzer as a tuned receiver to demodulate the 60, 120, or 180 Hz hum sidebands to baseband for measurement with a low frequency spectrum analyzer. This measurement technique is seldom used as it requires a spectrum analyzer with 10Hz or better resolution.

Before a correlation between the two measurement methods is shown, the equations for conventional AM and TV AM should be reviewed.

Conventional AM:

$$x(t) = A\big[1 + m(\cos\omega_m t)\big]\cos\omega_c t \qquad\qquad (A\text{-}14)$$

Where A is the carrier and m is the conventional modulation index. The equation for TV AM (A-1) is located in Appendix 1. If these equations are converted to show the AM sidebands:

Conventional AM:

$$x(t) = A\left[\cos\omega_c t + \frac{1}{2}m\big[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t\big]\right] \qquad\qquad (A\text{-}15)$$

TV AM:

$$y(t) = B\left[\big[1 - (k/2)\big]\cos\omega_c t - \frac{k}{4}\big[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t\big]\right] \qquad\qquad (A\text{-}16)$$

It can be determined from these equations that for conventional AM signals, the AM sidebands are m/2 volts(assuming that carrier A is 1 volt). For TV AM, the sidebands are k/4 volts(also assuming that carrier B is 1 volt). Appendix 1, through mathematical derivation, shows that Hum(dB) = 20log(k). If the frequency domain method is used to measure the sideband, the equation becomes:

$$\text{Hum(dB)} = 20\text{Log}\big(k/4\big) = 20\text{Log}(k) - 20\text{Log}4 = 20\log(k) - 12 \qquad\qquad (A\text{-}17)$$

Therefore, for frequency domain measurements, a correction factor of 12 dB must be subtracted from the measurement to correlate to the time domain measurement method.

Appendix 5 - Hum Modulation Test Methods

Note that both of the time-domain methods detailed in the procedure depend upon the comparison of an unknown envelope to a known calibrated envelope. The difference between the two methods lies in the way the reference envelope is established and measured. The general principles of hum modulation measurement are covered in Appendix 1.

1 dB Delta Method
The 1 dB delta method creates a standard reference envelope by switching a 1 dB attenuator in the signal line to the device under test, and calibrates the amplitude of this 1 dB envelope by measuring the rectified DC component of the carrier with a digital voltmeter. The oscilloscope is not involved in this calibration. This procedure presumes that a large signal DC measurement correlates to a small signal AC measurement using a different instrument, and it presumes that the AC/DC characteristics of the detector are constant for all test frequencies. The derivation of the formula for hum modulation using this method is found in Appendix 2.

The accuracy of this method is influenced by the accuracy of the 1 dB attenuation, the frequency and signal level response of the AM detector, the gain of the differential amplifier, and the correlation of the measurement instruments measuring different signal components. This kind of instrument diversity makes this an absolute measurement.

Differential Voltage Method

The differential voltage method creates a standard reference envelope by deploying the internal AM modulation function of the generator as described in 5.6 to establish calibration verification. This reference modulation envelope is measured as a peak to peak AC voltage waveform on the oscilloscope in the same way that the hum modulation waveform is measured using the same measurement instrument. The rectified DC component of the signal does not enter into the measurement, therefore, the detector response with respect to frequency does not affect the measurement. Likewise, the gain and insertion loss accuracy in the signal path does not influence the result because it is common to both the reference and the test measurement.

The accuracy of this method is influenced by the calibration of the modulation index of the internal modulation generator, and the vertical range selector of the oscilloscope. This kind of instrument commonality makes this a releative measurement.

In establishing a relation between the hum waveform and the peak carrier level, an intermediate reference waveform is used which has a known relationship to the carrier by virtue of its modulation index. From Appendix 1, the relationship of a conventional AM modulation envelope defined by its modulation index m, to the peak carrier amplitude B is given by:

$$\text{AM mod(dB)} = 20\text{Log}\left(kB\big/B\right) = 20\text{Log}(k), \text{ where } k = \frac{2m}{1+m} \qquad (A\text{-}3)$$

The relationship of the peak to peak hum waveform to the peak to peak reference modulation is simply:

$$20\text{Log}\left(\frac{V_{hum}}{V_{ref}}\right) \text{ as measured on the oscilloscope.}$$

$(A - 18)$

Combining these two relationships, the peak to peak hum is related to the peak carrier by:

$$\text{Hum(dB)} = 20\text{Log(k)} + 20\text{Log}\left(\frac{V_{\text{hum}}}{V_{\text{ref}}}\right) \text{ or} \qquad\qquad (A-19)$$

$$\text{Hum(dB)} = 20\text{Log(k)} - 20\text{Log}(V_{\text{ref}}) + 20\text{Log}(V_{\text{hum}}). \qquad\qquad (A-20)$$

A convenient modulation index to use is 0.5% AM. If this value is substituted for m, the first term in equation A-20 becomes –40.04 dB. If a higher degree of accuracy is required, the modulation index can be empirically determined by measuring the carrier and its sidebands across the test spectrum. From HP application note #150-1, the relationship between the logarithmic display and the modulation percentage is expressed as:

$$20\log m = E_{\text{SB(dB)}} - E_{\text{C(dB)}} + 6\text{dB} \qquad\qquad (A\text{ - }21)$$

$$m = 10^{(E_{\text{SB}} - E_{\text{C}} + 6)/20} \qquad\qquad (A-22)$$

Appendix 6 - Troubleshooting Guide

This appendix will serve as a guide to eliminate AC ground loops in the hum modulation test setup. Identification of a ground loop problem will normally be made when measuring the back-to-back hum modulation of the power combiners. If the noise floor is not lower than –75 dB, the setup should be investigated for possible contribution to the noise floor.

General Troubleshooting

If the noise floor goal cannot be met, take the following steps to determine if the test equipment/test setup is contributing to the problem:

1. Ensure all test equipment is set to the operating parameters detailed in this procedure.

2. Ensure all connectors and cables used in the test setup are correctly constructed and firmly connected. Light shaking or tapping on each connector can help to identify a potential problem.

3. Ensure the hum power combiners are constructed properly; i.e. check for poor solder connections, etc…

Ground Loop Elimination

If the conditions in the general troubleshooting guide are met, an AC ground loop is most likely the cause of the poor noise floor measurements. The following steps may be taken to prevent or eliminate these ground loops.

1. Utilize a power bar (driven from an isolation transformer) with the common ground removed on each piece of test equipment (signal generator, oscilloscope, and voltmeter).

2. Isolation plugs (2 – 3 prong adapter type) should be used on each piece of test equipment.

3. Ensure that any plug outlet being used for the test is not introducing any 60 Hz hum to the system.

4. Avoid multiple ground paths between equipment such as the signal generator and the oscilloscope. A cable connecting the generator modulation test point to the oscilloscope external trigger must not have a complete ground path

5. Special Consideration: If the test setup is automated, ground loops can occur between the PC and any test equipment via the instrument interface bus. Bus opto-isolators can be utilized to eliminate this problem.

Appendix 7 – Special Test Conditions/Considerations

The test setup and procedure in this document detail a test methodology that is specific to devices in which the power enters and exits on the RF test ports. However, some test devices do not contain this configuration. Drop amplifiers are an example of a device that does not contain two RF/power ports. Typical configurations of drop amplifiers include use of only one RF/power port, or a dedicated power port and stand alone (no power passing capability) RF ports.

Under circumstances such as the ones listed above, this procedure can be followed with minor test set-up modifications. If one or more RF ports of the DUT do not contain power passing capability, AC/RF power inserters/combiners are not required for those ports. They may be removed for testing purposes.

For example, a DUT containing only one RF/power port would be tested using one AC/RF power inserter/combiner on the RF/power port, and an RF only connection on the other port. A DUT containing a dedicated powering port would not require AC/RF power inserters/combiners on the test ports, as they are not meant to pass power.

A general rule of thumb when performing this test is to utilize AC/RF power inserters/combiners on any DUT port that shares RF and power passing capability. Otherwise, direct connections should be used. Additionally, the power load bank is not required on DUT's without power passing capability. The procedure can be followed as stated with these minor changes to the test set-up.