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Network Operations Subcommittee

SCTE STANDARD

SCTE 289 2024

Operational Practice for Building and Using Calibrated Leaks

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1. Introduction

1.1. Executive Summary

This operational practice describes two methods to verify the calibration of signal leakage detection equipment: 1) directly-connected radio frequency (RF) signal source, and 2) a calibrated field strength (also known as a calibrated leak) method. It helps cable operators ensure that compliance with Part 76 of the Federal Communications Commission's (FCC) leakage rules is maintained accurately.

This operational practice helps the cable industry ensure reliable network operation and subscriber satisfaction. Some key points are:

- Detailed procedure for using a directly-connected RF source to calibrate leakage detection equipment
- Recommendations on equipment types and configurations
- Detailed procedure for using a resonant half-wave dipole antenna and suitable signal source as a calibrated leak for testing leakage equipment as deployed and used
- Theoretical calculations to support the approach, and explanations for expected variations in results obtained.

1.2. Scope

Calibration of signal leakage detection equipment on a regular basis is mandatory to ensure measurement accuracy. This document covers two general types of calibration that can be used: directly-connected RF signal source and calibrated field strength (aka calibrated leak). The first technique is used to establish the general measurement accuracy of a piece of leakage detection equipment, and the second gauges its ability to measure a known signal leakage field strength in the outdoor environment.

1.3. Benefits

The immediate and long-term benefits of this Operational Practice are:

- Providing methods that can be used by technical personnel at the cable system level to check the accuracy of signal leakage detection equipment
- Ensuring the accuracy of signal leakage field strength measurements, in order to maintain the integrity of cable networks, and to comply with relevant FCC Rules

1.4. Intended Audience

The intended audience for this document is cable system-level technical personnel who are involved with the use of signal leakage detection equipment, their supervisors, and content developers of training material

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

Among the topics to consider for future versions of this document are creating a calibrated leak for leakage detector-equipped aircraft used for flyover measurements.

2. Normative References

The following documents contain provisions which, through reference in this text, constitute provisions of this document. The editions indicated were valid at the time of subcommittee approval. 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. Other Published Materials

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

[SMRP]	SCTE 183 2023 SCTE Measurement Recommended Practices for Cable Systems, available from https://www.scte.org/standards/library/catalog/scte-183-scte-measurement-recommended-practices-for-cable-systems/
[Field Strength]	SCTE 221 2020 Field Strength & Calculation of LTE User Equipment Field Strength
[Leakage]	SCTE 222 2020 Useful Signal Leakage Formulas
[Math]	SCTE 270 2021r1 Mathematics of Cable

3.2. Standards from Other Organizations

No informative references are applicable.

3.3. Other Published Materials

[Hranac1]	Hranac, R. “How to build a calibrated leak.” June 1990 *Communications Technology*
[Johnson]	Johnson, R., Jasik, H. (1984). *Antenna Engineering Handbook, Second Edition*. New York: McGraw-Hill
[Kraus]	Kraus, J., R. Marhefka, (2001). *Antennas, Third Edition*. New York: McGraw-Hill
[Part 76]	Title 47, Code of Federal Regulations, Part 76

[SCTE BDF] “BDF 17 Leakage/LTE interference measurement,” from SCTE Broadband Distribution Fundamentals training course, available from www.scte.org.

[SEGURA] Segura, N. “OUDP Bursts for High-Split RF Leakage Detection.” Summer 2022 *Broadband Library*. https://broadbandlibrary.com/oudp-bursts-for-high-split-rf-leakage-detection/

4. Compliance Notation

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shall not	This phrase means that the item is an absolute prohibition of this document.
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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

BNC	bayonet Neill Concelman [connector]
CM	cable modem
CMTS	cable modem termination system
CTA	Consumer Technology Association
CW	continuous wave
dB	decibel
dBi	decibel isotropic
dBmV	decibel millivolt
d_{km}	distance in kilometers
DOCSIS	Data-Over-Cable Service Interface Specifications
$E_{\mu V/m}$	field strength in microvolts per meter
f	frequency
FCC	Federal Communications Commission
FDD	frequency division duplex
FDX	full duplex [DOCSIS]
f_{MHz}	frequency in megahertz
G_{dBi}	gain, decibel isotropic
G_r	numerical gain of receive antenna
G_t	numerical gain of transmit antenna

IUC	interval usage code
log	logarithm[1]
kHz	kilohertz
km	kilometer
KPI	key performance indicator
LTE	long term evolution
MHz	megahertz
MPH	miles per hour
ms	millisecond
mV	millivolt
NOS	[SCTE] Network Operations Subcommittee
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OUDP	OFDMA upstream data profile
P_r	received power
P_t	transmitted power
QAM	quadrature amplitude modulation
R	1) distance; 2) resistance (impedance)
RF	radio frequency
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
TV	television
UHF	ultra high frequency
vCMTS	virtual cable modem termination system
VHF	very high frequency
λ	wavelength
µV/m	microvolt per meter

5.2. Definitions

Definitions of terms used in this document are provided in this section. Defined terms that have specific meanings are capitalized. When the capitalized term is used in this document, the term has the specific meaning as defined in this section.

attenuation	see *loss*.
decibel (dB)	A logarithmic-based expression of the ratio between two values of a physical quantity, typically power or intensity. The decibel provides an efficient way to express ratios which span one or more powers of the logarithmic base, most commonly 10. Mathematically, the ratio of two power levels P_1 and P_2 in decibels is $\text{dB} = 10\log_{10}(P_1/P_2)$.[2]

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[1] Unless stated otherwise, logarithms in this document are base 10.

[2] The decibel, while technically a ratio of two power levels, also can be used to represent the ratio of two measured voltages, assuming the two voltages are across the same impedance. Here is how that relationship is derived: The unit of electrical power, the watt, equals 1 volt multiplied by 1 ampere. Equation-wise $P = EI$, where P is power in watts, E is voltage in volts, and I is current in amperes. Substituting the Ohm's Law equivalent for E and I gives additional formulas for power: $P = E^2/R$ and $P = I^2R$. If the right hand side of the power equation $P = E^2/R$ is substituted for both P_1 and P_2 in the formula $\text{dB} = 10\log_{10}(P_1/P_2)$, the equation becomes $\text{dB} = 10\log_{10}[(E^2/R)/(E^2/R)]$ which is the same as $\text{dB} = 10\log_{10}[(E_1^2)/R_1)/(E_2^2/R_2)]$. In this example, R represents the 75 ohms impedance of a

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 across a 75 ohms impedance. Mathematically, dBmV = $20\log_{10}$(value in mV/1 mV).
dipole	A linear doublet antenna, typically comprising two conductive wire, rod, or tubular elements. A dipole antenna is usually fed at the center of the two elements (but may be fed off-center in some designs), with one conductor of a two-conductor transmission line connected to the inner end of one element, and the other conductor connected to the inner end of the other element. A resonant half-wave dipole has an end-to-end length equal to an electrical half-wavelength at the operating frequency.
far-field	The region of an antenna's radiation pattern in which the angular distribution of radiated energy is largely independent of distance from the antenna, and in which the power varies inversely with the square of distance. The approximate distance from the antenna to the beginning of the far-field is generally accepted to be $R = 2D^2/\lambda$, where R is distance from the antenna, D is the largest linear dimension of the antenna effective aperture, and λ is wavelength. Signal leakage field strength measurements are made in the far-field. See also *near-field*.
field strength	An RF signal's power density within an imaginary 1meter x 1 meter square (that is, watts per square meter) in free space or in the air. Usually expressed as a voltage; for example, microvolts per meter.
gain	An increase in the power of a signal or signals, usually measured in decibels. Expressed mathematically, $G_{dB} = 10\log_{10}(P_{out}/P_{in})$, where G_{dB} is gain in decibels, P_{out} is output power in watts, P_{in} is input power in watts, and $P_{out} > P_{in}$. When signal power is stated in dBmV, $G_{dB} = P_{out(dBmV)} – P_{in(dBmV)}$.
impedance	The combined opposition to current in a component, circuit, device, or transmission line that contains both resistance and reactance. Represented by the symbol Z and expressed in ohms.
loss	A decrease in the power of a signal or signals, usually measured in decibels. Expressed mathematically, $L_{dB} = 10\log_{10}(P_{in}/P_{out})$, 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, $L_{dB} = P_{in(dBmV)} – P_{out(dBmV)}$.
megahertz (MHz)	One million (10^6) hertz.
microvolt per meter (µV/m)	A measure of the field strength of an RF signal, calculated by dividing the received intensity in microvolts by the receiving antenna maximum effective aperture.
near-field	The space around an antenna comprises a reactive region and a radiating region. The radiating region is further subdivided into a near-field region and a far-field region. The radiating near-field is the propagation region where angular contributions from individual

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cable network. Since R_1 and R_2 are both equal to 75 ohms, those equation terms cancel, leaving the equation dB = $10\log_{10}(E_1^2/E_2^2)$. This can be simplified somewhat and written as dB = $10\log_{10}(E_1/E_2)^2$ which is the same as dB = 2 * $10\log_{10}(E_1/E_2)$ or dB = $20\log_{10}(E_1/E_2)$.

	antenna elements vary significantly with distance from the antenna. See also *far-field*.
radio frequency (RF)	That portion of the electromagnetic spectrum from a few kilohertz to just below the frequency of infrared light.
signal leakage	Unwanted emission of RF signals from a cable TV network into the surrounding over-the-air environment, typically caused by degraded shielding effectiveness of coaxial cable, connectors, and other network components, or by poorly shielded subscriber terminal equipment connected to the cable network.

6. Background

While some may assume that leakage detection equipment that is purchased is already calibrated and will stay that way automatically, the reality is that equipment does require regular calibration checks and recalibration from time to time. Also, some equipment may be purchased as used equipment, and thus the calibration status is unknown. Further, the process of recalibration can also be used as a training exercise for those technicians that are responsible for making leakage measurements on cable networks. Finally, the cost of making a suite of measurements on the entire network, only to discover that the equipment was out of calibration or otherwise gave faulty results can be significant.

Thus, the industry needs reliable, repeatable, and cost-effective ways to ensure their leakage measurement equipment is calibrated and functions properly. And technicians need to understand how to apply these methods in a repeatable and reliable manner as part of their work requirements. The purpose of this operational practices document is to offer two cost-effective methods for calibrating leakage measurement equipment, and to give illustrative examples of the approach.

To achieve maximum benefit from implementing this operational practice, operators should customize it for their workforce/cable network specifics. Implement the practices, keeping track of key performance indicators (KPIs) both before and after the implementation to ensure it is meeting the business goals of the cable operator.

7. Key Metric to Be Measured

The primary metric to be measured is the field strength in microvolts per meter (μV/m), or alternately, in decibel millivolt (dBmV) at the terminals of the leakage detection antenna in use. Where a test setup includes a preamplifier, bandpass filter, etc., between the antenna and test instrument, be sure to compensate for losses and gains in the test setup. For a detailed explanation of these concepts and conversions between them, refer to [Field Strength], [Leakage], and [Math].

8. Required Equipment

The equipment required to perform the procedures in this document include the following:

- Leakage measurement equipment for field technician use: antenna, coax and leakage detector
- High quality RF signal generator, frequency-agile headend analog TV modulator as a calibration signal source, or a dedicated commercial leakage test signal source
- 50 ohms-to-75 ohms impedance matching adapter if required
- Other miscellaneous connectors, adapters, variable/switchable 75 ohms impedance attenuator(s), etc., as required
- Analog video signal source that can provide 1 volt peak-to-peak baseband signal as input to the headend modulator (if used)

- Source of at least two adjacent downstream single carrier quadrature amplitude modulation (SC-QAM) signals (e.g., CTA channels 16 and 17 when the proprietary test signal is at 138 MHz, and/or CTA channels 88 and 89 when the proprietary test signal is 612 MHz), such as an edge-QAM modulator, or even the cable network's signals. Note: When the upstream spectrum overlaps the aeronautical band, an OFDMA upstream data profile (OUDP) testing burst signal source can be used.
- Bandpass filter(s)
- Spectrum analyzer (SA) or power meter
- Two resonant half-wave dipole antennas tuned to the calibration frequency

9. How to Build a Calibrated Leak

Calibration of signal leakage detection equipment on a regular basis is important to ensure measurement accuracy. Generally, two types of calibration are recommended:

1) Directly-connected RF signal source, which involves plugging a coaxial cable directly in to the external antenna connection on the leakage detector, which validates the general measurement accuracy of the equipment (this method will not utilize the device's internal antenna), and

2) Calibrated field strength, which leverages both a transmit antenna (leak source) and the device's antenna(s) to gauge the detector's ability to measure a known field strength. Remember to test the equipment operation when it is undocked from the vehicle cradle outside of the vehicle, as well as when it is docked inside the vehicle. Figure 1 shows an example of a transmit antenna used as part of a calibrated leak test setup.

Figure 1 - Transmit antenna for creation of a calibrated leak (image courtesy of Charter).

The first technique is used to establish the general measurement accuracy of a piece of leakage detection equipment and the second gauges its ability to measure a known field strength. Both calibration methods are discussed in the following sections, with an emphasis on the second method. As a best practice dedicate an RF feed for both the directly-connected RF signal source method (whether on a test bench or outdoors) and the calibrated signal source for the antenna. Place connections within a weather-protected house box or similar to prolong integrity of the connectors, cables, and other components, and to allow installation of labels on the outside and inside of the box indicating its calibration purpose. See Figure 2. This also prevents accidental disconnection and allows for the inclusion of written signal level references which can be used to later assure calibration and assist with troubleshooting. Be sure to include adequate signage near the outdoor antenna and other equipment used for the calibrated leak. An example is shown in Figure 3.

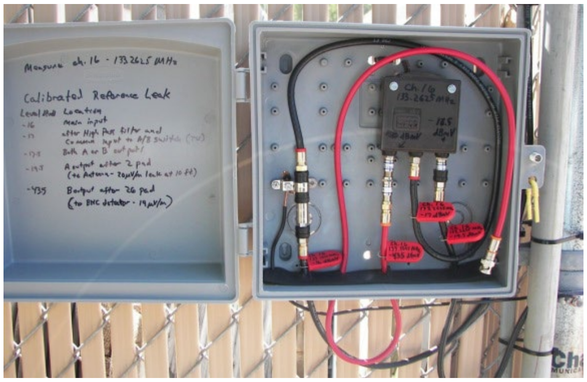

Figure 2 - Outdoor enclosure for A/B switch and other components (image courtesy of Charter).

The use of an A/B switch is a popular choice to route the signal source feed to the antenna or the directly-connected RF signal source test point; however, it might yield inconsistent results with regular operation, depending on the quality of that switch. An advantage of using an A/B switch is that it can be used to turn off the calibrated leak by switching the signal source to a terminated test point. A weatherproofed two-way splitter might be a better choice, but some method of turning off the leak will be needed, perhaps located indoors. Also, if in-line attenuators are installed in the outdoor enclosure, be sure to adequately weatherproof them. Otherwise, locate them indoors.


Charter
COMMUNICATIONS

Calibrated Leak
Located Here

Check Operation of equipment daily.
Make sure all leakage detectors are on
and working before leaving the yard.

Figure 3 - Example signage for calibrated leak (image courtesy of Charter).

If using production signals from an active cable network place a suitable bandpass filter in-line to block any unwanted upstream band noise/interference from returning to the headend/hub. A filter will also prevent unintended leakage of frequencies other than the desired calibration signal(s). Production signal feeds are a requirement when dedicated, tagged or proprietary test signals are necessary for operation of the leakage detectors. The frequency or frequencies of the calibrated leak should match the frequency or frequencies monitored for leakage in the system, whether in the very high frequency (VHF) or ultra high frequency (UHF) bands, or both.

9.1. Directly-Connected RF Signal Source

This method requires that a calibrated RF signal generator or similar source be connected directly to the leakage measurement equipment. In order to use the procedure described in this section, the detector must have an external antenna jack. If the detector does not have an external antenna jack, see the next section for checking detector performance with a calibrated leak. If the signal generator does not have the same impedance as the unit being tested, then an impedance matching device such as a minimum loss pad or a wideband impedance matching transformer[3] must be connected between the signal generator and leakage detector. As well, the signal generator's level and frequency stability must be good enough to keep the calibration signal at the proper amplitude and on the measurement frequency during the calibration process.

Several companies sell high-quality RF signal generators that are suitable for this purpose. Many are 50 ohms laboratory-grade instruments that will require an external 50 ohms-to-75 ohms impedance matching adapter (check with the leakage detector manufacturer to confirm the input impedance of the equipment under test). The use of older bench sweep or system sweep transmitters operated in continuous wave (CW) mode for this procedure is not recommended, since they may not have the necessary frequency stability.

An alternative to a lab-grade signal generator to simulate an analog visual carrier is to use a frequency-agile headend modulator as a calibration signal source. Not only is this less costly than a laboratory-grade signal generator but it also will allow the leakage detector's accuracy to be checked with both CW and modulated carriers. Most of the better quality agile units have the necessary level and frequency stability, are tunable in 1 MHz or finer steps and can be offset 12.5 kHz or 25 kHz to simulate actual offset carrier frequencies on the system. In addition, a frequency-agile modulator can double as the signal source for establishing a calibrated leak.

When using modern leakage detection equipment that has a proprietary leakage test signal source, that signal source should be connected directly to the leakage detector for this test. Alternatively, a live cable system feed that includes the proprietary test signal can be connected to the leakage detector.

In all cases, use an external attenuator between the test signal source and the leakage detector being checked, and adjust the attenuator as necessary to ensure the RF input to the detector is the desired value.

Assume the leakage detection equipment is being checked for its ability to accurately measure 20 µV/m on Ch. 16's visual carrier frequency. In this case, after setting the frequency of the signal source to 133.2625 MHz, attenuate the output of the signal generator to the equivalent of 20 µV/m (–42.9 dBmV for Ch. 16's visual carrier) at the input to the leakage detector under test. Connect the attenuated signal source to the equipment being checked, peak the leak detector (if applicable) and note the indicated field strength with a CW carrier. If readjustment of the leak detector is necessary, follow the manufacturer's instructions.

If an analog TV modulator is being used as the signal source, after the CW calibration check apply a 1 volt peak-to-peak baseband video signal to the modulator's video input (verify 87.5 percent depth of modulation) and again note the indicated field strength on the leakage detector. Quite likely the reading will be lower than the CW measurement since most legacy leakage detection equipment does not use a

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[3] When using an external impedance matching adapter, be sure to take into account the insertion loss of the adapter. A minimum loss pad generally has 5.7 decibels (dB) of insertion loss, and a wideband impedance matching transformer can have 0.5 dB to about 1 dB of insertion loss. Consult the device manufacturer's specifications.

peak detector circuit. Confirm with the leakage detector manufacturer whether the instrument was factory-calibrated with a CW carrier or a modulated analog visual carrier. The difference is an additional calibration factor that must be considered, depending on whether the leakage reference carrier in the cable network is a CW or modulated visual carrier.

Many operators use newer leakage detection equipment that relies upon a proprietary leakage test signal rather than an analog TV channel visual carrier or CW carrier. The proprietary test signal is typically injected in between adjacent SC-QAM signals, at a power level low enough to not cause interference with the SC-QAM signals. For example, the proprietary test signal can be injected on a frequency such as 138 MHz, at a power configured 30 dB below the digital channel power of the adjacent SC-QAM signal (the actual injection level varies somewhat among manufacturers). When the leakage detector detects a leak, it measures the actual field strength of the proprietary test signal and then applies an amplitude offset to give a corrected field strength equivalent to having measured the SC-QAM signal.

When using a proprietary leakage test signal for a directly-connected RF signal source calibration procedure, it is recommended that a live feed from the cable network be used as the source. See Figure 4. First, connect the live feed that includes the proprietary test signal to a spectrum analyzer, and confirm the test signal's amplitude is correct relative to the adjacent SC-QAM signals; refer to the detector manufacturer's instructions. (Note: A bandpass filter might be necessary to prevent front end overload of the leakage detector.) Next, install a variable attenuator between the live feed and the analyzer, then adjust the attenuator as necessary to provide the desired RF signal level of the leakage test signal that is equivalent to a specific indicated field strength. Disconnect the attenuated live feed from the analyzer, and connect it to the leakage detector's external antenna jack. Confirm that the detector reports the expected field strength. Note: Consult with the leakage detector manufacturer for details about the test signal amplitude needed to produce a given indicated field strength on the detector.

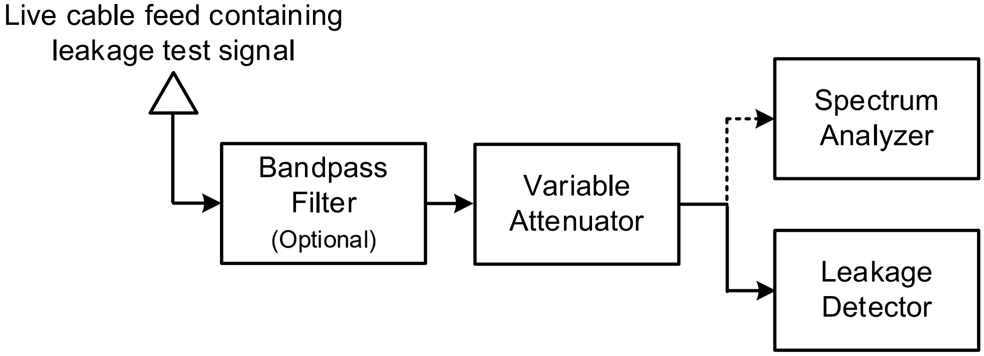

Figure 4 - Block diagram for equipment connection for directly-connected signal source method to confirm detector calibration.

In cable networks that use a high-split band plan in FDD, or use FDX, part of the upstream spectrum will overlap the 108 MHz to 137 MHz VHF aeronautical band. Compatible cable modems (CMs) can be configured to generate an OUDP testing burst for leakage detection purposes. See Figure 5 for an equipment configuration that can be used to confirm leakage detector calibration.

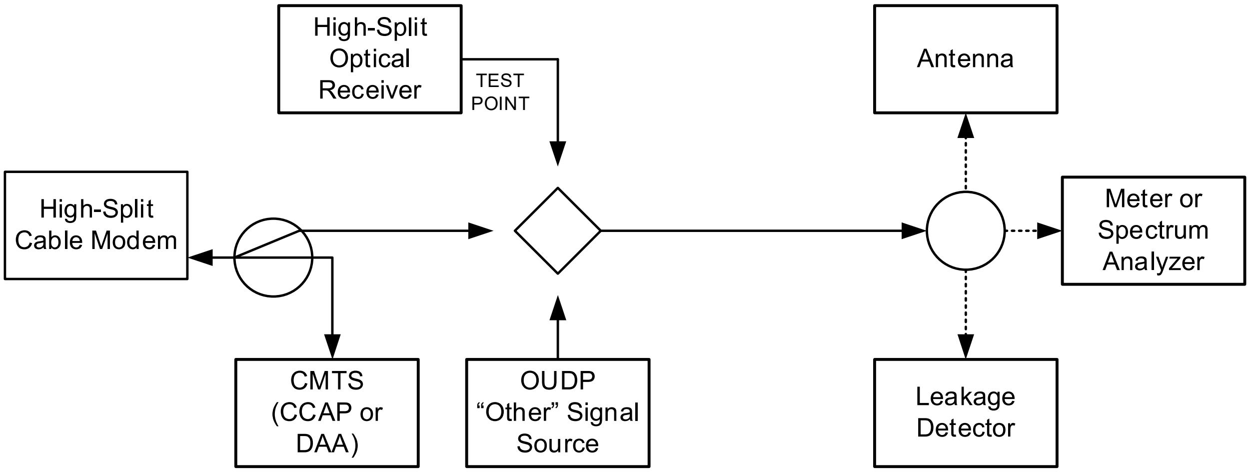

Figure 5 - Equipment block diagram for OUDP testing burst usage.

9.2. Calibrated Field Strength

This is also known as the calibrated leak method and allows the relative accuracy of field strength measurements to be determined. A complete leakage detection system – antenna, coax and receiver – as installed in a vehicle can be checked. Since this involves the intentional creation of a leak, it is very important that the duration of the calibration be kept fairly brief and that the leak be turned off when the calibration is finished.

Clearly mark the pavement for when a leakage detector alarms at the predetermined field strength for both the docked operation (unit is inside vehicle cradle leveraging external antenna) and when undocked in the technician's hand leveraging the leakage detector's integrated antenna. For the latter, make sure the calibration test area is as clear as possible to minimize unwanted reflections that could affect the accuracy and repeatability of the field strength measurement. Because of the number of variables that can affect the accuracy of open-air field strength measurements, this procedure should be considered secondary in accuracy to the directly-connected signal source method. However, it is convenient to ensure that leakage detection equipment is responding accurately to a known ambient field strength, and technicians will be able to identify possible antenna, cabling, or leakage detector issues. Some leakage detectors may not have an accessible external antenna input connector, so a calibrated leak is a useful option for confirming relative measurement accuracy.

9.2.1. Steps to Create a Calibrated Leak

The following steps can be used to create a calibrated leak; refer to Figure 6:

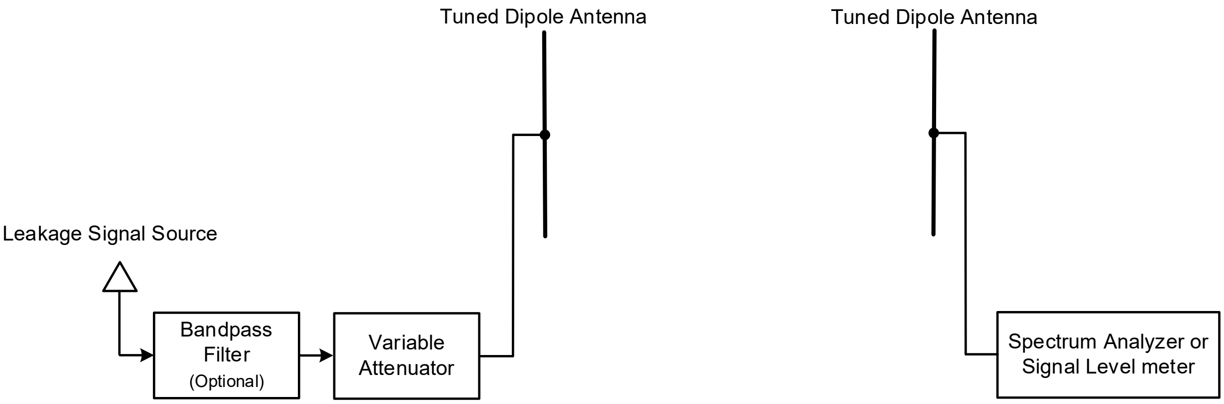

Figure 6 - Equipment setup for a calibrated leak.

- Place a resonant half-wave dipole tuned to the calibration frequency in an open area such as a large parking lot. If possible, install the antenna on a non-metallic support at about the same height as the leakage detection antennas on system vehicles. As a best practice locate the calibrated leak in an area where installers and technicians must drive their vehicles past it regularly so they can confirm that their detector is operational and that the leak's field strength measures roughly the same each time they drive by. Note: Take care to orient the receive antenna to obtain a peak field strength reading, to ensure the measurement location is not in a null of the transmit antenna's radiated pattern.
- Orient the polarity of the transmit antenna to match that of the leakage detecting equipment being checked. For example, if the vehicle leakage detection antennas are vertical whips, the transmit antenna should be vertically polarized, too.
- Connect a signal source to the antenna after ensuring that the source's signal type, frequency (or frequencies), tag type and configuration, and other parameters match the leakage detection equipment capabilities and settings. If the signal source is a live feed from the cable network, use a suitable bandpass filter at the input of the antenna to prevent leakage on other frequencies.
- Find a calibration location that is out of the transmit dipole's near field (see Figure 7) and set up a second resonant half wave dipole and calibrated measurement instrument (spectrum analyzer, signal level meter, etc.).[4] Orient the second dipole's polarity to match the transmit antenna's polarity.

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[4] Note: If the second antenna is in the transmit antenna's near field region, the field strength readings will not be accurate. It is important that the point where the second antenna is located is in the transmit antenna's far field region. For example, the near field/far field boundary for a 138 MHz half wave dipole antenna is about 39 inches, so the second antenna should be beyond that boundary (refer to Figure 4).

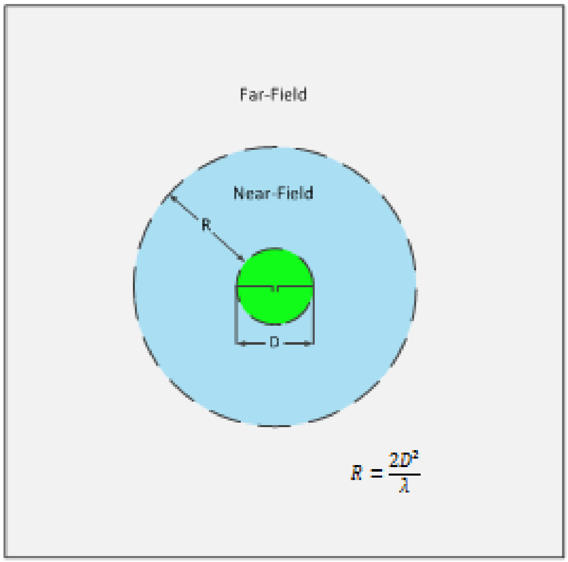

Figure 7 - Approximate distance from dipole to near-field/far-field boundary

- With the calibration signal source feeding RF into the transmit antenna, measure the received signal level at the calibration location. Have an assistant adjust the signal source's amplitude until the desired field strength – for example, 20 µV/m – is measured at the second antenna's location. Table 1 provides µV/m to dBmV conversions for the center frequency of CTA channels in or near the 108 MHz to 137 MHz aeronautical band, and for two other commonly used leakage detection frequencies. Note that the dBmV values in the table are what is calculated to appear at the terminals of a resonant half wave dipole antenna for the field strengths shown. Be sure to take into account receive antenna feedline losses, preamplifier gain (if used), and bandpass filter insertion loss (if used). For more information about converting field strength in µV/m to dBmV, see [Math].

Table 1 – Microvolts per meter to dBmV conversion

CTA Channel	Center Frequency	15 µV/m	17.4 µV/m	20 µV/m	50 µV/m
98	111 MHz	–43.83 dBmV	–42.54 dBmV	–41.33 dBmV	–33.37 dBmV
99	117 MHz	–44.29 dBmV	–43.00 dBmV	–41.79 dBmV	–33.83 dBmV
14	123 MHz	–44.72 dBmV	–43.43 dBmV	–42.22 dBmV	–34.26 dBmV
15	129 MHz	–45.13 dBmV	–43.85 dBmV	–42.64 dBmV	–34.68 dBmV
16	135 MHz	–45.53 dBmV	–44.24 dBmV	–43.03 dBmV	–35.07 dBmV
N/A	138 MHz	–45.72 dBmV	–44.43 dBmV	–43.22 dBmV	–35.26 dBmV
17	141 MHz	–45.91 dBmV	–44.62 dBmV	–43.41 dBmV	–35.45 dBmV
N/A	612 MHz	–58.66 dBmV	–57.37 dBmV	–56.16 dBmV	–48.20 dBmV

- Record the necessary RF input to the transmit antenna that produces the desired field strength at the receive antenna. While one can calculate the theoretical level (see Section 9.3), the actual signal level at the input to the transmit antenna required to produce the desired field strength at the receive antenna probably will be somewhat different than the calculated value because of the effects of reinforcing or cancelling reflections from the ground and nearby objects.
- Now it's a simple matter to have leakage detector-equipped vehicles driven through the calibration location when the calibrated leak is turned on to see if their leakage detectors provide a relatively

correct indication of the known field strength[5]. *Be sure to turn the leak off after each calibration session, because it is a leak that has the potential to cause interference to over-the-air users.*

9.3. Calculated Loss Between Two Dipole Antennas

The following provides an analysis of the attenuation of RF power between two dipole antennas and what signal level is required at the input terminals of one antenna to produce a certain signal level at the output terminals of the other. These calculations are based upon the assumption that no reflections or other problems affect the signals as they travel between the two antennas. Free space path loss calculations as discussed in this section should be considered a starting point. In practice, the actual loss between two antennas will not be the same as free space path loss, because of the effects of reflections (that is, the constructive/destructive interference from reflections), obstructions, polarization mismatch, failing to ensure the field strength measurement is in the far-field (see Section 9.2.1), and so forth. In these examples the signal source and receiver are assumed to be connected directly to their respective antennas, eliminating feedline loss.

The numerical gain of a linear half wave dipole in free space relative to an isotropic source is 1.64.

Or, expressed in decibel isotropic (dBi):

$$G_{dBi} = 10log_{10}(1.64)$$

$$G_{dBi} = 2.15\ dBi$$

The free space path loss in decibels between two points is:

$$Loss_{dB} = 20log_{10}(f_{MHz}) + 20log_{10}(d_{km}) + 32.45$$

where:

$Loss_{dB}$ is free space path loss in decibels
f_{MHz} is frequency in megahertz
d_{km} is path length in kilometers (1 meter = 0.001 km)

From these relationships, one can determine the required transmit signal level at the input to a dipole that will produce a field strength of 20 µV/m a certain distance away.

Assume a separation of 15 meters between two resonant half wave dipole antennas for Ch. 16, whose offset visual carrier frequency is 133.2625 MHz. The free space loss between the two dipoles is:

$$Loss_{dB} = 20log_{10}(133.2625\ MHz) + 20log_{10}(0.015\ km) + 32.45$$

$$Loss_{dB} = 38.47\ dB$$

Converting µV/m to dBmV is done with the formula:

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[5] One should expect some variation of a vehicle-mounted leakage detector's indicated field strength from ideal, perhaps by as much as several dB. The shape/size of the vehicle, the type of antenna, its location on the vehicle, its proximity to other antennas, as well as its proximity to safety lights/beacons, ladders, an aerial lift, and/or other objects will affect the antenna's gain and radiation pattern.

$$dBmV = 20log\left[\frac{\left(\frac{E_{\mu V/m}}{0.021 * f}\right)}{1000}\right]$$

where

dBmV is RF signal level in decibel millivolts at the terminals of a resonant half-wave dipole antenna
$E_{\mu V/m}$ is field strength in microvolt per meter
f is frequency in megahertz

Convert 20 µV/m at 133.2625 MHz to dBmV at the terminals of a resonant half-wave dipole:

$$dBmV = 20log\left[\frac{\left(\frac{20}{0.021 * 133.2625}\right)}{1000}\right]$$

$$dBmV = 20log\left[\frac{\left(\frac{20}{2.80}\right)}{1000}\right]$$

$$dBmV = 20log\left[\frac{(7.15)}{1000}\right]$$

$$dBmV = 20log[0.00715]$$

$$dBmV = -42.92$$

Working backwards from the desired received field strength of –42.92 dBmV, one can calculate the necessary transmit signal level:

transmit level = received field strength (dBmV) – receive antenna gain (dBi) + path loss (dB) – transmit antenna gain (dBi)

= –42.92 dBmV – 2.15 dB + 38.47 dB – 2.15 dB
= –8.75 dBmV

In practical situations, the actual transmit signal level will probably be something other than what is calculated, because of the effects of reflections from the ground and nearby objects.

The power intercepted by a receiving antenna also can be calculated with the formula:

$$P_r = \frac{P_t G_r G_t \lambda^2}{(4\pi R)^2}$$

where:

P_r = received power (watts)
P_t = transmitted power (watts)

G_r = numerical gain of receive antenna
G_t = numerical gain of transmit antenna
λ = wavelength of transmitted signal (meters)
R = distance between antennas (meters)

The transmitted power is –8.75 dBmV, or 1.78×10^{-9} watt. The gain of each dipole is 1.64 and Ch. 16's free space wavelength is 2.25 meters. The distance between the antennas remains 15 meters. Substituting these figures in the formula, we have:

$P_r = (1.83 * 10^{-9})(1.64)(1.64)(2.25)^2/(4\pi 15)^2$
$P_r = 2.49 * 10^{-8}/35530.58$
$P_r = 7.00 * 10^{-13}$ watt, or $7.15 * 10^{-6}$ volt
$P_r = 7.15\ \mu V$
$P_r = –42.92$ dBmV

Note: For the conversion between watts and volts, the impedance of each dipole is assumed to be a free space value of approximately 73 ohms.

10. Troubleshooting

If a discrepancy is observed between what a leakage detector reports and what the calibrated leak is supposed to produce, some simple troubleshooting steps can be taken. First, have one or more other detector-equipped vehicles drive through the calibrated leak area. If detectors in those vehicles do not have an issue, the problem is most likely the leakage detector in the first vehicle, its cabling, or antenna. Each of these can be checked visually to make sure damage hasn't occurred. If no obvious problem is found, remove the suspect detector and check it using the directly-connected RF signal source method. A problem identified with the latter method warrants sending the suspect detector to the manufacturer for service. Refer to the leakage detector's operating manual or the manufacturer for additional troubleshooting tips.

Assuming the cable company uses the same make/model detector in many or all vehicles, a known working detector can be removed from another vehicle and temporarily substituted in the problem vehicle to see if the accuracy problem remains. If it does, look for a problem with the in-vehicle detector cradle, its cabling (pinched, cut, or otherwise damaged coax), connectors, and antenna. Also look to see if something was placed on the vehicle that is obstructing the leakage antenna.

If detectors in other vehicles exhibit the same inaccuracy, then the culprit is likely the calibrated leak. Visually inspect the calibrated leak's transmit antenna, coax feedline, and connectors and other components. When the calibrated leak was first created, system personnel should have measured and recorded the actual level of the test signal feeding the calibrated leak antenna *at the input to the antenna*. Measure the signal level and compare it to the original value. If a difference is noted, the problem might be with the signal source (modulator, signal generator, or system feed), cabling, connectors, bandpass filter, or other component. Use the divide-and-conquer approach to identify where the problem exists.

11. Recording of Results

Most cable operators that use calibrated leaks have their installers and techs drive through the leak test area, and quickly check to make sure their in-vehicle leakage detectors are working as expected. The results are not normally recorded.

Where recording of results might be done is the directly-connected RF signal source calibration method, especially on the test bench, to document when and how the calibration check on a given detector was performed. If a leakage detector is sent to the manufacturer for routine calibration, a copy of the manufacturer's calibration data should be kept with local system documentation.

12. Conclusion

Cable operators should have a process in place for technicians to regularly check and ensure the calibration of their leakage measurement equipment. As an example, some cable operators require that technicians with leakage detection equipent in their fleet vehicles check the calibration of their equipment prior to heading out into the field for leakage measurements. If third party vehicles like garbage trucks are used, and detectors from the third party vehicles are used merely to indicate where specific leakage measurement teams from the cable workforce are to go using calibrated equipment, then the leakage detectors from the third party vehicles may not require such frequent calibration; rather, the cable operator's leakage team would check their equipment prior to making a targeted measurement run. Technicians should always check with and adhere to their cable company's policies and procedures for leakage equipment calibration and measurements.

13. Appendix

Setting up a properly configured OUDP testing burst to use for leakage monitoring and measurement comes with some complexities. The OUDP testing burst signal is created by a DOCSIS 3.1 or DOCSIS 4.0 cable modem. In some instances, the location of the calibrated leak used by installers and technicians to confirm the performance of their in-vehicle leakage detectors may not have a live cable network feed available. In those cases, an OUDP-compatible modem or modems will need to be set up as a standalone test signal source, so the technicians can do routine validation of their leakage detectors. That may require a dedicated CMTS or similar to connect to the modems and support the use of the OUDP testing burst. Ensure the CMTS and modems are properly configured. Table 2 includes a list of example configuration parameters, for a CMTS and leakage detector. Note: Consult with your equipment vendors for specific configuration parameters applicable to your CMTS and leakage detectors.

Table 2 - Example of a configuration parameters for OUDP testing burst

OUDP Parameters	
OFDMA start frequency (Hz)	104800000
OFDMA carrier width (MHz)	96
OUDP start frequency (Hz)	137300000
OUDP stop frequency (Hz)	138900000
OUDP center frequency (Hz)	138100000
Subcarrier spacing (kHz)	50
Cyclic prefix (samples, N_{cp})	256
Rolloff period (samples, N_{rp})	96
Symbols-per-frame (K)	16
Data IUC	13
Data IUC modulation	64-QAM
Data IUC pilot pattern	4
TransmitBurstGap - between CMs (number of OFDMA frames)	0
TransmitDuration – Per CM (number of OFDMA frames)	8
TransmitCycleGap – between cycles (number of OFDMA frames)	2
Minislots	4
Round robin time (ms)	<500

Ensure the OUDP testing burst configurations are precisely aligned between the CMTS and leakage detector. When using a single CM confirm the transmit level is below its maximum transmit capability, and that all OFDMA carriers are bonded (CM must not be in partial service). Note that the CM should transmit the OUDP testing burst at least twice per second by design, and because the leakage detector is detecting a bursty signal the reported field strength may not change as quickly as a downstream signal leakage detector would. For this reason, it is best to locate the calibrated leak antenna where vehicles can drive by that leak slowly, say, below about 20 MPH. Note: When monitoring and measuring leakage with an OUDP testing burst in the outside plant, techs should be advised to take their time, being careful not to drive too fast in the areas tested.

A dedicated coaxial feed (if available) and aeronautical band antenna are recommended for a setup that is simple to maintain, whereas troubleshooting a combined upstream in, say, the 138 MHz range, and downstream signals (612 MHz/774 MHz CW or OFDM pilot carriers) will be complicated. To prevent inaccurate readings, ensure there are no conflicting noise sources nearby, and that the location is not in a high-ambient noise environment. When measuring and documenting the leakage level of the modem OUDP testing burst source, use a compatible digital signal level meter, or spectrum analyzer, to make an accurate power measurement of the full 1.6 MHz-wide OUDP testing burst. Also, document meter/analyzer settings so the measurement can be accurately repeated. For more information about the use of an OUDP testing burst for leakage detection in high-split networks, see [SEGURA].