SCTE ISBE

# JOURNAL OF
# NETWORK OPERATIONS

**Volume 1, Number 1**
January 2016

www.scte.org | www.isbe.org

Society of Cable Telecommunications Engineers

International Society of Broadband Experts

# JOURNAL OF NETWORK OPERATIONS

VOLUME 1, NUMBER 1
JANUARY 2016

Society of Cable Telecommunications Engineers, Inc.
International Society of Broadband Experts™
140 Philips Road, Exton, PA 19341-1318

JOURNAL OF
NETWORK OPERATIONS

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JOURNAL OF
NETWORK OPERATIONS

# Operational Practice for Identifying, Locating and Mitigating UHF Ingress and Direct Pickup in Cable Networks and Devices

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
By

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# 1. Introduction

## 1.1. Executive Summary

***Target Audience:*** Outside plant technicians, field and installation technicians, training content developers, and those with an interest in ingress and direct pickup interference.

***What is it?*** This operational practice covers techniques for identifying, locating, and mitigating ultra high frequency (UHF) band ingress and direct pickup interference, especially that from over-the-air long term evolution (LTE) signals, in hybrid fiber-coax (HFC) access networks and associated devices.

***What is the function of it?*** This operational practice is to help cable operators meet the increasing potential from LTE and other UHF band ingress and direct pickup interference in order to maintain and improve customer satisfaction with cable services.

***What are the immediate and long-term benefits of adopting it?***

- Reducing customer care calls, truck rolls/repeat truck rolls, and the mean time to repair (MTTR)
- Increasing the spectral efficiency of the cable network
- Updating and/or elimination of certain legacy equipment, centralization of network monitoring

***How does this operational practice impact the industry and fit into the SCTE Engineering Committee's roadmap?*** It will allow the cable industry to keep up with exponential growth of LTE services and devices and their impact on cable networks. The approaches are part of a long term move in the industry towards more centralized, cloud-based network monitoring, control and management architectures.

***What are some of the key points of this operational practice?***

- Description of LTE and other UHF band ingress and direct pickup interference sources and common causes for their entry into the cable network and equipment
- UHF susceptibility-reducing improvements that should be employed in modern headend, outside plant, and customer equipment
- Key performance indicators (KPIs) that should be monitored to assess network performance relative to UHF/LTE ingress and direct pickup
- Practices for monitoring, detecting, locating and migitating UHF ingress and direct pickup
- Detailed procedures for troubleshooting problems associated with UHF ingress and direct pickup
- Equipment for monitoring ingress and direct pickup interference, including the use of proactive network maintenance (PNM) technology
- Suggestions for educating the workforce on causes of and troubleshooting UHF ingress and direct pickup interference

***What can you do to achieve maximum benefit from implementing this operational practice?*** Customize it for your workforce/cable network specifics. Implement the practices, keeping track of KPIs both before and after the implementation to ensure it is meeting the business goals of the cable operator.

***How can you learn more about this operational practice***? Join the Network Operations Subcommittee (NOS) working group and assist in revisions and updates to this document. Visit http://www.scte.org/standards, or email: standards@scte.org for more information.

## 1.2. Scope

This document discusses ingress and direct pick up interference in the UHF spectrum and details its effects on cable networks. Additionally, this document provides operational practices to help cable operators isolate the interference to its source in the coaxial network and devices.

## 1.3. Background

Cable operators have had to deal with ingress of over-the-air signals into the cable network for many years. Ingress could occur in the upstream from high frequency (HF) band communications such as broadcast radio stations like Voice of America or amateur radio (ham) or citizen's band (CB) radio. Ingress can also occur in the very high frequency (VHF) band from over-the-air frequency modulation (FM) radio stations and from over-the-air TV broadcast signals. Ingress can occur from over-the-air TV signals in the UHF band. There are also cases of radar signals and other radio frequency (RF) signals ingressing into the cable network.

There are two ways that over-the-air signals, which as far as the cable network is concerned is electromagnetic interference (EMI), can get into the cable network: via conduction over wireline or powerline, and via radiation, which is to say induction, where the coaxial cable or devices act like antennas to capture the EMI from the airwaves. In the cable industry, radiated EMI that ingresses into headend or hub site equipment, or customer premises equipment (CPE) is often called direct pickup.

In the cable network itself, ingress of over-the-air signals can occur via a variety of impairments in the access network, some of which are:

- Loose, improperly installed, corroded or otherwise damaged connectors, adapters, and terminators
- Cracked hardline cable shielding
- Damaged cable shielding (tree limb abrasion, severe corrosion, bullet holes, etc.)
- Loose passive device faceplates or active device housing lids
- Warped active device housing lids
- Corroded or otherwise damaged RF shielding gaskets in passive device faceplates or active device housings
- Rodent damage to cable and passives

In addition, direct pickup of over-the-air signals in the customer premises can occur from:

- Poorly shielded TVs, FM tuners, and other non-cable CPE
- Poorly shielded cases or covers of cable modems, embedded multimedia terminal adapters (eMTAs), set top boxes (STBs), or any other CPE connected to the subscriber drop
- CPE case seams, holes, ventilation slots, and so on

These causes and sources of ingress and direct pickup interference to cable services have been around a long time, and the cable industry has a variety of methods and tactics to identify, locate the source, and mitigate the cause of the interference. However, in late 2010, a new wireless technology called LTE was introduced in the United States. LTE service operates in several frequency bands, including the 698 MHz to 806 MHz band, as shown in Figure 1, which overlaps the frequency spectrum used by many cable operators to deliver services to their customers. As LTE deployment expanded to the point where the majority of users employ LTE phones, and LTE base stations are practically everywhere, this has created both a source of interference to cable networks, and an additional concern for leakage from the cable network. The latter issue is covered in another SCTE operational practices document, while this operational practices document is concerned with ingress and direct pickup of LTE and other EMI into the cable network or CPE and thereby causing interference to cable services and potential degradation of customer quality of experience and customer satisfaction.

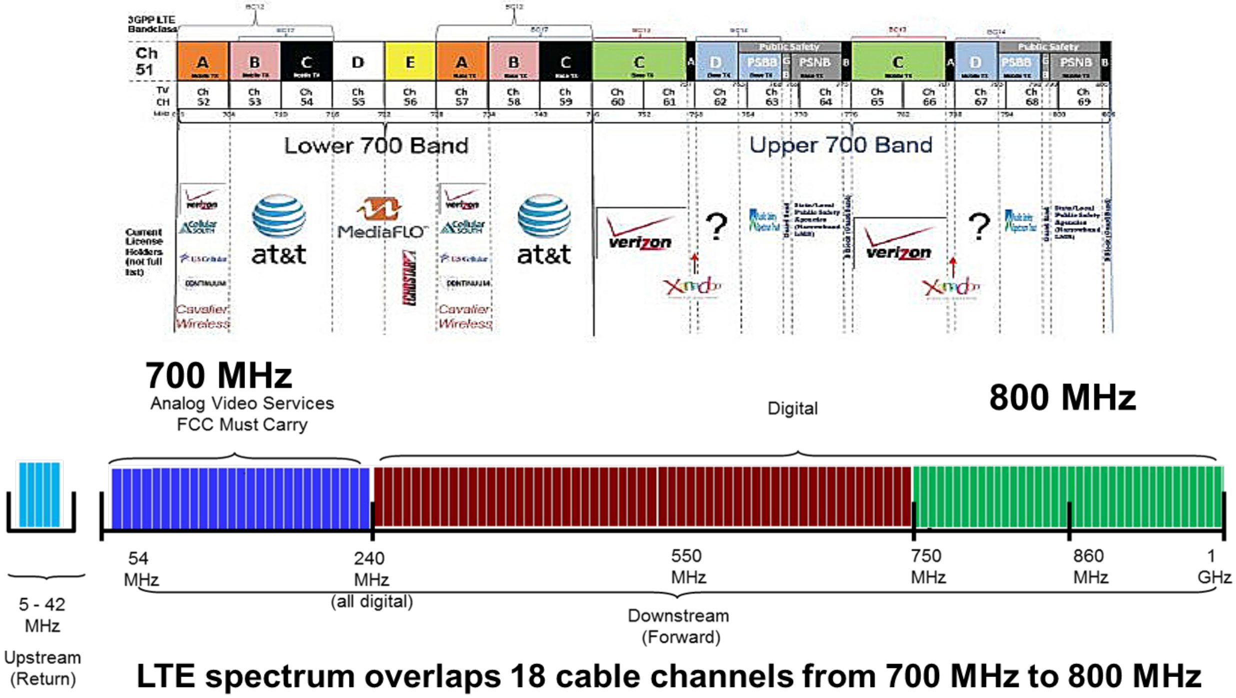


**Figure 1 - LTE spectrum allocation (from Watson [1])**

There are also femtocells and in-building LTE systems which have lower transmit power levels than a standard, tower-type LTE base station, but can be much closer to portions of the cable network and CPE. The lower path loss over much shorter distances between femtocells and the cable network, and nominal attenuation through buildings/walls could increase the LTE ingress and direct pickup issues for cable networks and customers, although it remains to be seen whether such femtocells or in-building LTE systems will be more or less problematic.

## 2. Operational Practices

### 2.1. Key Performance Metrics

This section includes the key performance metrics to be measured and provides a brief overview of the theory behind each one.

Ingress and direct pickup of over-the-air signals can affect the following KPIs in cable networks:

- Bit error ratio (BER) and associated metrics such as errored seconds (ES) and severely errored seconds (SES)

- Carrier-to-noise ratio (CNR)
- Modulation error ratio (MER)
- Codeword error ratio (CER, or $R_C$ is used in the DOCSIS specification)
- Main tap ratio (MTR) of the pre-equalization process, and related adaptive equalizer tap metrics
- Achievable order of modulation for reliable communications
- Required power margin for upstream and downstream laser operation
- Number of laser clipping events and/or mean time between laser clipping events

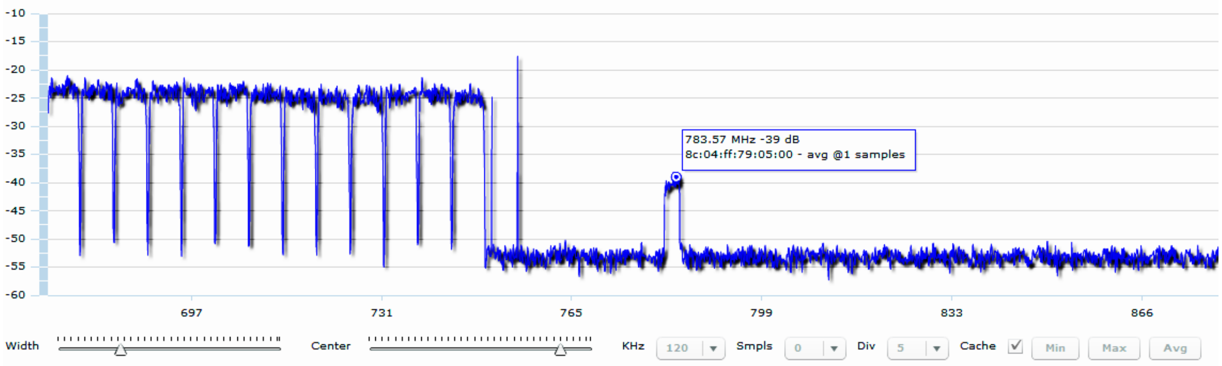
In addition, histograms of the previously listed metrics, e.g. MER, can be plotted for all CPE devices or versus various parameters such as plant age, plant repair activity, temporal history, construction nearby, and so on so that long term trends in ingress causes can be proactively identified in the future and repaired before they cause customer complaints.

In addition, metrics that relate to the workforce or effectiveness of ingress cause mitigation can be collected. These may include metrics such as:

- MTTR ingress cause after detection and location;
- Mean time between repeated detections on a node, system or region;
- Average number of ingress detections per node, system, or region;

and so on.

On the qualitative front, RF spectrum snapshots of both the cable upstream , from the cable modem termination system (CMTS) or  converged cable access platform (CCAP), and with DOCSIS 3.1, from the cable modem (CM), and also on the cable downstream from the CM, using full band/full spectrum capture capabilities, can be collected  and analyzed for the presence and magnitude of ingress and direct pickup getting into the network or CPE. Figure 2 shows such a capture where the user held an LTE phone within one foot of the eMTA in his home. The direct pickup LTE signal power spectral density is seen to be about 15 dB down from that of the downstream quadrature amplitude modulation (QAM) signals on the cable network. But while the signal power spectral density to interference power spectral density is about 15 dB, the total signal-to-interference ratio (SIR) is greater than 15 dB since the LTE signal in this case has a lower RF bandwidth than the cable QAM signals. Nonetheless, it is likely this direct pickup level of LTE interference would prevent operation of a QAM carrier, were it in use at the LTE frequency.



783.57 MHz -39 dB
8c:04:ff:79:05:00 - avg @1 samples

KHz 120
Smpls 0
Div 5
Cache ☑

**Figure 2 - Example spectrum capture from CM showing direct pickup of LTE signal**

Examples of these types of captures will be given in later sections of this document. From these captures, metrics such as relative power spectral density level differences between QAM carriers and the LTE direct pickup signal can be determined.

## 2.2. Required Equipment

It is now possible to use existing CMTS/CCAP equipment and CM (or DOCSIS-based STBs) to monitor and characterize ingress and direct pickup into the cable network and CPE, and this is now the preferred method since these devices are already in use in the network and the only additional cost is the back office software, integration with geographical information systems (GIS), and training of the workforce to use this PNM technology and capabilities. And PNM technology will be significantly enhanced in DOCSIS 3.1, to include upstream spectrum capture at the CM as well as the CMTS/CCAP, triggered captures, and greater resolution in impairment identification and location.

Conventional cable network monitoring equipment such as the following can also be used to identify and characterize ingress and direct pickup EMI in the cable network:

- Spectrum analyzer (SA) and QAM-based SA
- Digital sampling oscilloscope (DSO)
- FFT real time analyzer
- Vector signal analyzer (VSA)
- Handheld digital signal analyzers
- Centralized monitoring systems (e.g., the Viavi PathTrak™ system or the VeEx VeSion™ system)

For capturing stationary narrowband ingress such as HF or FM radio stations, a spectrum analyzer is often the easiest to use, while for transient ingress events, including impulse and burst noise events, a time domain capture from a DSO or FFT real time analyzer is often better. Again, with modern PNM technology built into CMTS/CCAP and CM equipment, it is possible to use the equipment already deployed to perform these capture and monitoring functions.

## 2.3. Calibration and Equipment Preparation

Calibration and equipment preparation are described as part of the detailed procedures in the next section.

## 2.4. Detailed Procedures

### *2.4.1. Ingress*

Signal ingress is the opposite of signal leakage, and occurs when over-the-air signals “leak” into the cable system through a shielding defect. Ingress can happen anywhere when the cable network’s shielding effectiveness has degraded, such as loose, improperly installed, or damaged connectors; cracked shielding; rodent chews; and so forth. The hardline plant and subscriber drop portions of the network are both susceptible to ingress interference. Anywhere shielding effectiveness is compromised, ingress interference is a possibility. It is important to understand that there is no correlation between leakage field strengths and ingress levels.

Ingress generally occurs when an external signal is coupled onto the outer surface of the coaxial cable shielding, creating a common mode current. That common mode current propagates along the outer surface of the cable's shield. If the common mode current reaches a shielding defect, some of the common mode current may be coupled into the inside of the coax, creating a differential mode current that now propagates along with the desired signals and potentially interferes with those signals.

#### 2.4.1.1. Common Frequencies of External Interference

Ingress in the upstream spectrum (typically 5 MHz to 42 MHz in North America) arguably is the most common, but downstream ingress from VHF broadcast TV signals, FM broadcast radio in the 88 MHz to 108 MHz band, 2-meter (144 MHz to 148 MHz) ham radio signals, 150 MHz pagers and two-way radios, and so on, also have been problematic. Some of the more common sources of UHF ingress have included 450 MHz two-way radio and pager signals, UHF broadcast TV signals (470 MHz to 698 MHz) – both analog and digital – and more recently, LTE signals in the 698 MHz to 806 MHz band. Figure 3 shows over-the-air signals in the 500 MHz to 806 MHz frequency range, including UHF TV signals, LTE signals, and public safety communications signals. Note that low-level leakage of several QAM signals is evident in the noise floor, too.

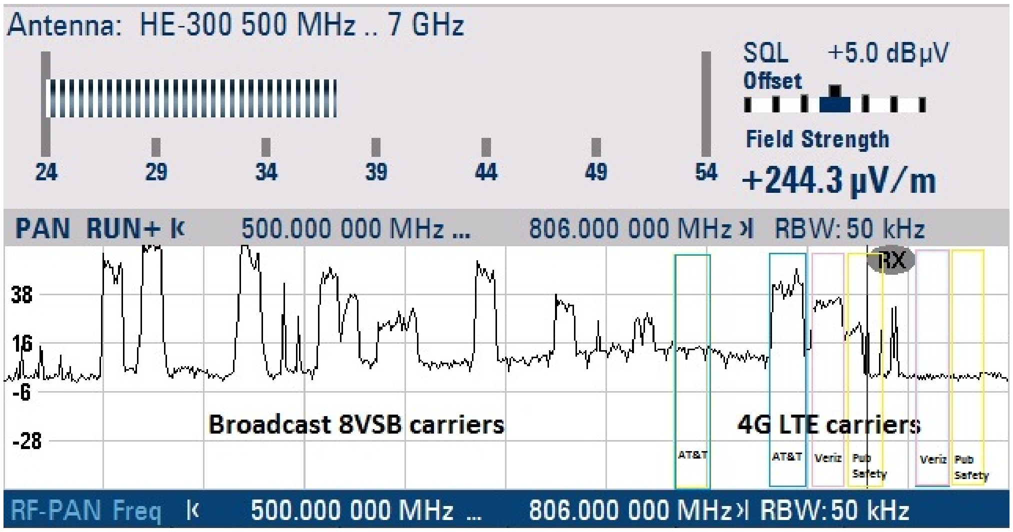


**Figure 3 - Example of signals visible in the UHF over-the-air spectrum**

The remainder of this document focuses on the UHF sources of ingress and direct pickup.

#### 2.4.1.2. Digital Broadcast Television

Ingress and direct pickup of television broadcast signals are not new to cable operators. There have been many papers and articles written on the subject, and operators have dealt with broadcast TV ingress and direct pickup interference since the beginning of the industry. Efforts to correct this issue have ranged from requiring subscribers to use set top boxes to reduce or eliminate direct pickup of local channels by the TV to more aggressive signal leakage programs.

An important distinction in broadcast interference is that broadcast transmitters operate from fixed locations. Most TV transmissions are now operating using digital modulation and at high transmission levels, and their effects tend to be isolated to specific geographical regions. Mentioned previously, North

American UHF broadcast TV channels occupy the 470 MHz to 698 MHz spectrum. The Federal Communications Commission (FCC) is preparing spectrum auctions for further expansion of LTE services into the 600 MHz spectrum.[1]

High levels of over-the-air broadcast ingress or direct pickup can degrade reception of a cable network's QAM channels, up to and including full loss of demodulation capability by the customer premises equipment (CPE), resulting in loss of picture on digital video channels or loss of data and/or voice service on cable modem channels. Most operators now require a STB or digital transport adapter (DTA) for reception and decryption of QAM video channels, which can minimize direct pickup interference problems to the TV.

Ingress from one UHF broadcast channel will affect two adjacent QAM channels, because of the 2 MHz overlap of the UHF TV channel assignments with the Consumer Electronics Association (CEA) channel plan used in North American cable networks. See Figure 4.

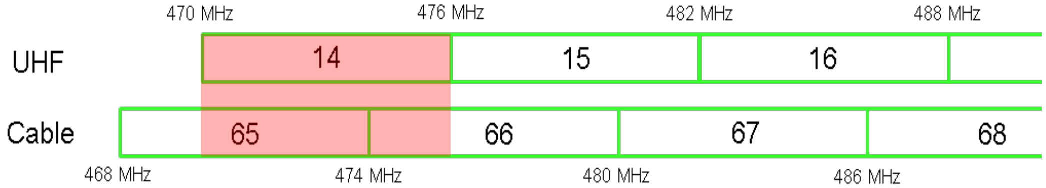


**Figure 4 - Overlap of UHF TV channel assignments with CEA channels used in cable networks**

Ingress interference can cause poor BER, low CNR, and degraded MER and can cause complete loss of data reception within the affected channel space. On DOCSIS channels, the types of traffic most likely affected are voice and Internet protocol (IP) content such as over-the-top (OTT) video, as well as local operator-provided video delivery services. Severe cases can affect high-speed data service..

### *2.4.1.3. Cellular and LTE Services*

3rd generation (3G) type cellular service has been established for some time. Most overlap of 3G transmissions with cable frequencies are in the 800 MHz frequency band. Generally, only cable plants operating above 806 MHz are affected by 3G transmissions, although some older CPE may be susceptible to front-end overload by signals from nearby cell phones[2].

4th generation (4G), or LTE, operation in the 700 MHz band (698 MHz to 806 MHz) has been problematic for cable operators mostly because of the widespread deployment of 750 MHz cable plants.

With cellular or LTE there are two distinct types of interference. First is the tower-to-user downlink (DL) transmission. DL interference is somewhat similar to UHF TV because the base stations on towers or buildings are fixed locations. Most base stations or macro cells have a service coverage radius of typically a few kilometers. Smaller installations referred to as pico, micro and femto cells might be located in poor

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[1] 600 MHz spectrum auctions are tentatively planned for 2016.

[2] Front-end overload, also known as fundamental overload, can occur even when an interfering signal is on a different frequency than what is trying to be received. Circuitry in the affected receiver is overloaded by a strong interfering signal (the total power of that signal may exceed the total power capability of the receiver), which causes reception of most or all desired frequencies to be affected.

coverage areas of macro cells, and in locations such as stadiums, office buildings, college campuses, industrial sites, and homes. All operate in the respective carriers' frequency bands. Downlink signals from towers can cause ingress interference near the towers, and may in some circumstances cause direct pickup interference.

The second type of interference is the LTE user equipment (UE)-to-tower uplink (UL) transmission. These transmissions can produce significant field strengths in close proximity to the UE. UE-related ingress or direct pickup interference, which most often occurs in the subscriber premises, can range from degrading to service-disruptive depending on severity. With the proliferation of LTE devices, the opportunity for harmful ingress or direct pickup interference to cable services can be very high, especially with older cables, connectors, and CPE installed in customers' homes. In particular, older CPE are often not as well-shielded as newer CPE, and may be more susceptible to direct pickup interference from nearby LTE UE. Both of these LTE interference geometries are shown in Figure 5.

RF signal levels are lower in the subscriber drop than in the hardline distribution plant, so a nearby over-the-air transmitter may cause more ingress interference in the drop than in the hardline plant, largely because the carrier-to-interference ratio may be worse in the drop. In some cases ingress interference in the hardline plant can be severe, especially if the ingress enters that plant near the input to an amplifier. Loose, improperly installed, damaged or corroded connectors, or poorly shielded retail-grade cables and components, remain common subscriber drop ingress points, as well as sources of leakage.

Furthermore, the drop, particularly the in-home portion, is often out of control of the cable company. For instance, subscribers disconnect and connect cabling when furniture is rearranged, or when new TVs and other CPE are installed.

Some homes and buildings may be wired with old copper-braid drop, which generally has poor shielding compared to modern bonded foil-braid coaxial cable designs. Multiple dwelling units (MDUs) are often susceptible to ingress, because of poor craftsmanship, older cabling and components, loop-through versus home-run cabling, and tampering or theft of service by residents.

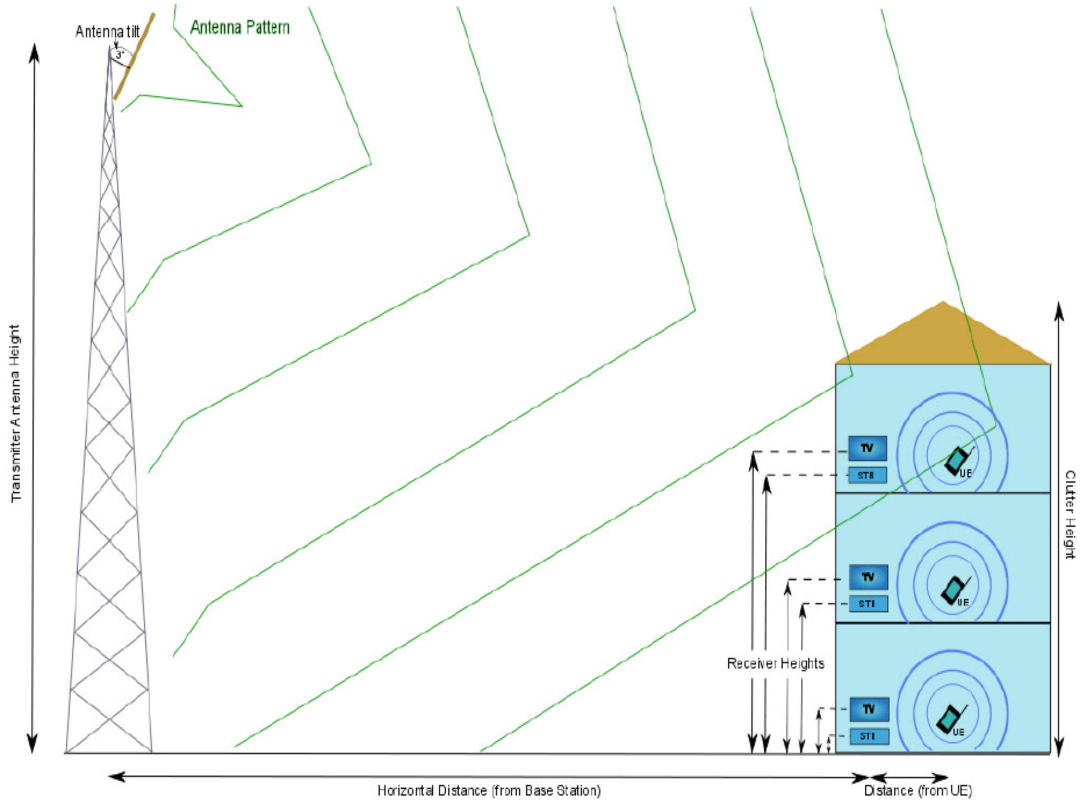


**Figure 5 - LTE interference geometry (from Excentis [2])**

Some cable operators have abandoned frequencies affected by strong ingress. At best this can be considered a short-term solution, because it simply is not practical to continue abandoning valuable RF spectrum whenever ingress is problematic. Eventually the plant will have to be fixed, so that the abandoned frequencies are usable. Troubleshooting UHF ingress can be challenging. When UHF ingress is suspected, a common response is to search for VHF aeronautical band leakage using legacy leakage detection equipment. The assumption is that where VHF signals are leaking out, signals in the UHF band are also leaking in. Unfortunately, the presence of VHF leakage does not necessarily mean that UHF ingress is occurring at that same point. In many instances UHF ingress can exist when there is little or no VHF leakage. In short, there is little or no correlation. VHF ingress can enter the plant through some shielding defects, UHF ingress can enter through others, and both can enter via yet others.

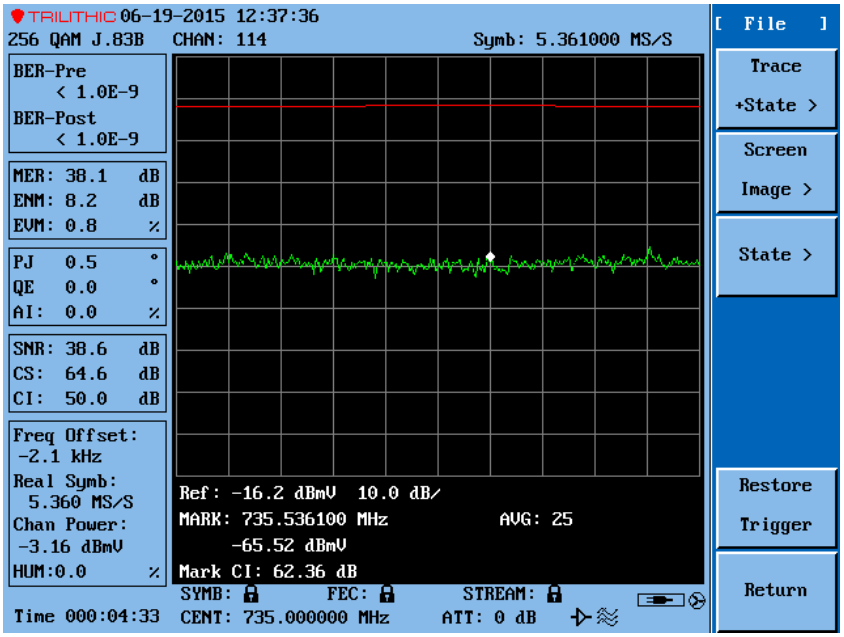
If system personnel have access to UHF leakage detection equipment, locations with UHF leakage might be where some of the ingress is entering the plant, but even that isn't assured.

In pedestals and cabinets with numerous connectors, adapters, actives and passives, it can be difficult to isolate the shielding defect. A near field probe in conjunction with suitable test equipment (spectrum analyzer, interference receiver, etc.) can often be used to identify to within a couple inches or less the specific location where UHF leakage is occurring, which might also be a UHF ingress point.

A spectrum analyzer or spectrum monitor can be used to troubleshoot ingress by first locating points in the service area where the ingress does and does not exist, such as an affected subscriber's premises and the node serving that subscriber. The divide-and-conquer method is then used to isolate where the ingress is entering the plant, by first going to the half-way point between the two original points, and continuing to subdivide the network segment into smaller half-segments until the trouble spot is located.

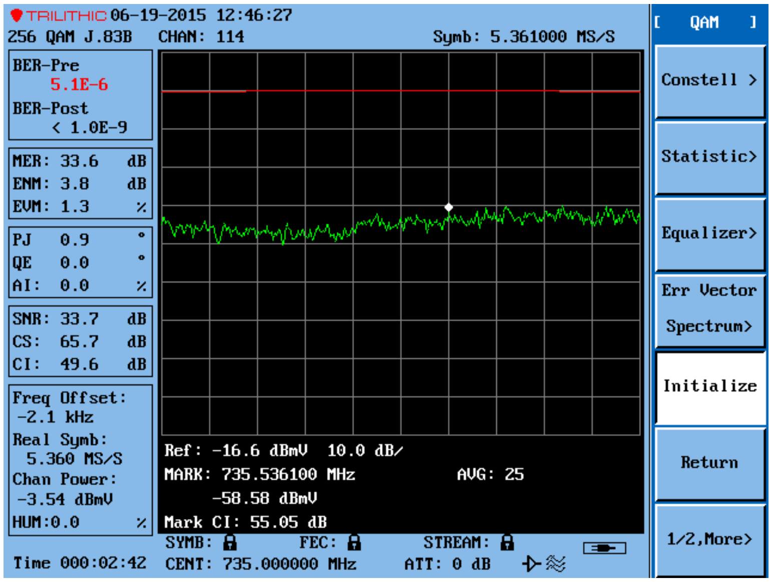
Further complicating the troubleshooting efforts, UHF ingress may be hidden beneath QAM signals occupying the same spectrum. It is generally not acceptable to temporarily turn off downstream signals to see if the suspect ingress is present, with the possible exception of doing that kind of service-disruptive work during a maintenance window.

One option when troubleshooting ingress is to use test equipment that displays the noise floor beneath an affected QAM signal. Some manufacturers have equipment with this feature available, variously called QAM Ingress (Viavi/JDSU), i-QAM (Sunrise Telecom/VeEx), and QAM Error Vector Spectrum (Trilithic, Deviser). As an example, Figure 6 shows CEA Ch. 114 without perceptible interference. Figure 7 shows CEA Ch. 114 with interference from an LTE Band 17 (AT&T) downlink signal, visible as a raised noise floor in the right two-thirds of the screen shot. And Figure 8 in this group shows an example of CEA Ch. 117 with interference from an LTE Band 13 (Verizon Wireless) downlink signal.



```
06-19-2015 12:37:36
256 QAM J.83B   CHAN: 114                     Symb: 5.361000 MS/S
BER-Pre
    < 1.0E-9
BER-Post
    < 1.0E-9
MER: 38.1    dB
ENM: 8.2     dB
EVM: 0.8     %
PJ   0.5     °
QE   0.0     °
AI:  0.0     %
SNR: 38.6    dB
CS:  64.6    dB
CI:  50.0    dB
Freq Offset:
 -2.1 kHz
Real Symb:
  5.360 MS/S
Chan Power:
 -3.16 dBmV
HUM:0.0      %
Ref: -16.2 dBmV  10.0 dB/
MARK: 735.536100 MHz          AVG: 25
      -65.52 dBmV
Mark CI: 62.36 dB
SYMB: 🔒       FEC: 🔒       STREAM: 🔒
Time 000:04:33  CENT: 735.000000 MHz   ATT: 0 dB
```

**Figure 6 - Noise floor beneath CEA Ch. 114, showing no interference**



TRILITHIC 06-19-2015 12:46:27
256 QAM J.83B CHAN: 114 Symb: 5.361000 MS/S

BER-Pre 5.1E-6
BER-Post < 1.0E-9

MER: 33.6 dB
ENM: 3.8 dB
EVM: 1.3 %

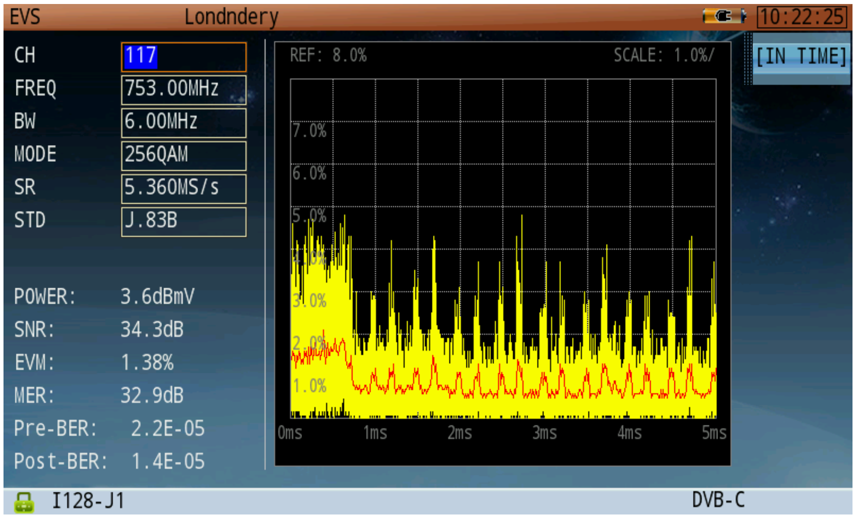
PJ 0.9 °
QE 0.0 °
AI: 0.0 %

SNR: 33.7 dB
CS: 65.7 dB
CI: 49.6 dB

Freq Offset: -2.1 kHz
Real Symb: 5.360 MS/S
Chan Power: -3.54 dBmV
HUM:0.0 %

Ref: -16.6 dBmV 10.0 dB/
MARK: 735.536100 MHz AVG: 25
-58.58 dBmV
Mark CI: 55.05 dB
SYMB: FEC: STREAM:
Time 000:02:42 CENT: 735.000000 MHz ATT: 0 dB

**Figure 7 - Noise floor beneath CEA Ch. 114, with in-channel interference indicated by an increase in the noise floor's amplitude in the right two-thirds of the display.**



EVS Londndery 10:22:25

CH 117
FREQ 753.00MHz
BW 6.00MHz
MODE 256QAM
SR 5.360MS/s
STD J.83B

POWER: 3.6dBmV
SNR: 34.3dB
EVM: 1.38%
MER: 32.9dB
Pre-BER: 2.2E-05
Post-BER: 1.4E-05

I128-J1 DVB-C

**Figure 8 - LTE interference in CEA channel 117**

A commonly used troubleshooting approach is to locate the ingress point using one of the previous discussed methods. Alternatively, it may be possible to use a QAM analyzer to find out where in the plant the CNR, MER, BER, and signal constellation for a given QAM signal have been degraded by the ingress, and where the QAM signal is unimpaired.

Technicians must pay particular attention to ensure that over-the-air signals do not inadvertently enter their test equipment setups when troubleshooting problems or performing routine maintenance. Ingress can occur via a poorly shielded test jumper or a loose connector on an amplifier test probe. This sort of scenario will lead troubleshooting efforts astray, and these false alarm situations may cause valuable time to be wasted.

Depending on the proximity of an active device to an LTE, broadcast, or other transmitter, over-the-air signals can cause ingress interference when an active device's lid is open. Degraded CNR, MER, and BER could occur on a handful of downstream signals with frequencies that overlap over-the-air signals. Many subscribers downstream may be affected, especially if the fiber node or first amplifier is the device with the open lid. One best practice is to keep the housings closed and secured[3], and use an external test point even if it must be created using a permanent tap installation.

### 2.4.2. Direct pickup

Direct pickup interference is similar to ingress, except that the interference enters a susceptible set-top, cable modem, TV set, or other device directly, often without any cables or other external devices physically connected. If the susceptible device's outer case or cover is inadequately shielded, then the internal wiring, printed circuit board traces, and/or components can directly receive interfering over-the-air signals. In some CPE, for instance, ventilation holes and case or cover seams may have physical dimensions and/or shapes that allow them to behave like UHF slot antennas. Sometimes affected devices have poor common mode rejection, and may be susceptible to common mode currents traveling on the outer surface of cabling (coaxial cable, power cord, video and audio cables, etc.) connected to the device. Any one of these, or a combination, can contribute to a device being affected by direct pickup interference.

Many cable operators have in the past several years experienced direct pickup interference to digital set-tops from cell phones sitting near or on top of the CPE. Figure 9 shows a lab test setup with an LTE phone and a digital STB, with the corresponding effect on the STB video quality.  The interference manifests itself as tiling, blocking, or complete loss of picture and sound on digital video signals – sometimes on-channel, and sometimes on all channels, the latter in the case of fundamental overload of the CPE by the interference.

**Figure 9 - LTE direct pickup on STB and effect on video quality (from Watson [1])**

Direct pickup interference by LTE UE causes the same symptoms. LTE UE supports a maximum transmit power of up to +23 dBm (decibel milliwatt) (±2 dB) (European Telecommunications Standards Institute,

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[3] Follow the equipment manufacturer's guidelines for bolt tightening sequence and torque, in order to minimize the possibility of warping the housing and possibly degrading shielding effectiveness.

2011, June), which can produce a field strength 1 meter away from the UE of more than 2 volts/meter (V/m). The latter is the same as a 2,000,000 µV/m.

Cable modems experiencing direct pickup interference can suffer mild to severe packet loss and degraded data throughput. eMTAs may have voice quality problems and dropped calls.

Older CPE often are more susceptible to direct pickup interference, largely because when those early products were designed and manufactured there was no concern about UHF direct pickup interference from mobile devices. Newer CPE are designed to meet more stringent shielding requirements, and typically are less susceptible to direct pickup interference.

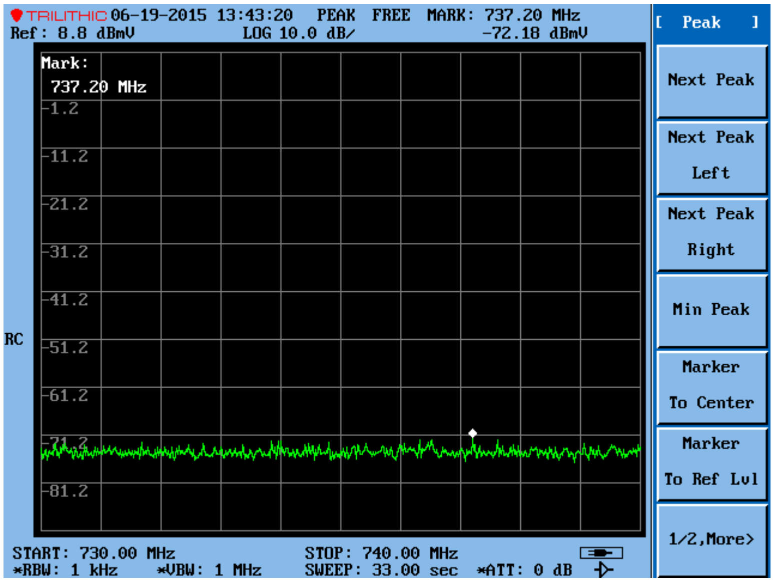
Of course, using newer CPE with improved shielding effectiveness is for naught if the interconnecting cables, connectors, and other components connected to the CPE have worse shielding effectiveness than the CPE. The latter is common with retail-grade cables and components installed by subscribers.

## 2.5. Troubleshooting

### *2.5.1. Troubleshooting Ingress*

When troubleshooting ingress the first test that should be done is to confirm the test setup itself is free from ingress or direct pickup. If the test equipment has a spectrum analyzer function it should be used to test the effective shielding of the test jumper and test equipment case.

1. Connect the test lead to the meter or analyzer to be used.
2. Connect an F-81 barrel the test lead and a 75 ohm terminator to the F-81.Ensure all connections are tightened to the appropriate torque.
3. Tune the analyzer to the channel of interest for the ingress test, or to the center frequency of the CEA channel.
4. If variable span bandwidth settings are available make sure the entire cable channel's 6 MHz bandwidth can be viewed on the screen.
5. If variable resolution bandwidth settings are available select the lowest setting allowed by the test equipment.
6. If variable video bandwidth filtering is available select the highest setting allowed by the test equipment.
7. Select max or peak hold for the test trace. Once the trace is stable there should be no perceptible change to the displayed noise floor. See Figure 10 and Figure 11 as examples.

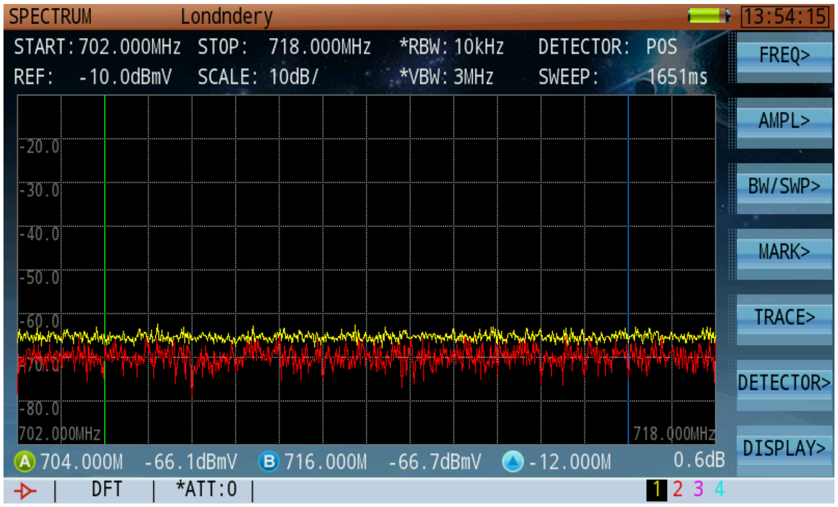


TRILITHIC 06-19-2015 13:43:20 PEAK FREE MARK: 737.20 MHz
Ref: 8.8 dBmV LOG 10.0 dB/ -72.18 dBmV

Mark:
737.20 MHz

START: 730.00 MHz STOP: 740.00 MHz
*RBW: 1 kHz *VBW: 1 MHz SWEEP: 33.00 sec *ATT: 0 dB

**Figure 10 - Evaluating test equipment and coax jumper for evidence of ingress and direct pickup interference, example #1**



SPECTRUM Londndery 13:54:15
START: 702.000MHz STOP: 718.000MHz *RBW: 10kHz DETECTOR: POS
REF: -10.0dBmV SCALE: 10dB/ *VBW: 3MHz SWEEP: 1651ms

A 704.000M -66.1dBmV B 716.000M -66.7dBmV Δ -12.000M 0.6dB
DFT | *ATT:0 |

**Figure 11 - Evaluating test equipment and coax jumper for evidence of ingress and direct pickup interference, example #2**

Once the test equipment setup is known to be free from ingress or direct pickup testing the cable system can be started.

As stated earlier in this document, there are two methods that can be used to locate where ingress is entering the network. The divide-and-conquer method involves the technician going to the half-way point between the location with a problem – say, the subscriber premises – and a location that is problem-free, such as the node. The technician checks at the first half-way point, and if interference is not present there, moves to a location that is half-way between the first half-way point and the location where the problem is known to exist (e.g., subscriber premises). The plant is further subdivided into smaller and smaller half-way test points until the source of the problem is located. A second method is comparative testing. Tune to a QAM channel that is not in the same frequency space as over-the-air signals, and compare its MER/BER to the channel where ingress is thought to be interfering. The comparative method can be combined with the divide-and-conquer method for troubleshooting ingress in a local area.

Care needs to be taken when accessing the plant during troubleshooting. Opening node or amplifier housing lids or removing passive faceplates when in close proximity to broadcast transmitters or cellular base stations could allow over-the-air signals to significantly impair downstream cable channels where the frequencies overlap. In addition, LTE phones can impact services when carried by technicians working on the system, at all access points: homes, outside plant, and headends.

As mentioned earlier, UHF signal leakage detection equipment can be used to identify locations where UHF leakage is occurring. Those same locations might also be points where UHF ingress is entering the plant.

Some cable operators are using integrated spectrum analyzer-like functionality supported by the latest Broadcom and MaxLinear CPE silicon for identifying downstream ingress in the VHF and UHF bands. Broadcom calls this feature full-band capture (FBC), and MaxLinear calls it full-spectrum capture (FSC). Technicians can look at a captured display (see Figure 12) for indications of the presence of downstream ingress. The spectrum data can be accessed remotely using simple network management protocol (SNMP) or similar, allowing a cable operator to see where ingress might be problematic. This can reduce unnecessary truck rolls.

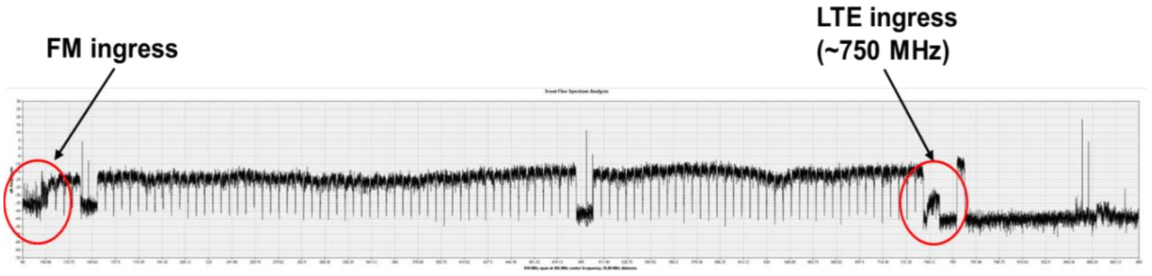


**Figure 12 - CPE downstream spectrum capture with FM ingress visible on far left edge of the display and LTE ingress visible at about 750 MHz, from a Broadcom FBC silicon-equipped cable modem**

### *2.5.2. Troubleshooting direct pickup*

Direct pickup interference to CPE is often caused by high-level signals from nearby devices such as LTE UE and cell phones. As discussed earlier, an LTE UE transmitting at its maximum output power of +23 dBm can create a field strength in the 2 to 3 V/m (2 million to 3 million µV/m) range just a meter from the UE, and even higher at closer distances. First check to see if a cell phone, LTE UE, or similar suspect device is located near the affected CPE. If a suspect device is present, temporarily turn it off. If the interference stops, there is a high probability that the suspect device was the source of the interfering signal. However, what remains uncertain at this point is whether the interference mechanism is ingress, direct pickup, or a combination of the two.

Ingress interference enters the subscriber drop via loose, improperly installed, or damaged connectors, poorly-shielded retail-grade cables and/or components, damaged or older poorly shielded drop cable (e.g., old copper braid drop, non-bonded foil drop cable, etc.), and poorly shielded drop passives or actives. Direct pickup interference enters an affected CPE directly, even when there are no external cables connected to the device. In some cases, CPE with poor common mode rejection may experience direct pickup interference when the interfering signal(s) enters the device as a common mode current traveling on the outer surface of one or more conductors connected to the CPE.

Some set-top manufacturers allow access to an internal diagnostic page that provides useful RF metrics on the channel or video stream to which the CPE is tuned. The presence of correctable or uncorrectable errors, errored or severely errored seconds, and/or degraded SNR (MER) could be caused by direct pickup. To confirm, the technician will need a known good working meter or other instrument tested for interference susceptibility as described earlier in this document. By using a two-way splitter and monitoring the channel being tested on the technician’s meter and the set-top’s diagnostic page simultaneously, the technician can confirm if the interference is entering the cable system as ingress or the set-top box as direct pickup. If the interference is present only on the set-top, it is likely direct pickup; if the interference appears on the set-top and test equipment, it is likely ingress.

Troubleshooting direct pickup on a cable modem can be more difficult depending on the type of traffic flowing to the modem, and the type of data packets (UDP vs. TCP). A comparative type of testing similar to the set-top box may be employed by the technician. Many modems in RF meters will display pre- and post-FEC bit errors and MER for downstream channels used by the modem. Operators may have internal tools that allow a specific modem’s performance to be simultaneously monitored on all downstream channels. Like the set-top testing method, a known good meter as well as a known good two-way splitter can be used to provide a comparative analysis of channels as data traffic flows to the modem. Modems that display errors and/or degraded MER while the meter’s modem does not register errors or degraded MER on the same channel(s) indicate direct pickup interference.

### 2.5.3. Educating the workforce on causes of leakage and the general lack of correlation between VHF and UHF leakage field strength levels

At the time of this writing, many papers, presentations, and articles on the impact of UHF (LTE) ingress and direct pickup on cable networks, devices, and services have been published. The bibliography in this document gives just a few of these.

However, it is still possible that the current workforce does not yet fully appreciate the fact that UHF and in particular LTE interference is pervasive and growing as a challenge for keeping plants tight, hence there is a need for a systematic education of the workforce, at levels appropriate to the technician level.

The following are general recommendations for keeping the workforce up to date on the importance of minimizing UHF/LTE ingress- and direct pickup-based interference on cable networks, devices, and services:

- Deploy PNM technology and software (if not already deployed) and use captures from actual equipment in the network to show the workforce how ingress and direct pickup are happening in their own network, as well as how to recognize it and common solutions for troubleshooting and mitigating the interference

- Assemble a library of articles of published case studies for LTE ingress and direct pickup interference in cable networks, including the UHF technical report, this document, and related SCTE journal articles, and any other industry publications on the subject, and make that library readily available to the workforce
- Ensure that the workforce has access to SCTE resources on the subject, including
  - SCTE's LiveLearning™ archives
  - SCTE Cable-Tec Expo papers and presentations
  - The collected *Communications Technology* articles of Ron Hranac, now archived by the SCTE
  - SCTE chapter presentations, and so on
- Create internal webinars, presentations, and videos that highlight specific company examples/case studies of UHF/LTE ingress and direct pickup issues. Have the company's subject matter experts involved in these case studies speak to the workforce on the importance of finding and fixing the sources of UHF/LTE ingress and direct pickup
- Develop detailed company-specific operational practices, which can be based on the present document, that provide detailed, specific instructions to employees involved in ingress and direct pickup monitoring, detection and mitigation.
- Develop company specific key performance indicators related to UHF/LTE ingress and direct pickup interference that can be used to ensure the workforce is accountable and measured based on minimization of signal leakage in the UHF spectrum (in addition to the rest of the spectrum of the cable plant).

#### *2.5.4. Maintenance, and the importance of high quality craftmanship standards and the prevention of ingress in the first place*

The same recommendations given in the document "SCTE operational practices for minimizing signal leakage in the UHF spectrum" apply equally well to UHF/LTE ingress prevention.

### 2.6. Recording of Results

When troubleshooting ingress and direct pickup interference, be sure to document the process. Documentation should include a relatively detailed description of the interference, dates and times of the interference (useful for intermittent problems), channels and/or services affected, subscriber contact information (if applicable), steps taken to correct the problem, and before and after signal levels and other operating metrics (MER, BER, etc.). Recording this information will be helpful for troubleshooting similar problems in the future, and can be incorporated in training programs.

## 3. Conclusions and Recommendations

The cable industry has done a commendable job managing ingress for many years, and its ability to address these issues is constantly improving through new processes, technology, equipment, and education. Many new approaches for ingress monitoring such as centralized upstream monitoring systems, modern handheld digital signal analyzers, and PNM technology found in modern CMTS, CCAP, CM, eMTA, and STB equipment have significantly enhanced the ability to quickly identify, locate, and mitigate both ingress and direct pickup interference. But the number of LTE devices in homes, businesses, and in the field is growing exponentiallly, with an attendant growth in the number of base stations as well as smaller, even more numerous femtocells and in-building systems.  Therefore, the cable engineer and technician must be constantly vigilant to the presence of UHF/LTE ingress and/or direct pickup interference occuring in the cable network, and take steps as soon as possible to mitigate the problem and maintain customer satisfaction, especially this era of competitive broadband service delivery.

# 4. Abbreviations and Definitions

## 4.1. Abbreviations

| | |
|---|---|
| 3G | 3rd generation cellular data transmission |
| 4G | 4th generation cellular data transmission |
| BER | bit error ratio |
| CB | Citizens Band |
| CCAP | converged cable access platform |
| CEA | Consumer Electronics Association |
| CM | cable modem |
| CMTS | cable modem termination system |
| CNR | carrier-to-noise ratio |
| CPE | customer premises equipment |
| dBm | decibel milliwatt |
| DOCSIS | Data-Over-Cable Service Interface Specifications |
| DL | downlink |
| DTA | digital transport adapter |
| e.g. | for example (*exempli gratia*) |
| EMI | electromagnetic interference |
| eMTA | embedded multimedia terminal adapter |
| ES | errored seconds |
| SES | severely errored seconds |
| FBC | [Broadcom] full band capture |
| FCC | Federal Communications Commission |
| FEC | forward error correction |
| FM | frequency modulation |
| FSC | [Maxlinear] full spectrum capture |
| GIS | graphical information system |
| HF | high frequency |
| HFC | hybrid fiber coax |
| IP | Internet protocol |
| KPI | key performance indicator |
| LTE | long term evolution |
| MDU | multiple dwelling unit |
| MER | modulation error ratio |
| MHz | megahertz |
| MTR | main tap ratio |
| MTTR | mean time to repair |
| NOS | [SCTE] Network Operations Subcommittee |
| OTT | over-the-top |
| PNM | proactive network maintenance |

| | |
|---|---|
| QAM | quadrature amplitude modulation |
| RF | radio frequency |
| SA | spectrum analyzer |
| SCTE | Society of Cable Telecommunications Engineers |
| SIR | signal-to-interference ratio |
| SNR | signal-to-noise ratio |
| STB | set top box |
| TCP | transmission control protocol |
| TV | television |
| UDP | user datagram protocol |
| UE | user equipment |
| UHF | ultra high frequency |
| UL | uplink |
| VHF | very high frequency |
| V/m | volt per meter |
| µV/m | microvolt per meter |

### 4.2. Definitions

**common mode** – A mode of conduction in which current in multiple conductors is in-phase, with earth ground as the typical return conductor. In the case of coaxial cable networks, the desired RF signals inside of the coax are differential mode, which means the desired signals propagate on a pair of conductors – on the outer surface of coaxial cable's center conductor and inner surface of its shield – with a 180 degrees phase difference between the conductors. Common mode currents propagating on the outer surface of the shield can enter the coax via a shielding defect, and become interfering differential mode signal(s).

**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 $dB = 10\log(P_1/P_2)$.[4]

**digital sampling oscilloscope (DSO)** – The modern version of an oscilloscope that samples the waveform and can store and perform analysis on it, in addition to displaying the triggered voltage vs. time of a typical oscilloscope trace.

**direct pickup** – Unwanted entry of over-the-air signals and/or noise directly into a device (with or without cables or wires connected to that device) via case seams, holes, ventilation slots, or poorly

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[4] The decibel, while technically a ratio of two power levels, also can be used to represent the ratio of two voltage levels, 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 $dB = 10\log(P_1/P_2)$, the equation becomes $dB = 10\log[(E^2/R)/(E^2/R)]$ which is the same as $dB = 10\log[(E_1^2)/R_1)/(E_2^2/R_2)]$. In this example, R represents the 75 ohm impedance of a cable network. Since $R_1$ and $R_2$ are both equal to 75 ohms, those equation terms cancel, leaving the equation $dB = 10\log(E_1^2/E_2^2)$. This can be simplified somewhat and written as $dB = 10\log(E_1/E_2)^2$ which is the same as $dB = 2 * 10\log(E_1/E_2)$ or $dB = 20\log(E_1/E_2)$.

shielded cases or covers. Similar to ingress, except that direct pickup most commonly directly affects some devices such as customer premises equipment, test equipment, and headend equipment..

**fast Fourier transform (FFT)** – A computationally efficient way to convert time domain samples into a frequency spectrum, and a function that is typically built into modern sampling oscilloscopes. See also *FFT analyzer*.

**FFT analyzer** – An advanced version of a digital sampling oscilloscope. Unlike a conventional spectrum analyzer, which scans across a frequency range and can miss portions of a signal, an FFT analyzer captures and digitizes the signal in the time domain so that the resulting spectrum displayed via the FFT is the instantaneous spectral representation across the entire frequency range. Thus the entire spectral character of a transient signal can be displayed, not just the portion that was in-band when a spectrum analyzer scanned the entire frequency range.

**field strength** – An RF signal’s power density within an imaginary 1 meter 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.

**ingress** – Unwanted entry of over-the-air signals and/or noise into a cable network via insufficient, degraded, or damaged shielding in coaxial cable, connectors, and other cable network components, or via poorly shielded subscriber terminal equipment connected to the cable network. The opposite of signal leakage.

**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.

**milliwatt** – One-one thousandth ($10^{-3}$) of a watt.

**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 antenna elements vary significantly with distance from the antenna.

**proactive network maintenance (PNM)** – A process that uses DOCSIS cable modems and set-tops as continuous “probes” throughout the network to identify and locate plant and subscriber drop problems. From a high-level perspective, in-channel upstream complex frequency response signatures are derived from pre-equalization coefficients. Responses indicative of the presence of linear distortions are identified, and locations of modems whose upstream channel responses are impaired are overlaid on a system topology display of some sort—for instance, digitized outside plant maps. Later implementations include spectrum capture functionality that is supported in the latest CPE silicon, allowing spectrum analyzer-like functionality.

**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.

**ultra high frequency (UHF)** – That portion of the electromagnetic spectrum from 300 MHz to 3000 MHz.

**vector signal analyzer (VSA)** – An even more advanced version of a digital sampling oscilloscope or FFT analyzer where a highly stable local oscillator reference is used to sample the captured signal in both magnitude and phase and thereby facilitate complete demodulation and detailed QAM analysis of the captured signal.  The most modern versions include software that can configure the equipment as a fully-functional, software-based receiver, including decoding the forward error correction and so on.

# 5. Bibliography & References

## 5.1. References

[1] L. Watson, Rogers Communications, “Cable Telecommunications & Wireless Spectrum: A Two Way Street,” SCTE Canadian Summit 2012 Wireless Symposium.

[2] “Analysis report on the influence on cable networks of the deployment of electronic communications service in the 790-862 MHz band,” Excentis, v 1.1 Aug 24, 2010.

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Kraus, J. (1988). *Antennas, Second Edition*. New York: McGraw-Hill

Title 47, Code of Federal Regulations, Part 76

ANSI C63.5-2006: *American National Standard Electromagnetic Compatibility–Radiated Emission Measurements in Electromagnetic Interference (EMI) Control–Calibration of Antennas (9 kHz to 40 GHz)*; Institute of Electrical and Electronics Engineers

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JOURNAL OF
NETWORK OPERATIONS

# Operational Practice for Building and Using Calibrated Leaks

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
By

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# 1. Introduction

## 1.1. Executive Summary for Building and Using Calibrated Leaks

***Target Audience:*** Cable system-level technical personnel who are involved with the use of signal leakage detection equipment, their supervisors, and training content developers.

***What is it?*** This operational practice describes two methods to verify the calibration of signal leakage detection equipment: direct voltage source and calibrated field strength (also known as a calibrated leak).

***What is the function of it?*** This operational practice is to help cable operators ensure that compliance with Part 76 of the Federal Communications Commission's (FCC) leakage rules of Part 76 is maintained accurately.

***What are the immediate and long-term benefits of adopting it?***

- 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 comply with relevant FCC Rules

***How does this operational practice impact the industry and fit into the SCTE Engineering Committee's roadmap?*** It will allow the cable industry to keep up with exponential growth of long term evolution (LTE) services and devices and their impact on cable networks, as well as ensuring reliable network operation and subscriber satisfaction.

***What are some of the key points of this operational practice?***

- Detailed procedure for using a direct voltage source to calibrate leakage detection equipment
- Recommendations on optimal equipment types and configurations, and also low cost options
- 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

***What can you do to achieve maximum benefit from implementing this operational practice?*** Customize it for your workforce/cable network specifics. Implement the practices, keeping track of key performance ndicators (KPIs) both before and after the implementation to insure it is meeting the business goals of the cable operator.

***How can you learn more about this operational practice***? Join the Network Operations Subcommittee (NOS) working group and assist in revisions and updates to this document. Visit http://www.scte.org/standards, or email: standards@scte.org for more information.

### 1.2. Scope

Calibration of signal leakage detection equipment on a regular basis is mandatory to ensure measurement accuracy. This document covers the two general types of calibration that are recommended: direct voltage-source and calibrated field-strength. 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 known signal leakage field strength in the outdoor environment.

### 1.3. 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.

## 2. Operational Practices

### 2.1. 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). For a detailed explanation of these concepts and conversions between them, refer to SCTE document “Operational Practices for Calculating Field Strength,” available from www.scte.org and for which there is a companion paper in this journal.

### 2.2. 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 receiver
- High quality radio frequency (RF) signal generator or frequency-agile headend modulator as a calibration signal source
- 50 to 75 ohm impedance matching adapter if required
- Video signal source that can provide 1 volt peak-to-peak baseband signal as input to the modulator
- Spectrum analyzer (SA) or quadrature amplitude modulation (QAM)-based SA or power meter
- Two resonant half-wave dipole antennas tuned to the calibration frequency

## 2.3. 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) Direct voltage source, which involves plugging a coaxial cable directly in to the typical BNC (or other) connection on the leakage detector, which validates the general measurement accuracy of the equipment (this method will not utilize the device's antenna), and

2) Calibrated field strength, which leverages both a transmit antenna (leak source) and the device's antenna(s) to gauges its 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.

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 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 direct voltage 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 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 1. 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.

The use of an A/B switch is a popular choice to route the signal source feed to the antenna or the direct voltage 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 direct voltage source 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.

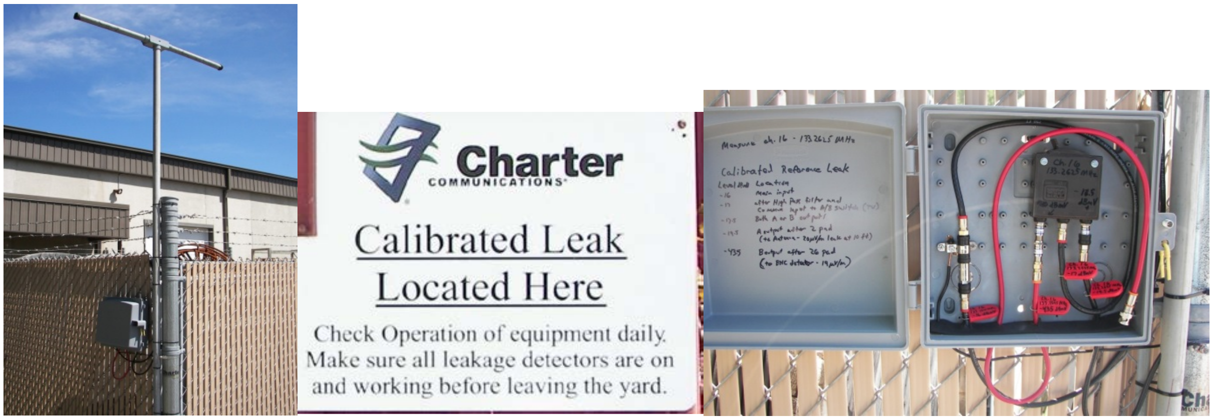

**Figure 1 - Suggested signage to post near the calibrated leak (images courtesy of Charter)**

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. Production signal feeds are a requirement when dedicated, or tagged signals, are necessary for operation of the leakage detectors. The frequency 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.

### 2.3.1. Direct voltage source

This method requires that a calibrated RF signal generator be connected directly to the leakage measurement equipment. 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[1] 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. Most are 50 ohm laboratory-grade instruments that will require an external 50 to 75 ohm 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 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 or 25 kHz to simulate actual aeronautical carrier frequencies on the system. In addition, a frequency-agile modulator can double as the signal source for establishing a calibrated leak.

Assume the leakage detection equipment is being checked for its ability to accurately measure 20 µV/m on Ch. 16. 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) 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 a 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 leakage detection equipment does not use a peak detector. Confirm with the leakage detector manufacturer whether the instrument was factory-calibrated with a CW carrier or a modulated 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.

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[1] 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 to 1 dB of insertion loss. Consult the device manufacturer's specifications.

### 2.3.2. 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 rubber duck antenna. For the latter, make sure the vehicle is well away from the calibration test area to minimize unwanted reflections that could affect the accuracy 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 direct voltage-source methods. 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 measurement accuracy.

#### 2.3.2.1. Steps to create a calibrated leak

The following steps can be used to create 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 technicians must drive their vehicles past it regularly so they can confirm that their detector is operational and that the leak measures roughly the same each time they drive by.
- Orient the polarity of the dipole antenna to match that of the leakage detecting equipment being checked.
- Connect a signal source to the antenna after ensuring that the source's frequency matches the leakage detection equipment frequency. If the signal source is the cable network, use a single-channel bandpass filter at the input of the antenna to prevent leakage on other frequencies.
- Find a calibration location that is out of the first dipole's near field (see Figure 2) and set up a second resonant half wave dipole and calibrated measurement instrument (spectrum analyzer, signal level meter, etc.). Orient the second dipole's polarity to match the first antenna's.

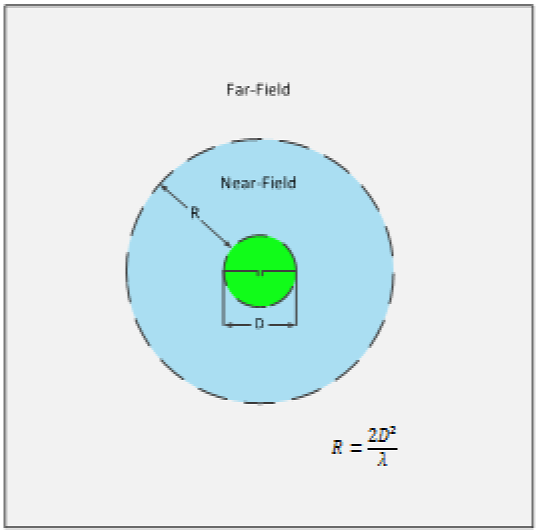

**Figure 2 – Approximate distance from dipole to near-field/far-field boundary**

- With the calibration signal source feeding RF into the first 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 channels in or near the 108 MHz to 137 MHz aeronautical band with standard +12.5 or +25 kHz offsets.

**Table 1 – Microvolts per meter to dBmV conversion**

| Channel | 20 µV/m | 50 µV/m |
|---|---|---|
| 98 | - 41.19 dBmV | - 33.24 dBmV |
| 99 | - 41.66 dBmV | - 33.70 dBmV |
| 14 | - 42.10 dBmV | - 34.14 dBmV |
| 15 | - 42.52 dBmV | - 34.56 dBmV |
| 16 | - 42.92 dBmV | - 34.96 dBmV |
| 17 | - 43.30 dBmV | - 35.34 dBmV |

- Record the necessary RF input to the first dipole that produces the desired field strength at the second dipole. While one can calculate the theoretical level (see section 2.3.3), the actual signal level at the input to the first antenna required to produce the desired field strength at the second 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[2]. *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.*

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[2] 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.

### 2.3.3. 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. In these examples the signal source and receiver are assumed to be connected directly to their respective antennas, eliminating transmission line 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):

$$G_{dBi} = 10\log(1.64)$$
$$G_{dBi} = 2.15 \text{ dBi}$$

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

$$Loss_{dB} = 20\log(f_{MHz}) + 20\log(d_{km}) + 32.45$$

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:

$$A_{dB} = 20\log(133.2625 \text{ MHz}) + 201og(0.015 \text{ km}) + 32.45$$
$$A_{dB} = 38.47 \text{ dB}$$

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

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

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
$\lambda$ = wavelength of transmitted signal (meters)
R = distance between antennas (meters)

The transmitted power is -8.75 dBmV, or 1.78 x $10^{-9}$ 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:

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

**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.

## 2.4. 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 direct voltage 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 antenna, coax feedline, and connectors and other components. When the calibrated leak was first created, system personnel should have measured 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.

## 2.5. 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 direct voltage 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.

# 3. Conclusions and Recommendations

## 3.1. Conclusions

It is not difficult to perform the calibration procedures described in this document. 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.

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

Topics to consider for future versions include creating a calibrated leak for leakage detector-equipped aircraft used for flyover measurements, and possibly also for third party vehicles such as garbage trucks that might be equipped with leakage detection equipment.

# 4. Abbreviations and Definitions

## 4.1. Abbreviations

| | |
|---|---|
| BNC | bayonet Neill Concelman [connector] |
| CW | continuous wave |
| dB | decibel |
| dBi | decibel isotropic |
| dBmV | decibel millivolt |
| $d_{km}$ | distance in kilometers |
| $E_{\mu V/m}$ | field strength in microvolts per meter |
| f | frequency |
| FCC | Federal Communications Commission |
| $f_{MHz}$ | frequency in megahertz |
| $G_{dBi}$ | gain, decibel isotropic |
| $G_r$ | numerical gain of receive antenna |
| $G_t$ | numerical gain of transmit antenna |
| log | logarithm |
| kHz | kilohertz |
| km | kilometer |
| KPI | key performance indicator |
| LTE | long term evolution |
| MHz | megahertz |
| NOS | [SCTE] Network Operations Subcommittee |
| $P_r$ | received power |
| $P_t$ | transmitted power |

| | |
|---|---|
| QAM | quadrature amplitude modulation |
| R | distance |
| RF | radio frequency |
| SCTE | Society of Cable Telecommunications Engineers |
| UHF | ultra high frequency |
| VHF | very high frequency |
| λ | wavelength |
| µV/m | microvolt per meter |

## 4.2. Definitions

**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 $dB = 10\log(P_1/P_2)$.[3]

**decibel millivolt (dBmV)** – Unit of RF power expressed in terms of voltage, defined as decibels relative to 1 millivolt, where 1 millivolt equals 13.33 nanowatts in a 75 ohm impedance. Mathematically, dBmV = 20log(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 1 meter 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.

---

[3] The decibel, while technically a ratio of two power levels, also can be used to represent the ratio of two voltage levels, 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 $dB = 10\log(P_1/P_2)$, the equation becomes $dB = 10\log[(E^2/R)/(E^2/R)]$ which is the same as $dB = 10\log[(E_1^2)/R_1)/(E_2^2/R_2)]$. In this example, R represents the 75 ohm impedance of a cable network. Since $R_1$ and $R_2$ are both equal to 75 ohms, those equation terms cancel, leaving the equation $dB = 10\log(E_1^2/E_2^2)$. This can be simplified somewhat and written as $dB = 10\log(E_1/E_2)^2$ which is the same as $dB = 2 * 10\log(E_1/E_2)$ or $dB = 20\log(E_1/E_2)$.

**gain** – An increase in the power of a signal or signals, usually measured in decibels. Expressed mathematically, $G_{dB} = 10\log(P_{out}/P_{in})$, 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, $L_{dB} = 10\log(P_{in}/P_{out})$, 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 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.

## 5. Bibliography & References

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JOURNAL OF
NETWORK OPERATIONS

# Operational Practice for Calculating Field Strength

## Definition of Field Strength as Used in Cable Networks, and Calculation of LTE User Equipment Field Strength

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
By

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# 1. Introduction

## 1.1. Executive Summary

***Target Audience:*** Outside plant technicians, field and installation technicians, training content developers, and others with an interest in the fundamentals of signal leakage and field strength.

***What is it?*** This operational practice provides a tutorial on radio frequency (RF) signal field strength, its measurement and calculation, and a method for calculating field strength emanating from long term evolution (LTE) user equipment (UE). The aforementioned method can be adapted for calculating field strength from signal sources in other frequency ranges.

***What is the function of it?*** This operational practice is to help the cable workforce properly measure and calculate field strength in frequency ranges used by the cable industry, and facilite compliance with Federal Communications Commission (FCC) leakage requirements. This operational practice also provides an understanding of how devices such as LTE UE can produce a field strength that has the potential to cause ingress and/or direct pickup interference.

***What are the immediate and long-term benefits of adopting it?***

- Ensuring compliance with FCC Part 76 regulations
- Tightening the plant for reduced leakage and also reduced ingress from over-the-air signals
- Improved plant monitoring and maintenance, and thereby customer satisfaction

***How does this operational practice impact the industry and fit into the SCTE Engineering Committee's roadmap?*** It allows the cable industry to keep up with exponential growth of LTE and other over-the-air services and devices and their impact on cable networks.

***What are some of the key points of this operational practice?***

- Theoretical development of field strength as a physical concept
- Specific application of field strength to cable network operations, and common assumptions
- Frequency dependence and implications for measuring field strength in the ultra high frequency (UHF) band vs. only the very high frequency (VHF) band
- Application of the field strength measurement and calculation to LTE user equipment, which can interfere with cable signals and vice versa via leakage, ingress, and direct pickup
- Suggestions for educating the workforce further on field strength concepts

***What can you do to achieve maximum benefit from implementing this operational practice?*** Customize it for your workforce/cable network measurement frequency and equipment specifics. Implement the practices, keeping track of key performance indicators (KPIs) both before and after the implementation to insure it is meeting the business goals of the cable operator.

***How can you learn more about this operational practice***? Join the Network Operations Subcommittee (NOS) working group and assist in revisions and updates to this document. Visit http://www.scte.org/standards, or email: standards@scte.org for more information.

### 1.2. Scope

In late 2010, a new wireless technology called LTE was introduced in the United States. LTE service operates in several frequency bands, including the 698 MHz to 806 MHz band, which overlaps the frequency spectrum used by many cable operators to deliver services to their customers. As LTE service providers continue to deploy LTE service, the RF signal emanating from LTE UE represents another source of potential interference to services carried on cable systems.

This operational practice provides a tutorial on RF signal field strength and a method for calculating field strength emanating from LTE UE.

## 2. Operational Practices

### 2.1. What is Field Strength?

Fundamentally, the field strength of an electric field is the force exerted on a charge, divided by the amount of that charge, at a particular point in space from an electric field that exists at that point in space. The closer the charge is to the source of the electric field, the stronger the field strength generally is. The electric field strength is thus fundamentally measured as a force per charge. Through a manipulation of units, this can be converted into volts per meter, V/m, or given typical values found in cable field strength measurements, in microvolts per meter (µV/m). Another term for electric field strength is electric field intensity.

Since the electric field is a vector quantity, that is, having both a magnitude and a direction, the electric field strength is also a vector quantity. The direction is the direction a charge would move if placed in the electric field. Practically speaking, this is important because the way field strength is measured in network operations is using an antenna, and the vector nature of the field means the measured magnitude will change as the orientation of the antenna is changed, just as the received signal strength indicator (RSSI) on a cell phone can change as the orientation of the phone changes. However, in cable network operations, the value measured and reported is generally only the magnitude of the field strength; ideally, this is the maximum value measured after moving the antenna a bit to get the maximum reading. The magnitude of the field strength is what is discussed in the rest of this document, but it is important to keep in mind the directional nature of the electric field that is actually being measured, and this is the reason for orienting the antenna to get a maximum reading.

The measurement of signal leakage *field strength* – a term used extensively in this document – often is taken for granted. The procedure is fairly straightforward: Using a dedicated leakage detector with a resonant half-wave dipole antenna (or equivalent), which is typically used as a reference since its electrical characteristics are well known and is specified in §76.609 of the FCC Rules, orient the antenna to get a maximum reading and see what value the leakage detector reports. The measured field strength is stated in µV/m,[1] and hopefully is below the maximum limit defined by the FCC.

The field strength in µV/m can be converted to a power measurement in decibel millivolt (dBmV) at the dipole antenna's terminals using the formula

---

[1] Outside of the North American cable industry, field strength measurements are more commonly stated in decibel microvolt per meter, or dBµV/m.

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

where $E_{\mu V/m}$ is the field strength in microvolts per meter, and $f$ is frequency in MHz.

The frequency dependence in the previous equation comes from the fact that the power captured is dependent on the power gain of the antenna, and the relationship between the antenna's effective area or aperture and, as will be shown later, the gain of the antenna is strictly dependent on the wavelength of the radiated electric field that is being measured. Thus there is a variation when measuring signal leakage at more than one frequency. Assuming the same field strength – say, 20 µV/m – at two frequencies and the use of separate resonant half-wave dipoles for the measurements, the dBmV values at the two dipoles' terminals will be different. For example, a field strength of 20 µV/m at 121.2625 MHz will produce -42.1 dBmV at the terminals of a resonant half-wave dipole for that frequency. A field strength of 20 µV/m at 782 MHz will produce -58.29 dBmV at the terminals of a resonant half-wave dipole for that frequency.

To understand how these two different power values at different frequencies come about for the same field strength, consider the following example, based upon the assumptions in Table 1.

**Table 1 - Example Assumptions for Cable Networks**

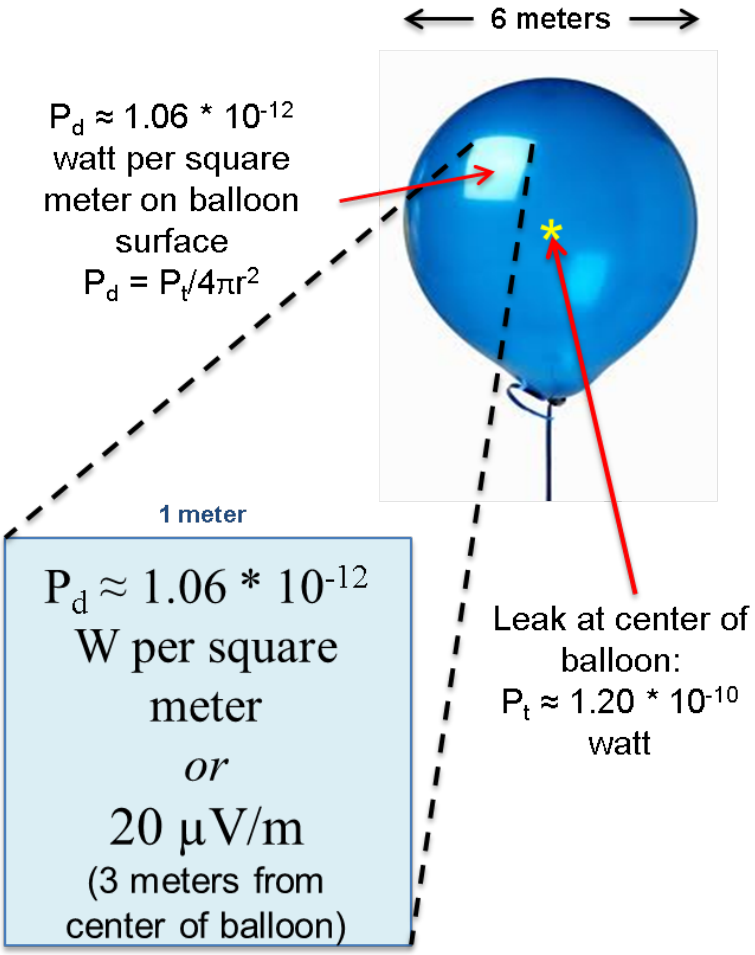
| |
|---|
| • Measurement frequencies are 121.2625 MHz and 782 MHz |
| • Antennas for the two frequencies are lossless resonant half-wave dipoles |
| • Field strength at the point of measurement is 20 µV/m for both frequencies |
| • Measurement distance from the leak is 3 meters, which is in the far-field for this exercise |
| • Each antenna is terminated by a load equal to its radiation resistance (approximately 73 ohms for a half-wave dipole) |
| • Each dipole is oriented for maximum received signal level |
| • Each antenna does not re-radiate any of the intercepted signal |
| • The polarization of the RF signal coming from the leak is linear and is the same as the orientation of the dipoles when the field strength measurements are made |

Visualize a loose connector radiating RF into the space around it. Now imagine a 6-meter diameter balloon surrounding the loose connector, with the connector at the center of the balloon (see Figure 1). Assume the RF leaking from the loose connector is uniformly "illuminating" the entire surface of the balloon from the inside. Next, imagine a 1 meter x 1 meter square drawn somewhere on the surface of the balloon. The task at hand is to measure the RF power density within the 1 meter x 1 meter square. The power density in that square also can be expressed as a voltage, which is how field strength is expressed: volts per meter. In other words, field strength is the RF power density in a 1 meter x 1 meter square (in free space, in the air, or, as in this example, on the surface of an imaginary 6-meter diameter balloon), expressed as a voltage – hence, the "volts per meter" or "microvolts per meter" designation. See Figure 1.

The RF power transmitted by the loose connector in the center of the balloon is designated $P_t$, and is called the source power. In order to produce a field strength of 20 µV/m 3 meters away, $P_t$ must equal 0.00000000012 watt or $1.2 * 10^{-10}$ watt. Because the RF source power $P_t$ is uniformly illuminating the entire balloon (an analogy is a light bulb at the center of the balloon), the power density $P_d$ on the surface of the balloon in watts per square meter is simply the source power $P_t$ divided by the surface area of the balloon, or

$$P_t/4\pi r^2$$

where $r$ is the radius of the balloon. Since the balloon's diameter is 6 meters, $r$ = 3 meters.



$$E_{\mu V/m} = \sqrt{([1.06103295 * 10^{-12}\ watt] * 120\pi)}$$

**Figure 1 - Field strength example illustrating power density in a 1 meter x 1 meter square on the surface of an imaginary balloon**

Plugging the just-discussed values for $P_t$ and $r$ into the previous formula, the calculated power density on the surface of the balloon is equal to about 1.06 * $10^{-12}$ watt per square meter (the actual value is 0.00000000000106103295 watt per square meter).

The impedance $Z$ of free space is 120π, or about 377 ohms. Using the formula

$$E = \sqrt{PZ}$$

the voltage $E$ on the surface of the balloon in volts per meter is

$$E = \sqrt{([1.06103295 * 10^{-12}\ watt] * 120\pi)}$$

= 0.000020 volt per meter, or 20 µV/m.

So far, so good. A source power $P_t$ of 1.20 * $10^{-10}$ watt "transmitted" by the loose connector illuminates the surface of the balloon 3 meters away to produce a power density $P_d$ of about 1.06 * $10^{-12}$ watt per square meter, which is equal to a field strength of 20 µV/m. This relationship is true for both frequencies.

Next, the resonant half-wave dipoles are placed one at a time in the square on the balloon, and the field strength within that square measured. The question is how much of the power in the square will be intercepted by each dipole and delivered to the load connected to each antenna's terminals? All of it? Only an amount occupying an area equal to the physical dimensions of each antenna? Or some other amount?

Visualize what happens when a dipole is placed at the surface of the balloon, where RF from the loose connector 3 meters away is passing by at the speed of light. The RF field induces a voltage $V$ in the dipole, resulting in a current $I$ through the ~73 ohms impedance at the antenna terminals. What's of interest is the power $P$ delivered by the antenna to that impedance, where $P = I^2R_T$. Here $R_T$ is the sum of the antenna's radiation resistance (~73 ohms) and loss resistance, the latter assumed to be zero for this example.

Kraus [1] illustrates a scenario using a horn antenna:

> Let the…power density of the plane wave be $S$ watts per square meter and the area of the mouth of the horn be $A$ square meters. If the horn extracts all the power from the wave over its entire area $A$, then the total power $P$ absorbed from the wave is $P = SA$ (W). Thus, the electromagnetic horn may be regarded as an aperture…

The same is true of a dipole antenna – that is, it can be regarded as an aperture with a specific area that extracts power from a passing wave and delivers it to the load connected to the antenna terminals. Defining aperture isn't quite as simple as one might assume, though. According to Kraus, three types of aperture describe "…ways in which power collected by the antenna may be divided: into power in the terminal resistance (effective aperture); into heat in the antenna (loss aperture); or into reradiated power (scattering aperture)."

A fourth aperture, called collecting aperture, is the sum of the three previous apertures. Finally, physical aperture is basically "a measure of the physical size of the antenna," but surprisingly doesn't have all that much to do with how much power is intercepted by an antenna.

Since the dipoles in this example are assumed to be lossless, effective aperture – more specifically, maximum effective aperture $A_{em}$ – is the criteria that will be used to describe how much of the RF power in the 1 meter x 1 meter square is intercepted and delivered to the load at the antenna terminals. Mathematically, this is

$$A_{em} = (\lambda^2/4\pi)G$$

where $\lambda$ is wavelength in meters ($299.792458/f_{MHz}$) and $G$ is the antenna's numerical gain (1.64 for a half-wave dipole). A linear half-wave dipole's maximum effective aperture is an elliptically shaped aperture with an area equal to $0.13\lambda^2$, as shown in Figure 2.

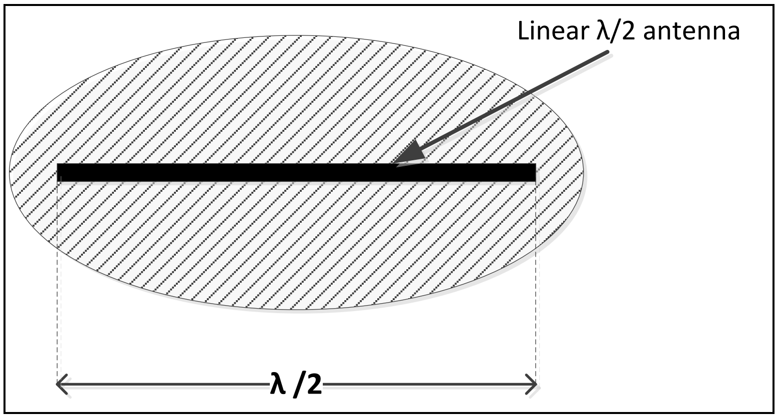


**Figure 2 - A linear half-wave dipole's maximum effective aperture $A_{em}$ is represented by an ellipse with an area of $0.13\lambda^2$. Adapted from J. Krauss [1]**

The free-space wavelength for 121.2625 MHz is approximately 2.47 meters (2.47226024534) and for 782 MHz is approximately 0.38 meter (0.383366314578). Plugging these numbers into the previous formula gives a maximum effective aperture of 0.797668339532 $m^2$ for the 121.2625 MHz dipole, and 0.0191805865422 $m^2$ for the 782 MHz dipole. The $A_{em}$ values denote what percentage of the power within the 1 meter x 1 meter square is intercepted by each dipole and delivered to the load at the antenna terminals. The difference between the two $A_{em}$ values in decibels is

$$10log\left({A_{em}}^{dipole\ 1}/{A_{em}}^{dipole\ 2}\right)$$

or 16.19 dB, which is equal to the antenna factor[2] difference between the two dipoles.

In other words, when measuring a 20 µV/m field strength at 121.2625 MHz and 782 MHz with resonant half-wave dipoles, the lower frequency antenna intercepts and delivers more power to its load (~8.46 * $10^{-13}$ watt) than the higher frequency antenna does (~2.04 * $10^{-14}$ watt). Here, too, the decibel difference is

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[2] The antenna factors for the VHF and UHF dipoles in this example are 8.12 dB/m and 24.31 dB/m respectively.

the same as the antenna factor difference. All of this jibes with the two different signal levels at the dipoles' terminals: -42.1 dBmV at 121.2625 MHz and -58.29 dBmV at 782 MHz, for identical 20 µV/m field strengths at the two frequencies.

## 2.2. How to Calculate Maximum Field Strength of LTE Equipment

The maximum LTE UE transmit power is +23 dBm (decibel milliwatt) or 200 mW, with a 2 dB tolerance, and the minimum is -40 dBm (0.0001 mW). That's a pretty significant power range that must be supported by LTE UE. Numbers for UE antenna gain ranging from -1 dBi (decibel isotropic) to -3.5 dBi, with -3 dBi being typical. With that information, the following example calculates the predicted field strength (far-field) that might occur 1 meter away from an LTE handset if that handset were transmitting at the maximum +23 dBm power output (the 2 dB tolerance could mean that some UEs transmit as high as +25 dBm at maximum output, but the +23 dBm value in being used in this example). The transmit frequency range for a Verizon LTE handset, for example, is 777-787 MHz, so the center of that range, 782 MHz, is used for the calculation.

Free space path loss is calculated with the formula

$$\text{Loss}_{\text{dB}} = 20\log(f_{\text{MHz}}) + 20\log(d_{\text{km}}) + 32.45$$

where

$f_{\text{MHz}}$ is the frequency in megahertz

$d_{\text{km}}$ is the path length in kilometers (1 meter = 0.001 km)

The free space path loss over a 1 meter distance at 782 MHz is

$$\text{Loss}_{\text{dB}} = 20\log(782\text{ MHz}) + 20\log(0.001\text{ km}) + 32.45$$

$$\text{Loss}_{\text{dB}} = [20 * \log(782\text{ MHz})] + [20 * \log(0.001\text{ km})] + 32.45$$

$$\text{Loss}_{\text{dB}} = [20 * 2.89] + [20 * -3.00] + 32.45$$

$$\text{Loss}_{\text{dB}} = [57.86] + [-60.00] + 32.45$$

$$\text{Loss}_{\text{dB}} = 30.31\text{ dB}$$

Assume a resonant half-wave dipole antenna located at the point where field strength 1 meter away the LTE UE is being measured. The received signal power at the receive dipole's terminals is:

Received power (dBm) = Transmit power (dBm) – transmit feedline loss (dB) + transmit antenna gain (dBi) – free space path loss (dB) + receive antenna gain (dBi)

For this exercise, assume a UE transmit antenna with -1 dBi gain, and the antenna is connected *directly* to the transmitter's power amplifier stage – no feedline loss, no filter insertion loss. Also assume that there is no additional attenuation to the LTE UE's transmitted signal caused by someone holding the device. Plugging in some numbers gives

$$23 \text{ dBm} - 0 \text{ dB} + (-1 \text{ dBi}) - 30.31 \text{ dB} + 2.15 \text{ dBi} = -6.16 \text{ dBm at the dipole's terminals.}$$

Converting the received power in dBm to dBmV is done by adding 48.75 to the dBm value, so -6.16 dBm + 48.75 = +42.59 dBmV. This conversion assumes the receive dipole's impedance is 75 ohms, which is close to a half-wave dipole's approximate free-space impedance value of 73.1 ohms. Next, convert dBmV to field strength in µV/m:

$$\mu\text{V/m} = 21 * (782 \text{ MHz}) * 10^{(42.59/20)} = 2{,}212{,}718\ \mu\text{V/m or} \sim 2.2 \text{ V/m}$$

From this, the calculated field strength 1 meter away that could be produced by an LTE handset operating at maximum transmit power is ~2.2 million microvolts per meter, or ~2.2 V/m. Doubling the distance to 2 meters will still result in a calculated field strength of around 1.1 V/m.

Practically speaking, the UE antenna gain is likely to be closer to -3 dBi, and some additional attenuation will occur as a result of the UE being handheld or sitting by itself on a table or other surface. For example, with 6 dB of total additional attenuation, the 1-meter field strength would be about 1.1 V/m and the 2-meter field strength would be about 0.55 V/m when the UE is transmitting at its maximum power of +23 dBm.

# 3. Conclusions and Recommendations

## 3.1. Conclusions

As the cable industry adapts to higher frequencies on the coaxial network, and the preponderance of LTE signals and devices in the UHF band, the importance of translating legacy techniques for maintaining plant integrity and compliance with FCC requirements into revised and more fundamentally based techniques is clear.  Standard formulas that only apply for certain equipment, geometries or frequencies, must be revisited and their application to current and future network operations must be developed, which is the purpose of this operational practices document.

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

Since the frequencies at which field strength is measured will continue to vary because of on-going increases in cable network operating RF bandwidths and upstream/downstream splits, the availability of leakage detection equipment that covers expanded operating frequencies, , and future changes in LTE and other services' spectrum usage, a complete mapping of expected measurement values from different frequencies and measurement scenarios may be needed  in a future version of this operational practice document.

# 4. Abbreviations and Definitions

## 4.1. Abbreviations

| | |
|---|---|
| µV/m | microvolt per meter |
| $A_e$ | effective aperture |
| $A_{em}$ | maximum effective aperture |
| dB | decibel |
| dBi | decibel isotropic |

| | |
|---|---|
| dBm | decibel milliwatt |
| dBmV | decibel millivolt |
| dBµV/m | decibel microvolt per meter |
| e.g. | for example (*exempli gratia*) |
| FCC | Federal Communications Commission |
| km | kilometer |
| LTE | long term evolution |
| m | meter |
| MHz | megahertz |
| mW | milliwatt |
| NOS | [SCTE] Network Operations Subcommittee |
| NOS WG1 | [SCTE] Network Operations Subcommittee Working Group 1 |
| $P_d$ | power density |
| $P_t$ | source power |
| RF | radio frequency |
| SCTE | Society of Cable Telecommunications Engineers |
| TR | [SCTE] Technical Report |
| TV | television |
| UE | user equipment |
| UHF | ultra high frequency |
| VHF | very high frequency |
| V/m | volt per meter |

### 4.2. Definitions

**antenna factor** – The ratio of the field strength of an electromagnetic field incident upon an antenna to the voltage produced by that field across a load of impedance $Z_0$ connected to an antenna's terminals.

**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 $dB = 10\log(P_1/P_2)$. The decibel also can be used to represent the ratio of two voltages under certain circumstances.[3]

**decibel microvolt (dBµV)** – Unit of RF power expressed in terms of voltage, defined as decibels relative to 1 microvolt, where 1 microvolt equals 13.33 femtowatts in a 75 ohm impedance. Mathematically, $dB\mu V = 20\log_{10}(\text{value in } \mu V/1\ \mu V)$.

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[3] The decibel, while technically a ratio of two power levels, also can be used to represent the ratio of two voltage levels, 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 $dB = 10\log_{10}(P_1/P_2)$, the equation becomes $dB = 10\log_{10}[(E^2/R)/(E^2/R)]$ which is the same as $dB = 10\log_{10}[(E_1^2)/R_1)/(E_2^2/R_2)]$. In this example, R represents the 75 ohm impedance of a 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 $dB = 20\log_{10}(E_1/E_2)$.

**decibel isotropic (dBi)** – the forward gain of an antenna compared with the hypothetical isotropic antenna, which uniformly distributes energy in all directions.

**decibel microvolt per meter (dBμV/m)** – An RF signal's power density expressed in terms of voltage, defined as decibels relative to 1 microvolt per meter, where 1 microvolt per meter equals 1 microvolt delivered to a receiving antenna's terminals recovered from an imaginary 1 meter x 1 meter square in free-space or air. Mathematically, $\text{dB}\mu\text{V/m} = 20\log_{10}(\mu\text{V/m})$.

**decibel millivolt (dBmV)** – Unit of RF power expressed in terms of voltage, defined as decibels relative to 1 millivolt, where 1 millivolt equals 13.33 nanowatts in a 75 ohm impedance. Mathematically, $\text{dBmV} = 20\log_{10}(\text{value in mV/1 mV})$.

**decibel milliwatt (dBm)** - Unit of power, defined as decibels relative to 1 milliwatt, where 0 dBm equals 1 milliwatt. Mathematically, $\text{dBm} = 10\log_{10}(\text{value in mW/1 mW})$.

**effective aperture ($A_e$)** – The geometric area over which an antenna receives power from an incident wave and delivers that power to a connected load. Mathematically, $A_e = \lambda^2 G/4\pi$, where $\lambda$ is the wavelength of the RF signal, G is the receiving antenna's numerical power gain (e.g., 1.64 for a half-wave dipole), and $\pi = 3.14159265$. If the antenna is considered lossless, effective aperture is called maximum effective aperture ($A_{em}$). For a half-wave dipole antenna, $A_{em}$ can be approximated by a rectangle that has dimensions of $0.5\lambda$ by $0.25\lambda$, or an ellipse whose area is $0.13\lambda^2$.

**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 aperture, and $\lambda$ 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 1 meter 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, $G_{dB} = P_{out(dBmV)} – P_{in(dBmV)}$.

**hertz (Hz)** – A unit of frequency equivalent to one cycle per second.

**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, $L_{dB} = P_{in(dBmV)} – P_{out(dBmV)}$.

**maximum effective aperture ($A_{em}$)** – See *effective aperture*

**megahertz (MHz)** – One million ($10^6$) hertz. See also *hertz*.

**microvolt (μV)** – One millionth ($10^{-6}$) of a volt.

**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.

**millivolt (mV)** – One thousandth ($10^{-3}$) of a volt.

**milliwatt (mW) -** One thousandth ($10^{-3}$) of a watt.

**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 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 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.

**vector** – In physics and mathematics, a quantity that has both a magnitude and a direction.  It is possible for both the magnitude and direction of a vector quantity to change at each point in space at which the quantity is measured. Graphically, a vector is often represented using an arrow, where the length of the arrow corresponds to the vector's magnitude (for instance, signal level), and the direction the arrow is pointing represents the direction of the vector.

## 5. Bibliography & References

### 5.1. References

[1] Kraus, J. (1988). Antennas (2nd. ed.). New York: McGraw-Hill

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

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JOURNAL OF
NETWORK OPERATIONS

# Operational Practice for Minimizing Signal Leakage in the UHF Spectrum

An Operational Practice Prepared for the
Society of Cable Telecommunications Engineers
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# 1. Introduction

## 1.1. Executive Summary

***Target Audience:*** Network engineers, network architects, access network engineers, critical facility engineers, outside plant technicians, field and installation technicians, and training content developers.

***What is it?*** This operational practice covers techniques for minimizing signal leakage in the ultra high frequency (UHF) band in hybrid fiber-coax (HFC) access networks.

***What is the function of it?*** This operational practice is to help cable operators meet the concerns of over-the-air users and the Federal Communications Commission (FCC) for the potential of cable leakage in the UHF spectrum that can cause harmful interference to over-the-air services such as broadcast television, long term evolution (LTE), public safety, trunked two-way radio, and other communications.

***What are the immediate and long-term benefits of adopting it?***

- Reducing customer care calls, truck rolls/repeat truck rolls, and the mean time to repair (MTTR)
- Ensuring compliance with FCC Part 76 regulations
- Tightening the plant for reduced leakage indirectly increases the cable network's achievable spectral efficiency

***How does this operational practice impact the industry and fit into the SCTE Engineering Committee's roadmap?*** It will allow the cable industry to keep up with exponential growth of LTE and other services and devices and their impact on cable networks.

***What are some of the key points of this operational practice?***

- Description of modern technologies for detecting and locating UHF band leakage from cable networks using three different methods: injected carriers/marker tones, spectrum analyzers with high gain antennas, and correlation of field measurements with downstream quadrature amplitude modulation (QAM) signals
- Common causes and troubleshooting practices for detecting, locating and mitigating UHF band leakage and leakage in general
- Key performance indicators (KPIs) that should be monitored to assess UHF band leakage
- Detailed procedures for troubleshooting problems associated with UHF band leakage, especially in all-digital plants
- Equipment for monitoring ingress and direct pickup interference, including the use of proactive network maintenance (PNM) technology
- Suggestions for educating the workforce on causes and troubleshooting of UHF leakage

***What can you do to achieve maximum benefit from implementing this operational practice?*** Customize it for your specific workforce/cable network. Implement the practices, keeping track of KPIs both before and after the implementation to ensure it is meeting the business goals of the cable operator.

***How can you learn more about this operational practice***? Join SCTE's Network Operations Subcommittee (NOS) working group and assist in revisions and updates to this document. Visit http://www.scte.org/standards, or email: standards@scte.org for more information.

## 1.2. Scope

This document provides a practical basis for operational practices in UHF leakage mitigation in HFC networks, and will be of interest to those responsible for plant maintenance, especially those who manage leakage monitoring and repair. Also included are explanations of leakage causes and characteristics, recommendations for acquisition and use of proper tools, explanation of the requirement for UHF leakage monitoring as part of a continuous program, discussion of maintenance, the importance of high quality craftsmanship standards, and recommendations related to what to do when contacted by an LTE provider about interference.

## 1.3. Background

The FCC has for many years required cable operators to monitor for signal leakage in or near the 108 MHz to 137 MHz very high frequency (VHF) aeronautical band. Leakage detection and repair programs have helped outside plant personnel manage signal leakage and ingress. Properly implemented, signal leakage detection and repair programs minimize the likelihood of leakage-related interference to over-the-air services, as well as help to prevent over-the-air signals from “leaking” into cable networks and interfering with cable signals.

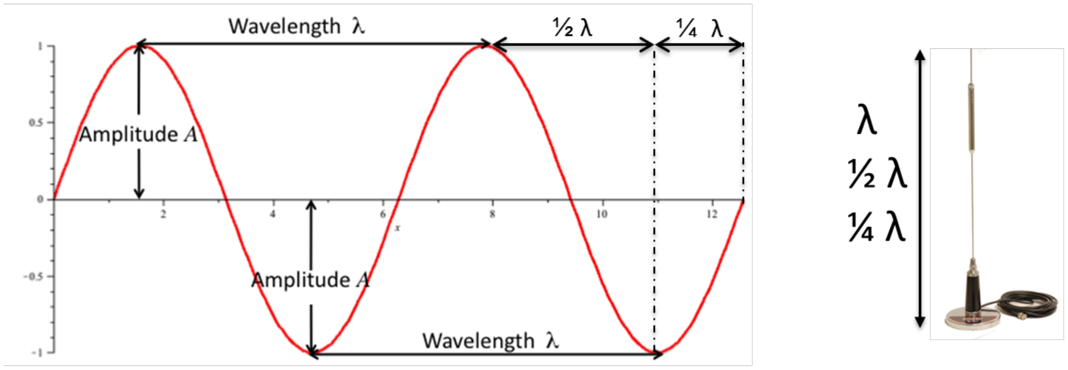
In late 2010, a new wireless technology called LTE was introduced in the United States. LTE service operates in several frequency bands, including the 698 MHz to 806 MHz band, which overlaps the frequency spectrum used by many cable operators to deliver services to their customers. As LTE service providers started to deploy LTE service, their field engineers discovered another source of potential interference to their equipment: signal leakage from cable networks.

Leakage in the higher frequency ranges, specifically the UHF spectrum, until recently had not been a major concern. Some cable operators assumed that a tight plant at VHF meant a tight plant across the entire operating spectrum, but that is now known to be an incorrect assumption (Hranac, Tresness, 2012).

To better understand the differences in signal leakage field strengths (and thus detection) between the VHF and UHF bands, it is always useful to return to antenna basics.  To effectively radiate (or receive) electromagnetic energy, the antenna should be a simple fraction of the wavelength of the signal, such as $\lambda$. $\lambda/2$, or $\lambda/4$.

At higher frequencies, such as 612 MHz for example, the wavelength $\lambda$ =1.58 feet and $\lambda/2$ is just under 9 inches. This allows leakage detection equipment to be designed with much smaller antennas, but also means that the higher the frequency, the shorter the wavelength, and thus the smaller a crack or break in the coax cable may be in order to become an effective radiator for leakage. The antenna factor difference between VHF and UHF results in an effective loss of sensitivity at higher frequencies, which complicates UHF leakage detection and measurement. Smaller cracks or breaks in the shielding of the coaxial portion of an HFC network have a greater propensity to become sources of leakage in the UHF band than at the lower VHF band of frequencies. Figure 1 shows this relationship between frequency and wavelength and gives two examples commonly used in leakage measurement, 138 MHz and 612 MHz.

Antenna Length should be a fraction of the wavelength (λ)



At 138 MHz:
λ = 7 feet
¼ λ = 21 inches

At 612 MHz:
λ = 1.58 feet
¼ λ = 4.74 inches

**Figure 1 - Antenna basics (from Couch [1]).**

It should also be noted that the free space path loss (FSPL) is greater at higher frequencies. The FSPL is given by $(4\pi R/\lambda)^2$, in linear terms, where R is the distance between the leak and the detecting antenna. Note that it is a common misconception that signal loss from propagation in free space is frequency-dependent. The free space path loss only appears to be frequency-dependent because of the relationship between gain and the effective aperture ($A_e$) of the receiving isotropic antenna, which does indeed change with frequency. As frequency increases, effective aperture decreases. This is the source of the frequency term (or alternately as given here, the wavelength term) in the FSPL and why the loss increases with increasing frequency. For more about antenna effective aperture, see the SCTE operational practices document “Field Strength & Calculation of LTE User Equipment Field Strength” or the companion paper on this topic in this journal. So a UHF signal at 828 MHz, which is six times the frequency of one at 138 MHz, has 15.6 dB more free space path loss than a VHF signal at 138 MHz. The actual difference in measured field strength from a leak depends on several things: the signal level-versus-frequency inside the cable network at the point of the leak; the wavelength, free space path loss, and obstructions or reflections between the leak and the leakage detection equipment; the effective gain and radiation pattern of the aperture formed by the break in the coaxial cable or network component that forms an ‘antenna’ for radiating the leaked cable signal; the polarization, coupling currents, and many variables such that the signal leakage field strengths measured at VHF and at UHF are not only very different, but generally uncorrelated with each other, as is shown in reference [2].

What, then, can cable operators do to guard against signal leakage affecting LTE and other services operating in the UHF spectrum? Develop thorough and updated operational practices for minimizing signal leakage, especially in the UHF spectrum, that employs modern principles, equipment, tactics, processes and procedures, and provide a rapid response when contacted by LTE or other service providers. These operational practices are detailed in the next section of this document.

# 2. Operational Practices

## 2.1. Key Performance Metrics

This section includes the key performance metrics to be measured and provides a brief overview of the theory behind each one.

Measured signal leakage field strength, in microvolts per meter (µV/m): The amount of radio frequency (RF) energy leaking out of a coaxial cable-based network, measured by using a dedicated leakage detector with a resonant half-wave dipole antenna (or equivalent), orienting the antenna to get a maximum reading and noting what value the leakage detector reports. The measured field strength in microvolts per meter must be below the maximum limit defined by the FCC, as set in FCC 76.605(a)(12), which is generally that VHF leaks above 20 µV/m must be logged and fixed, and that leaks above 50 µV/m must be used in the cumulative leakage index (CLI) calculation. Signal leakage limits in the UHF spectrum are different than at VHF. More specifically, the FCC limits from §76.605(a)(12) specifies maximum leakage field strength limits-versus-frequency, and is provided here for reference.

> (12) As an exception to the general provision requiring measurements to be made at subscriber terminals, and without regard to the type of signals carried by the cable television system, signal leakage from a cable television system shall be measured in accordance with the procedures outlined in § 76.609(h) and shall be limited as shown in Table 1.

**Table 1 – Signal Leakage**

| **Frequencies** | **Signal leakage limit (micro-volt/meter)** | **Distance in meters (m)** |
|---|---|---|
| Less than and including 54 MHz, and over 216 MHz | 15 | 30 |
| Over 54 up to and including 216 MHz | 20 | 3 |

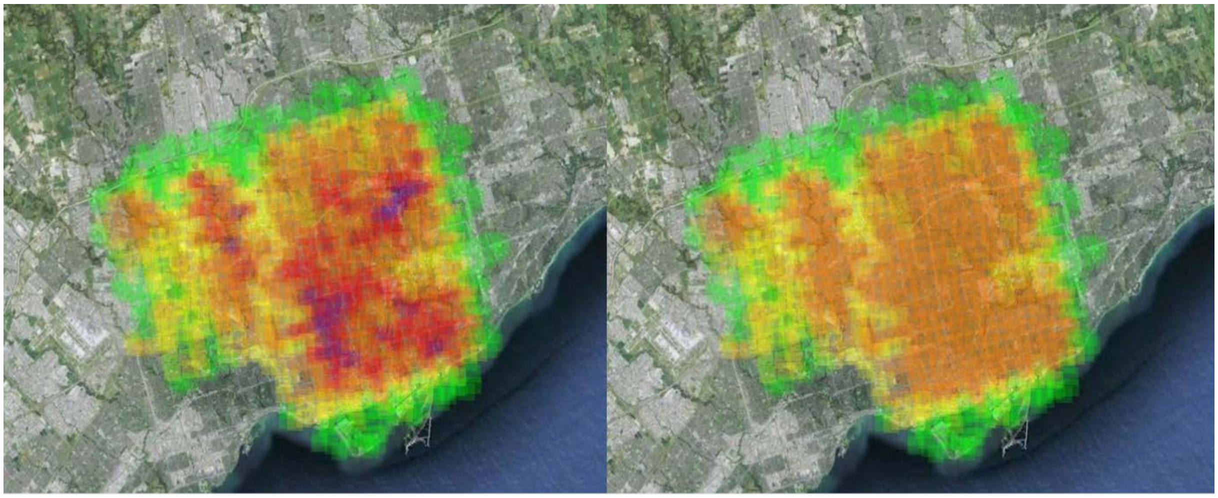
The majority of U.S. cable operators are familiar with the signal leakage limit in the 108 MHz to 137 MHz VHF aeronautical band: 20 µV/m at a measurement distance of 3 meters (approximately 10 feet) from the cable network. This limit applies to the entire frequency range from >54 MHz to and including 216 MHz, as noted in the previous table.

Note that outside of the North American cable industry, field strength measurements are more commonly stated in decibel microvolt per meter, or dBµV/m.

For a complete definition of this metric and the theory behind it, see the operational practices document “Field Strength & Calculation of LTE User Equipment Field Strength,” available from www.scte.org, or the companion paper on this subject in this journal..

This metric may be collected in a binary method (measurements above FCC threshold vs. below FCC threshold) or as actual measured field strength levels as a function of location where the measurement was made. The measurements of this metric may also be aggregated by node, region, or other network element or geographical reference so that continuing or worsening problems can be effectively tracked for longer term decisions on plant maintenance or upgrades. It can also be collected as a histogram of measured signal levels that depicts relative frequency of the different field strengths measured. And of course the metric will be collected as a function of frequency of the measurement.

One very effective best method for collecting and depicting the field strength is a “heat map” of leakage signal detections, seen in Figure 2, where both airborne and ground-based measurements were used to generate the heat map before a scheduled maintenance activity, and after a scheduled maintenance activity. Some modern leakage detection equipment, whether ground based or airborne, also collects the global positioning system (GPS) coordinates when making a measurement of leakage field strengths.



Airborne Signal Leakage Map Before Maintenance Activity

Airborne Signal Leakage Map After Maintenance Activity

**Figure 2 - Heat map of signal leakage detections (from Watson [3]).**

CLI is another metric to be calculated as part of an effective leakage mitigation practice, and is given by

$$CLI = 10 * Log\left\{\left[\frac{Total\ Plant\ Miles}{Miles\ Driven\ in\ Detecting}\right] * \sum (Leakage\ Levels)^2\right\}$$

CLI is unfortunately a commonly misused leakage-related term, because it is not the same as signal leakage. CLI is a figure of merit that provides a snapshot of the magnitude of a cable system’s overall signal leakage. It is not possible to measure or test CLI directly; one must measure signal leakage in order to ***calculate*** CLI.

The FCC maintains a CLI online calculator at https://transition.fcc.gov/mb/engineering/clical.html. Compliance requires the CLI to be 64 or less, and note that a single leak of level 1588 μV/m in an HFC system is enough to fail the CLI requirement.

However it should be strongly pointed out that the FCC harmful interference clause in §76.613 mandates that leakage signals that cause any harm to existing services must be fixed regardless of the leakage field strength. To the LTE service providers, ***any*** detected signal energy in their licensed spectrum from nearby HFC networks may be characterized as harmful to their services from their perspective.

It is often not possible to immediately determine the exact location of a leak based solely on the detected leakage signal. While triangulation from multiple measurements was widely used in the early days of cable networks to locate the source of a leaking signal (and is still used today by technicians to locate leaks), the capture of GPS coordinates when measuring leakage can be used to correlate these measurements with metadata about the plant at those coordinates. The GPS coordinates can thus be used to pull up plant data at that location such as: the nearest strand mounted devices like actives, Wi-Fi hotspots, and taps; the age of plant; recent repair activity; nearby homes; and reported signal/plant impairments from PNM software and technology used in network operations. By correlating a leakage level above threshold with any metadata about the plant at that location, it is now possible to identify the potential location of the leakage much more quickly.

In addition, a histogram of measured leakage signal strength can be plotted versus various parameters such as plant age, plant repair activity, temporal history, construction nearby, and so on such that long term trends in sources of leakage can be proactively identified in the future and repaired before they cause violations of FCC limits or complaints from over-the-air users.

In addition to leakage field strength and associated metadata such as GPS coordinates and plant metadata, CLI, and metrics that relate to the workforce or effectiveness of leakage detection and mitigation can be collected. These may include metrics such as:

- MTTR leakage after detection;
- Mean time between repeated detections on a node, system, or region;
- Average number of leakage detections per node, system, or region;

and so on.

## 2.2. Required Equipment

Existing analog leakage detectors were not designed to operate in the UHF spectrum, nor were they designed to measure noise-like digital signals – the most likely signal type carried at higher frequencies in cable networks. Without the right test equipment, one cannot determine the extent of leakage at higher frequencies. Fortunately, all of the major signal leakage test equipment manufacturers are now shipping digital-compatible detectors that operate in the UHF spectrum. These detectors are recommended as the first choice for detecting and accurately measuring UHF leakage, and ensuring compliance with the FCC Rules.

One of the challenges in detecting leakage nowadays is that the cable signals are wideband QAM waveforms that lack the sharp spectral characteristics of visual carriers in analog TV signals. Modern leakage detection equipment must therefore be optimized for detection of both legacy analog carriers when they are still in use, and also for digital signals that are more difficult to pull up out of the noise floor of a low cost portable receiver. There are three categories of modern leakage detection technologies currently available in the industry that enhances the signal to noise ratio of field measurements:

- Portable spectrum analyzers coupled with high gain directional antennas (and preamplifiers and bandpass filters if necessary),
- Correlation-based receivers that use snapshots of the QAM carriers from the headend or elsewhere in the network, and
- Low-level non-interfering test signals injected into the downstream spectrum between adjacent QAM signals.

Each of these is described in the following subsections.

### 2.2.1. Portable spectrum analyzer method using high gain, directional antenna

This method uses a low-noise, portable monitoring receiver (similar to a spectrum analyzer) in combination with an active, directional, high gain antenna to capture a large portion of the spectrum of the cable network. Rohde & Schwarz is an example of a manufacturer of this type of equipment, and an example of a spectrum capture showing cable signals leaking into the over-the-air spectrum is shown in Figure 3.

While this method can provide a complete snapshot of the leakage signal, it requires a technician to use the equipment manually, and may not be capable of measuring the field strength of a leaking QAM signal.

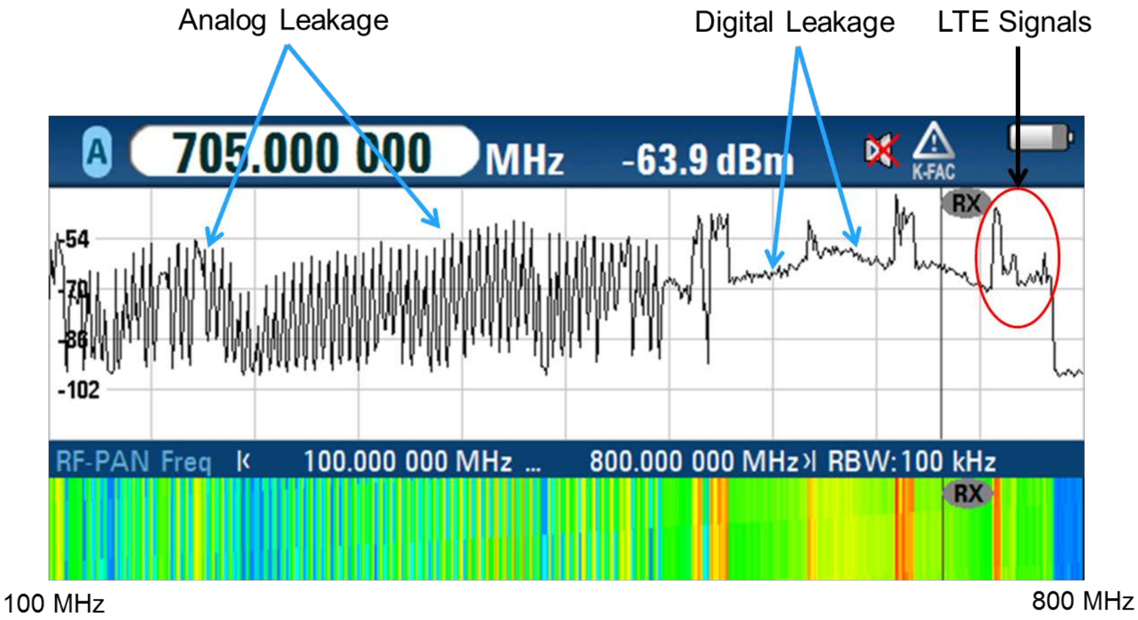


**Figure 3 - LTE interference from cable leakage (from Couch [1])**

It can be seen how the leakage of digital signals from the cable plant caused a raised noise floor in the LTE spectrum and this would likely be reflected in metrics used by the LTE provider such as base station uplink received signal strength indicator (RSSI) as described later in this document. The screen shot in Figure 3 is a snapshot near a very large leak (>1,000 uV/m). The analog channel leakage up to about 520 MHz and the digital channel leakage up to about 780 MHz are clearly seen. The digital leakage effectively raised the noise floor from -92 dBm to about -60 dBm on average. In this case the digital leakage was so high that it almost completely swamped the spectrum of the public safety network signal ***at this point in space***. While this single leak might not be enough to significantly alter the overall performance of an LTE service, the cumulative effect of many leaks could.

### 2.2.2. Correlation method

Another method found in the equipment from Arcom Digital involves a correlation process to match digital QAM signals generated in headend or hub with those found in the field. Essentially a digital snapshot of the QAM signal at the headend (or other location in the network) is sent to the field unit for correlation with measurements to significantly enhance the signal-to-noise ratio of the leakage measurement, and the time difference of arrival between the two waveforms is used to assist in locating the source of the leakage.

Figure 4 shows a block diagram of how such a system works.

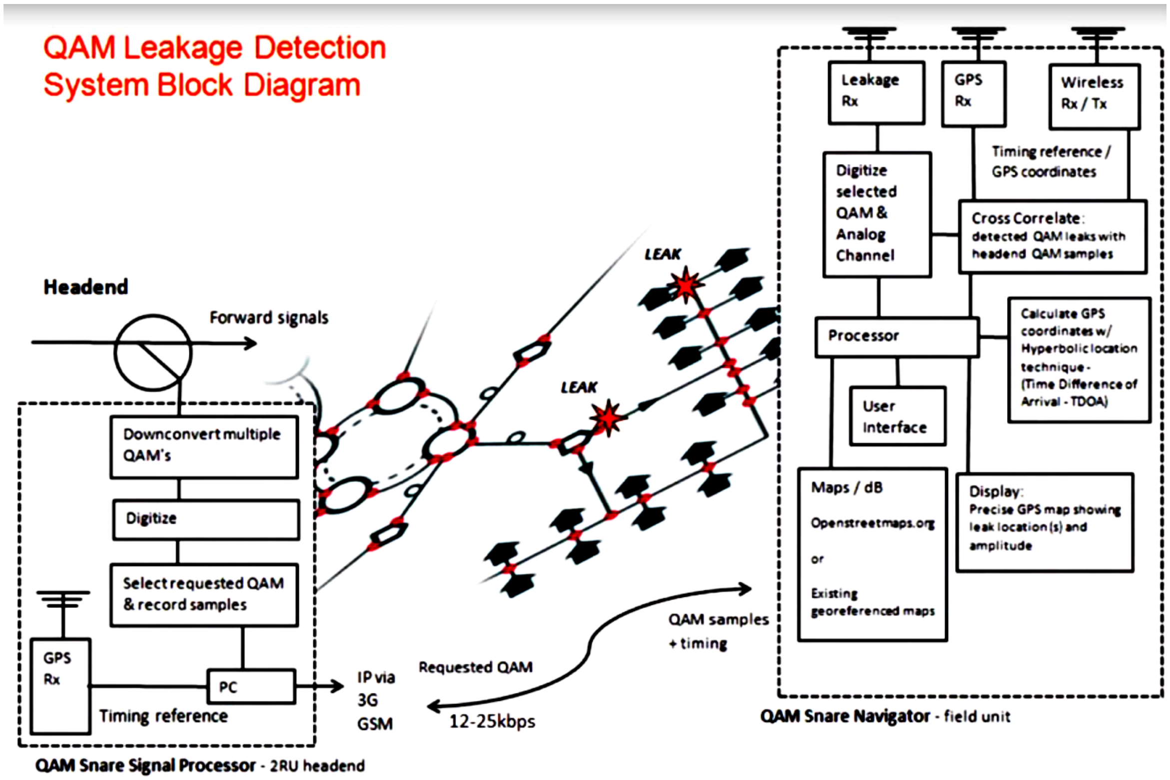
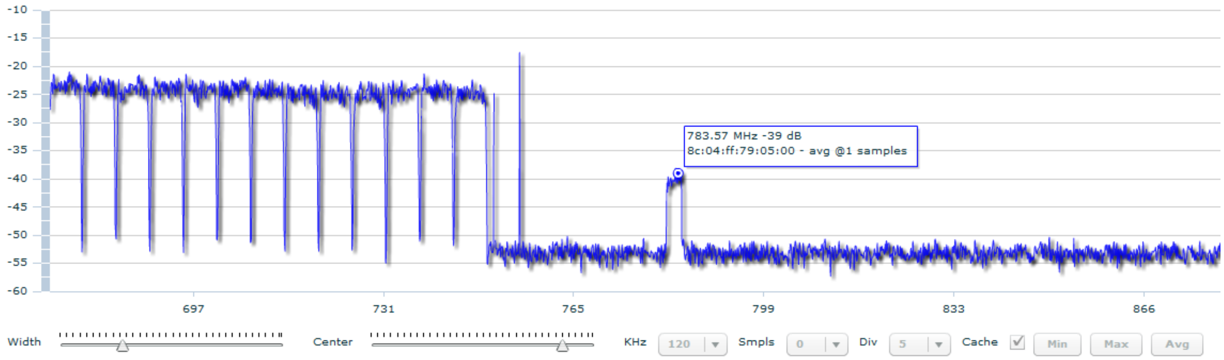


**Figure 4 - Correlation method for leakage detection (from Pierzchanowski [4]).**

### 2.2.3. Injected carrier method

Another method found in the industry uses a unique, narrowband test signal injected between two adjacent QAM channels that can be received by corresponding field detector units. This method is similar to the original approach of detecting the narrowband (25 kHz) visual carriers using a narrowband receiver that has a correspondingly low noise floor. The injected narrowband test signals have unique signatures so that if leakage is present from other cable operators' plants nearby, it is possible to determine from which plant the leaked test signal was radiated and thus has the leak to be fixed. The use of injected test signals and low cost field measurement devices is found in equipment currently available from ComSonics, Effigis, and Trilithic.

A sample cable spectrum showing narrowband carriers just above the QAM signals is shown in Figure 5, which was captured from a cable modem which supports RF spectrum capture of the downstream signal. In actual practice, injected marker tones/carriers may be used at several frequencies so that leakage in VHF and UHF bands may be assessed. Note also the presence of an LTE signal which entered the cable spectrum via direct pickup. In this case, an LTE phone handset was held within one foot of the cable modem to test the ability of the modem to shield itself from such direct pickup of LTE interference. For more information on direct pickup interference, see the SCTE operational practices document "Ingress and Direct Pickup," or the companion paper in this journal.



783.57 MHz -39 dB
8c:04:ff:79:05:00 - avg @1 samples

**Figure 5 - Narrowband pilot tones for leakage detection, along with direct pickup of LTE**

One of the advantages of the injected test signal method is that relatively low cost receivers may be deployed in all fleet vehicles for automatic and continuous monitoring of leakage field strength. Or field equipment (antennas and receivers, both leakage and GPS) can be deployed in other companies' fleet vehicles, such as garbage trucks, and use Wi-Fi to transmit the data collected to the cable operator for analysis and action. Since garbage trucks also cover most if not all streets in a city, they can be useful for deploying leakage detectors if the local waste company is amenable to the partnership.

### *2.2.4. Listing of current manufacturers of leakage measurement equipment*

SCTE's Network Operations Subcommittee Working Group 1 (NOS WG 1) is aware of the following commercially-manufactured digital-compatible UHF leakage detection products, which were available or under development at the time the UHF technical report, SCTE 209 2015 [5], was written. Appendix A of that report includes descriptions of most of the leakage detection products, how they work, and how to use them. The reader is urged to contact the manufacturers for additional information. The following list and the material in Appendix A of SCTE 209 201 [5] are not intended to be an endorsement of the manufacturers or their products by SCTE or members of NOS WG1, nor is it intended to be an exhaustive list.

Company: Arcom Digital
Products: QAM Snare, Navigator, Navigator Plus, Monitor Plus, Isolator Plus, Isolator, and SP-10 headend signal processor
Web site: http://www.arcomlabs.com

Company: Cable Leakage Technologies
Products: C Lite and Yagi antenna
Web site: http://www.wavetracker.com

Company: ComSonics
Products: QAM Sniffer and QAM Marker
Web site: http://www.comsonics.com

Company: Effigis
Products: CPAT Flex with DRV3 meter and DSG1 signal generator
Web site: http://effigis.com

Company: Viavi (formerly JDSU)
Products: QAM Egress Option, DSAM
Web site: http://www.viavisolutions.com/

Company: Rohde & Schwarz
Products: PR100 portable receiver and HE300 antenna; EFL 110/210 cable TV analyzer and leakage detector
Web site: http://www.rohde-schwarz.com

Company: Trilithic
Products: Seeker D detector and CT-4 digital leakage tagger
Web site: http://www.trilithic.com

As previously mentioned, products from three of the manufacturers – ComSonics, Effigis, and Trilithic – work by injecting a low-level, non-interfering test signal between two adjacent QAM signals. A very narrow-bandwidth, high-sensitivity receiver detects and measures the test signal leaking out of the cable network. The products from Arcom Digital use the aforementioned correlation method to directly detect and measure QAM signal leakage, by comparing with a cross correlation detector the leaking QAM signal to a reference captured at the headend or from the outside plant. The Rohde & Schwarz PR100 and HE300 are the same instruments used by LTE field engineers to identify and locate interference to their facilities, including leakage-related interference. The Cable Leakage Technologies and Rohde & Schwarz products provide spectrum analyzer-like functionality, allowing the user to identify and in some cases measure the field strength of leaking signals. The Viavi (formerly JDSU) product also provides spectrum analyzer-like functionality, automatically indicating when a QAM signature is detected in the spectrum scan.

## 2.3. Calibration and Equipment Preparation

This section will be completed in subsequent versions of this operational practice.

## 2.4. Detailed Procedure

Since the FCC harmful interference clause in §76.613 permits complaints to cable operators from LTE providers from potentially any detected level of cable signal leakage from the plant, UHF leakage monitoring must become part of a continuous program of monitoring and maintenance for the cable operator. Plus, high quality craftsmanship standards have never been more important, both for minimization of leakage but also for customer satisfaction in the modern competitive landscape of broadband service provision.

#### 2.4.1. Requirement for UHF leakage monitoring as part of a continuous program

Other than making measurements in the UHF band using equipment designed to effectively detect such emissions, the monitoring of UHF leakage should proceed similarly to continuous leakage monitoring programs currently in place. These will be summarized here and differences or enhancements needed for UHF leakage detection are noted.

##### 2.4.1.1. How monitoring systems generally work

Monitoring systems used by cable operators use field equipment to detect the leaked presence of one of the following three types of signals:

- Analog pilot carriers (typically unmodulated or modulated visual carriers)
- QAM signals
- Injected narrowband test signals between adjacent QAM signals

Analog pilot carriers and injected marker carriers are detected using narrowband receivers (typically 25 kHz or less receiver bandwidth). QAM carriers are detected either via direct spectrum analyzer measurements, or via the aforementioned QAM correlation method.

The LTE providers are known to use the direct spectrum analyzer method, e.g. a Rohde & Schwarz spectrum analyzer and high gain/directional blade antenna. However this is actually the second step in their process. The first step involves seeing a higher-than-normal uplink RSSI from the LTE base station. RSSI basically acts as a cumulative noise floor measurement for the cell site. If the noise floor increases beyond the normal operating levels, it is usually due to interference within the cell site. Often the next step is to connect a spectrum analyzer to the uplink antenna test point and look for obvious signs of RF interference. The operator may not able to immediately determine the source of the noise or interference from this measurement, and thus must investigate. This is done by using a trained technician who uses the aforementioned specialized equipment to find and track down the source of interference. In the course of looking for interference sources, they may find cable leakage within the cell site boundaries. Figure 6 shows such a report of detected leaks near a cell phone (LTE) site.

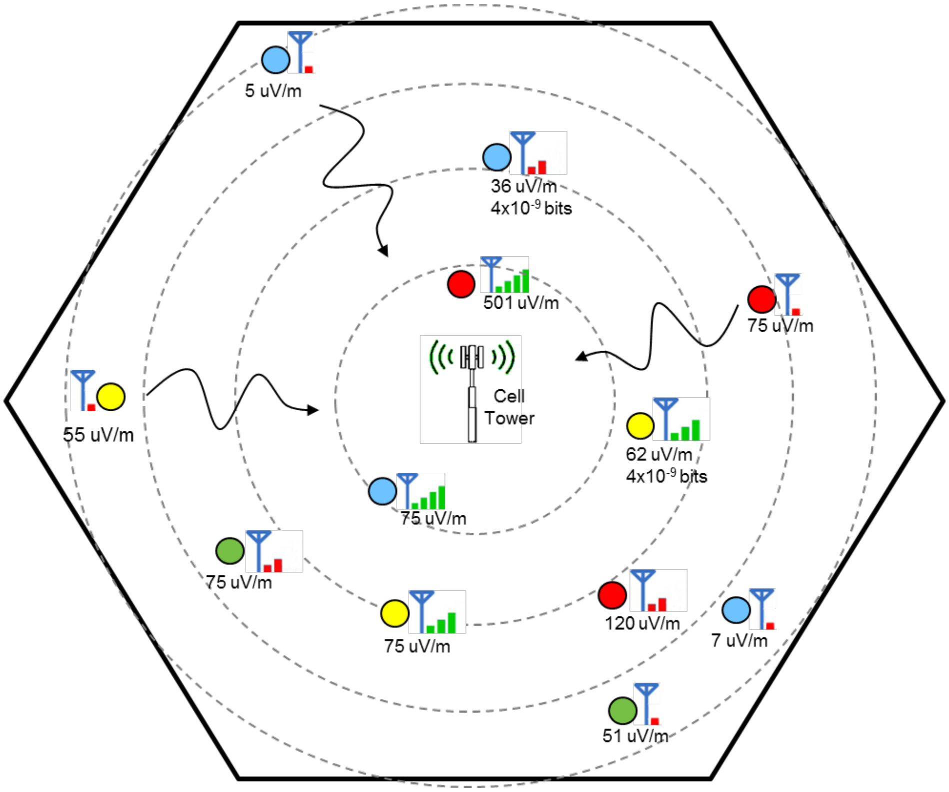


**Figure 6 - LTE measurements of suspected cable plant leaks near a base station (from Watson[3] and SCTE [6]).**

If this is the case, the leaks and their locations will be reported back to the cable operator responsible for the leaks with the expectation that they will be fixed. While these leaks may not have been the only cause of the noise floor to elevate beyond its operating parameters, they certainly will contribute to the problem. The expectation is that the cable operator will fix the leaks regardless of whether they are the main problem or not.

In summary, the steps used by LTE providers are:

- The RSSI is monitored by cellular providers such as AT&T and Verizon. An increase in the RSSI provides the first indicator to them of interference, which might indicate a possible leakage issue.
- If a high level of noise is detected, the LTE provider must troubleshoot the cell site to find the source of interference. LTE field engineers connect a spectrum analyzer to the uplink receive antenna test point, and look for signs of external interference. If 6 MHz-spaced QAM signals are seen, they might contact the cable company at that point, or drive the cell site looking for the specific source of the suspected leakage.
- Leaks are reported back to cable operator. Cable operators are obligated to fix these leaks – even if they are only a possible cause of reduced receiver performance.

#### *2.4.1.2. Monitoring analog channels for leakage in the UHF band*

If the cable operator still has analog channels operating in the UHF band, then conventional narrowband leakage monitoring equipment that is capable of detecting visual carriers in the UHF spectrum can be used in much the same way as legacy VHF leakage detection equipment. Narrowband leakage receivers that detect analog visual carriers in the UHF band can be very effectively used to monitor higher frequency leaks in the plant. Detailed procedures for this type of measurement are found in section 12.2 “Signal Leakage” of the SCTE Measurement Recommended Practices document [7].

#### 2.4.1.3. Monitoring digital channels for leakage in the UHF band

Detailed procedures for this type of measurement are found in section 12.3 “Signal Leakage, All Digital System” of the SCTE Measurement Recommended Practices document [7].

#### 2.4.1.4. Monitoring pilot tones for leakage in the UHF band

Detailed procedures for using low level narrowband test signals in the UHF band for leakage detection are found in Appendix A of the UHF technical report, SCTE 209 2015 [5].

#### 2.4.1.5. Using cable operator fleet vehicles for leakage monitoring

Detailed procedures for using fleet vehicles for UHF band leakage detection are found in Appendix A of the UHF technical report SCTE 209 2015 [5].

#### 2.4.1.6. Using third party vehicles (e.g. garbage trucks) for leakage monitoring

To be completed in a later update to this operational practices document.

#### 2.4.1.7. Aerial flyovers for leakage monitoring

Firms that specialize in provide aerial flyover leakage detection services for cable operators include The Frequency Finders at https://www.thefrequencyfinders.com/index.html. They offer the following description of aerial flyovers for leakage monitoring and detection:

“Flyover testing involves equipping an aircraft with a suitable antennas and test equipment and measuring signal leakage in the airspace above the cable TV plant at an altitude of approximately 1500 feet (450 meters). Parallel passes are flown at approximately 1 mile spacing covering the entire cable plant. Signal leakage levels and GPS data are collected in a matrix to associate leaks found with specific locations. Care is taken in selecting the test frequency to avoid interference with known over the air transmitters in the area. Specific offsets or tagging can be used with the test signal to rule out signals from adjacent cable or SMATV systems, if necessary. Finally, the collected data is analyzed and a report is created showing "hot spots" and percentage of data points below the 10 µV/m threshold.”

And they offer the following advantages of flyovers:

> “A Snapshot in Time: Groundbased measurements can be extremely time consuming, depending on the cable system size. Conditions can change over time and collecting data for a ground-based CLI calculation can take up to 3 months. Changing conditions can have a dramatic effect on leakage levels over time. One advantage of a flyover is that it gives you a snap shot in time of system leakage performance over a period of a few hours rather than a few months.”

> “Third-party Verification: A flyover provides an outside audit of a cable system's ground based monitoring work. How effective is your in-house signal leakage monitoring program? A flyover provides the credibility of a 3rd party review, similarly to that of an outside financial audit.”
>
> “Cost Effective and Minimal Impact to System Operations: Using resources to measure leakage and calculate the Cumulative Leakage Index diverts personnel from service calls and maintenance affecting customer service. Performing a flyover requires minimal system resources; generally limited to a technician installing and setting up the headend signal generator (leakage signal source). The cost per mile of a flyover on most systems is less than the cost per mile of a ground-based measurement and calculations.”
>
> “A Useful Tool: Beyond meeting the FCC requirement for annual signal leakage measurement and reporting, a flyover can be a useful tool for locating signal leakage in the cable plant. Hot spots found during the flyover can be correlated to a half mile radius on the ground to help isolate leak locations. After major natural disasters such as tornados, hurricanes, or ice storms, many cable systems perform flyovers to determine the extent of plant damage and to prioritize repair resources based on where the strongest leaks are.”

#### 2.4.1.8. Use of third party firms/consultants for leakage monitoring

To be completed in a later update to this operational practices document.

#### 2.4.1.9. New approaches for leakage monitoring: drones

A new approach for aerial leakage monitoring is the use of drones with leakage monitoring systems onboard them. PrecisionHawk is a company in this space and they presented this solution at the CableLabs 2015 Winter Conference. See their website at http://www.precisionhawk.com/ for more details on this solution.

### 2.4.2. Educating the workforce on causes of leakage and the general lack of correlation between VHF and UHF leakage field strength levels

By the time of this writing, many papers, presentations, and articles on the general lack of correlation between VHF leakage measurements and those at UHF have been presented. The bibliography in the UHF technical report [SCTE 209 2015] has a complete list of references on this subject.

However, it is still possible that the current workforce does not yet fully appreciate the fact that UHF leaks are both different and more common than VHF leaks, hence there is a need for a systematic education of the workforce, at levels appropriate to technicians, installers, and other outside plant personnel. For a given leak source such as a radial crack or loose connector, it is important to understand that there ***is little or no correlation*** between leakage field strengths in the VHF aeronautical band and the UHF spectrum used for LTE and other services. Field studies have shown that a leak source can produce little or no leakage in the aeronautical band, yet produce significant leakage in the LTE band. The opposite can also be true: A leak source can produce significant VHF leakage, but little or no UHF leakage. And in some cases, a leak source can produce leakage in both frequency ranges. To gain a better understanding of signal leakage in the outside plant, cable operators need to monitor for leakage in both the VHF and UHF bands.

The following are general recommendations for keeping the workforce up to date on the importance of minimizing signal leakage in the UHF spectrum:

- Assemble a library of articles of published case studies for UHF leakage measurement and mitigation based on the bibliography in the UHF technical report [SCTE 209 2015], include the report itself and the SCTE journal articles, and any other industry publications on the subject, and make that library readily available to the workforce.
- Ensure that the workforce has access to SCTE resources on the subject, including
    - SCTE's LiveLearning$^{TM}$ archives
    - SCTE Cable-Tec Expo papers and presentations
    - The collected *Communications Technology* articles of Ron Hranac, now archived by the SCTE
    - SCTE chapter presentations, and so on
- Create internal webinars, presentations, and videos that highlight specific company examples/case studies of UHF leakage issues and interactions with LTE providers. Have the company's subject matter experts involved in these case studies speak to the workforce on the importance of finding and fixing UHF leaks, from an LTE provider perspective, from a customer satisfaction perspective, and of course from an FCC compliance perspective.
- Develop detailed company-specific operational practices, which can be based on the present document, that provide detailed, specific instructions to employees involved in leakage monitoring, detection and mitigation.
- Develop company specific key performance indicators related to UHF leakage that can be used to ensure the workforce is accountable and measured based on minimization of signal leakage in the UHF spectrum (in addition to the rest of the spectrum of the cable plant),

### 2.4.3. Maintenance, and the importance of high quality craftmanship standards and the prevention of leakage in the first place

As always, technicians should follow the cable operators' internal procedures for leakage monitoring, detection and mitigation, which generally involves random inspection and quality control (QC).

A "do it right the first time" attitude is critical when performing new subscriber drop installations, reconnects, service calls, routine plant maintenance, and new builds, plant extensions, and network upgrades. Many UHF leaks are caused by poor craftsmanship such as loose drop and hardline connectors and adapters. A hardline connector that is loose by as little as a turn to a turn-and-a-half can result in signal leakage at UHF but not VHF; even if that loose connector is covered by heat shrink tubing. Corrosion damage resulting from incorrectly installed or lack of weatherproofing is another culprit, along with loose passive device faceplates and active device housing lids. Craftsmanship issues are avoidable with training, the use of quality materials and components, and follow-up quality control inspections.

Specific recommendations for UHF leakage mitigation include:

- Extend signal leakage patrols beyond the aeronautical bands
- Use these extended signal leakage patrols to direct plant maintenance
- Use quality subscriber drop components
- Use drops that help protect the network from interference caused within the customer premise such as enhanced shielding connectors (sometimes called "continuity connectors") and tri-shield drop cable

- Ensure that all future CPE equipment that is procured is designed and manufactured with the improved shielding in the UHF band, as most already is; be prepared to swap out older CPE that is not well shielded if customer calls indicate this is the problem.
- Diligent attention to craftsmanship on installation and service calls
- Use methods of ensuring the integrity of customer premise wiring such as home certification test equipment
- The 700 MHz and white space spectrum will require cable networks to be even more vigilant
- Leverage both vendors and manufacturers for modern equipment, its use, and troubleshooting tactics
- Use digital-compatible leakage detection equipment
- Follow updates from the SCTE with revised signal leakage measurement practices that extend the current document.
- Keep vigilant plant maintenance!

## 2.5. Recording of Results

Most modern leakage detection systems automatically collect and generate reports from leakage measurements, including formatting them properly for submission to the FCC. If such systems are not in use, then refer to the cable operators' recommendations for recording and reporting results. Ultimately, FCC Form 320 must be filed, and this form can be found at ftp://ftp.fcc.gov/pub/Forms/Form320/320.dot, and an online submission form can be found at https://www.fcc.gov/encyclopedia/basic-signal-leakage-performance-report-form-320.

## 2.6. Analysis of Results and Examples

To be completed in a subsequent version of this operational practices document.

## 2.7. Troubleshooting: Explanation of Leakage Causes and Characteristics

### *2.7.1. Troubleshooting leakage detection issues*

Consult the equipment manufacturers of the leakage equipment in use for specific instructions for troubleshooting issues with their equipment. One challenge moving forward is that as DOCSIS 3.1 signals are deployed in cable networks, they may resemble the LTE signals more, since both are based on orthogonal frequency division multiplexing (OFDM) technology. However the DOCSIS 3.1 signals are likely to be much wider in total RF bandwidth, hence leaked versions of them may be easier to discern from the LTE over the air signals purely from this characteristic. This points to another advantage of the analog visual carriers (or dedicated CW carriers), injected carrier and correlation-based leakage measurement approaches, since it is far less likely to mistake an over the air LTE signal for the measured leakage field strength.

### *2.7.2. Troubleshooting leakage causes and mechanisms*

Leakage causes have been discussed in several SCTE Cable-Tec Expo papers, notably Hranac and Tresness [2] and Hranac and Segura [8]. A fairly complete list of UHF leakage papers and publications that has many specific causes and mitigations in case studies is found in the bibliography of the UHF technical report SCTE 209 2015 [5]. The reader is referred in particular to Hranac and Segura [8] for an excellent list of leakage causes, which are reproduced below for completeness.

“The mechanisms that cause UHF leakage are the same as the ones that cause VHF leakage. UHF leakage tends to be more common in the hardline plant, in large part because signal levels there are greater than they are in the subscriber drop. Tilted active device outputs elevate the upper end of the downstream spectrum relative to lower frequencies. But both the hardline plant and drop can be the source of UHF leakage. As mentioned previously, some of the typical causes of UHF leakage are loose connectors and adapters, radial shield cracks, loose passive device faceplates, damaged or missing gaskets in actives and passives, rodent chews, and so on.”

“The following photos illustrate a few examples of typical sources of UHF leakage in the outside plant.”

Rodent damage

Loose tap faceplate

Tree limb rubbing on coax

Power line fell on coax, melted shield

Illegal MDU connection

Tree limb grown around coax

Corroded and loose terminators

Radial crack in feeder cable

Bad F connector in MDU box

More rodent damage

## 2.8. What to Do When Contacted by an LTE Provider About Interference

Given the availability of commercially-manufactured digital-compatible UHF leakage detection equipment, cable operators should be incorporating UHF band monitoring and repair into their existing leakage programs as soon as possible. Cable signal leakage in the UHF band is a serious matter. The FCC has taken enforcement action against some cable operators for UHF leakage that exceeded the 15 µV/m limit at 30 meters, as well as for harmful interference to LTE services.

Establishing and maintaining effective communications and positive relationships with local LTE service provider field engineers are critical. When contacted by LTE field engineering staff about possible UHF leakage-related interference, the important words are cooperation and responsiveness. Cable operators have been increasingly cooperative when contacted by LTE field engineers about UHF leakage that has been identified as a source of interference.

The following guidelines will help to ensure a positive working relationship with LTE field engineers when local system personnel are contacted regarding UHF leakage interference.

- Respond immediately – do NOT delay.
- Schedule technicians as soon as possible.
- Remember that there could be substantial UHF leakage even if there is no VHF leakage.
- If UHF leakage detection gear is available, use it, and ideally both before and after repairs are made.
- If commercial UHF leakage gear is not yet available locally, a “homebrew” method, combining equipment such as a spectrum analyzer, preamplifier, bandpass filter, and high-gain UHF antenna can be used to at least confirm the presence of UHF leakage. If a downstream analog carrier

- exists above 500 MHz, try to measure it before and after repair, since that carrier may be easier to identify on a spectrum analyzer than leaking QAM signals. (Note: If your system incorporates a CW test carrier in the 700 MHz band, make sure it is ***not located*** atop an active over-the-air LTE signal.)
- Fix the problem.
- Provide system point-of-contact information to the LTE engineers.
- Notify customer service representatives to direct LTE interference complaints and inquiries to the appropriate cable company technical personnel.
- Document everything (e.g., dates and times of all communication with LTE service provider, field work including repair details, before and after repair leakage measurements, etc.).
- Each cable operator may choose to assign a unique trouble call code for LTE-related service calls to enable better tracking and reporting throughout all systems within the company.

## 3. Conclusions and Recommendations

The cable industry has done a commendable job managing VHF leakage for many years. Only recently have cases of leakage-related interference to LTE equipment in the UHF spectrum pointed toward the need to monitor outside of the traditional 108 MHz to 137 MHz VHF aeronautical band. Cable signal leakage that affects LTE is a solvable challenge. To meet this challenge, cable operators should be incorporating UHF band monitoring and repair into their existing VHF leakage monitoring and repair programs as soon as possible.

## 4. Abbreviations and Definitions

### 4.1. Abbreviations

| | |
|---|---|
| CLI | cumulative leakage index |
| dB | decibel |
| dBm | decibel milliwatt |
| dBµV/m | decibel microvolt per meter |
| DOCSIS | Data-Over-Cable Service Interface Specifications |
| FCC | Federal Communications Commission |
| GPS | global positioning system |
| HFC | hybrid fiber-coax |
| kHz | kilohertz |
| KPI | key performance indicator |
| LTE | long term evolution |
| MHz | megahertz |
| MTTR | mean time to repair |
| NOS | [SCTE] Network Operations Subcommittee |
| NOS WG1 | [SCTE] Network Operations Subcommittee Working Group 1 |
| OFDM | orthogonal frequency division multiplexing |
| PNM | proactive network maintenance |
| QAM | quadrature amplitude modulation |
| QC | quality control |
| RF | radio frequency |
| RSSI | received signal strength indicator |
| SCTE | Society of Cable Telecommunications Engineers |

| | |
|---|---|
| SMATV | satellite master antenna television |
| UHF | ultra high frequency |
| VHF | very high frequency |
| $\lambda$ | wavelength |
| µV/m | microvolt per meter |

## 4.2. Definitions

**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 P1 and P2 in decibels is dB = 10log(P1/P2). The decibel also can be used to represent the ratio of two voltages under certain circumstances.[1]

**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.

**radio frequency (RF)** – That portion of the electromagnetic spectrum from a few kilohertz to just below the frequency of infrared light.

**radio resource control (RRC)** – The part of the LTE protocol that sends requests and receipts for data, and thus can indicate when packets are not received properly due to interference, for example.

**received signal strength indicator (RSSI)** – A measurement of the power present in a received radio signal (desired signal plus noise and interference) that is commonly used in Wi-Fi and in cellular telephony.

**signal leakage** – Unwanted emission of RF signals from a cable TV network into the 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.

**ultra high frequency (UHF)** – That portion of the electromagnetic spectrum from 300 MHz to 3000 MHz.

**very high frequency (VHF)** – That portion of the electromagnetic spectrum from 30 MHz to 300 MHz.

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[1] The decibel, while technically a ratio of two power levels, also can be used to represent the ratio of two voltage levels, 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 $dB = 10\log_{10}(P_1/P_2)$, the equation becomes $dB = 10\log_{10}[(E^2/R)/(E^2/R)]$ which is the same as $dB = 10\log_{10}[(E_1^2)/R_1)/(E_2^2/R_2)]$. In this example, R represents the 75 ohm impedance of a 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 $dB = 20\log_{10}(E_1/E_2)$.

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NETWORK OPERATIONS

# Dark Fiber Leases for Business Services: Threat or Opportunity

## A Breakeven Analysis

A Technical Paper Prepared for the
Society of Cable Telecommunications Engineers
By

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# 1. Introduction

## 1.1. Executive Summary

Business organizations are evolving to take advantage of new business models that leverage connectivity among colleagues and connectivity to the consumer for competitive advantage. This process is increasing bandwidth and connectivity requirements.

- Many connectivity options both wired and wireless are available and useful, but fiber optic cable offers the maximum capacity compared to all other alternatives. Therefore, most new installations are done with fiber, not copper. Even wireless networks including cellular, microwave and WiMAX use fiber optic backhaul networks for the wireline portion of their links.
- Local, regional and national governments across the globe are promoting the installation of fiber optic networks to improve economic vitality and the quality of life in their regions.
- In the private sector, new service provider business models are emerging that offer wavelength services and/or dark fiber leases. The success of these organizations is demonstrated by: 1) the size of their new networks, 2) the growth in their customer base and 3) the impressive stock market valuations they receive.
- Service providers are increasing the amount of bandwidth they offer for business and residential services. Quality of service (QoS)-assured 1gigabit per second (Gbps) service is common for business organizations. Best effort 1Gbps services are also becoming more common for residential Internet access.

In this paper, it is shown that the most cost-effective connectivity option for organizations with large bandwidth requirements is leasing dark fiber and using wavelength division multiplexing (WDM) to increase their bandwidth on-demand and subsequently as required. The financial analysis shows that in a scenario with four nodes in a metro region, each node connected with four wavelengths of 10 Gbps, the revenue breakeven point or simply ‘breakeven’ for dark fiber is about 24 months. Breakeven could be significantly shorter if more than four wavelengths are required during that period. We have seen examples where breakeven is even achieved in less than one year. Therefore, we conclude that dark fiber represents a competitive alternative to traditional lit service for the largest and rapidly growing enterprise customers that use connectivity as a competitive advantage in their business models.

# 2. The Importance of Connectivity

We have come a long way from Henry Ford’s famous quote in his autobiography, *My Life and Work*: "Any customer can have a car painted any colour that he wants, so long as it is black." The evolution of technology brings ever more choice and today we are faced with fantastic choices on every purchase from toothpaste to telecommunications.

Telecommunications options alone have progressed from telegraph and rotary phones to modems, computers, cell phones, and tablets. Data services now support endless personal and professional applications. Where we once spent a few minutes a day on the phone, we now spend many hours per day online. A recent study by the analyst firm RVA, LLC sponsored by the Fiber to the Home Council[1] finds 58 providers offering residential Internet service of 1 Gbps or more in the U.S. Users report spending more than five hours a day online at home, with an average of 5.5 connected devices.

A few examples demonstrate the trend:

- The state of New Hampshire spent $63 million to build 865 miles of fiber optic network that puts 12,000 (25%) of the state's business entities within 3 miles of a fiber backbone.
- In Illinois, the Governor recently approved a $100 million project to add 1,000 miles of new fiber optic cable to the state. This network connects with 750 miles of existing fiber thereby reaching 285,000 businesses with 400 anchor institutions and 24 community colleges.
- Besides governments, Google has been building public fiber networks in Kansas City, MO; Austin, TX; and Provo, UT. The company has plans to build similar networks in 34 other cities.
- Traditional service providers are growing their fiber networks as well. AT&T is building symmetrical gigabit access networks in Charlotte, N.C. and San Antonio, TX (which adds to their existing networks in Dallas and Fort Worth, Texas) and Nashville, TN, as well as in Raleigh, Durham, and Winston-Salem, North Carolina.
- Lumos is a new telecommunications provider with a 7,645 mile fiber network and a 665-mile expansion that soon will pass within ½ mile of 104,000 buildings. The fiber strands on each mile of their route varies from 46 strands up to 125. The network connects 673 fiber-to-the-cell sites, 15 data centers, and 1,420 on-net buildings.
- Even some wealthy individuals like Jim Barksdale, founder of NetScape, are getting into the fiber business. He created Spread Networks to build a 825-mile fiber connection from Chicago to NYC, just to shave a few milliseconds of one-way delay off an existing fiber link.
- And of course many cable operators such as Comcast, Cox, Suddenlink, Armstrong, and others are making fiber to the home (FTTH) over technologies such as radio frequency over glass (RFoG), gigabit passive optical network (GPON), Ethernet passive optical network (EPON), and point-to-point Ethernet or metro Ethernet, their preferred access network for new construction in greenfields.

The ATLANTIC-ACM U.S. Long Haul Wholesale Carrier Report Card[2] shows that 27 percent of the participating service provider wholesale buyers have recently purchased dark fiber. In addition, 57 percent of those buyers plan to increase spending on dark fiber in the coming year.

To serve the U.S. dark fiber market, new providers and construction firms have arisen including: Allied Fiber, FiberLight, Maine Fiber Company, Wilcon and Zayo among many others. Zayo's recent $5 billion initial public offering (IPO) is further evidence of ongoing demand. Another indication is that Level 3 made a $5.65 billion acquisition of TW Telecom. This acquisition adds 35,000 commercial buildings to Level 3's fiber network. The U.S. is not alone in developing fiber assets. As shown in Figure 1, the OECD (Organization of Economic Cooperation and Development) reports in 2012 through 2013 more than 20 developed countries grew their fiber assets faster than the US. All this activity tells us that 1) connectivity is important, and 2) fiber is fundamental to connectivity.

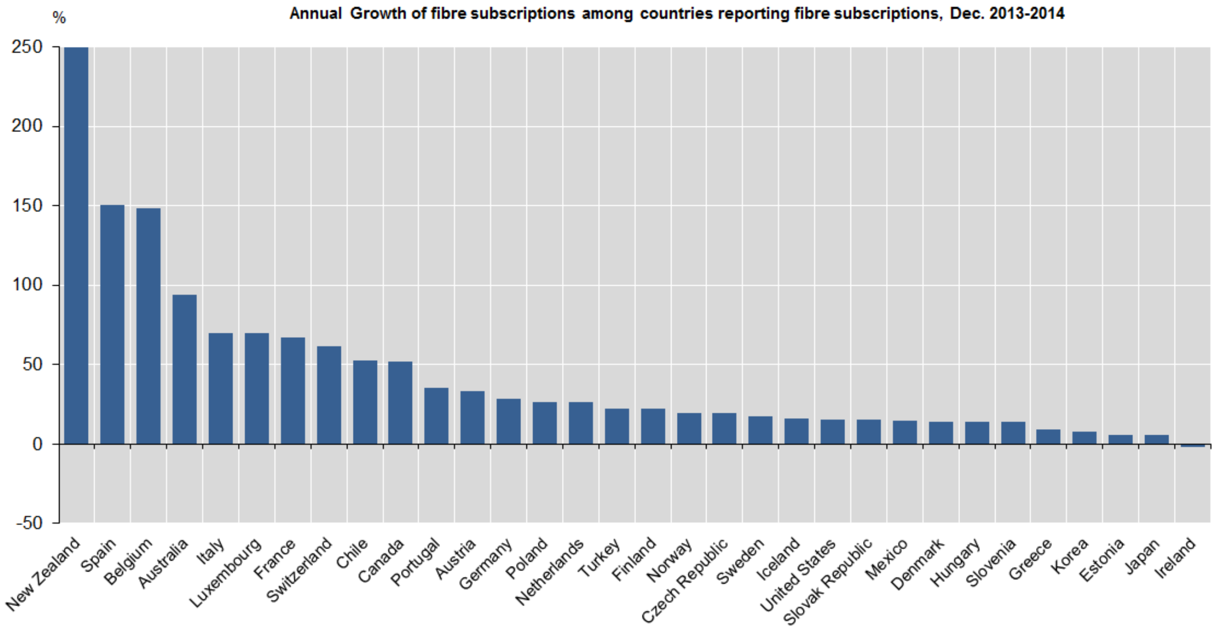


**Figure 1 - OECD Data 2014**[3]

Even though fiber is superior, connectivity is still delivered over a variety of media due to the high cost of upgrading legacy networks Each of these media are discussed briefly in this section as they compare to fiber.

## 3. Types of Physical Media

### 3.1. Copper

Copper has historically been the media of choice and unshielded twisted pair copper cabling has been around for over 100 years. Coaxial cable or twisted pair is still the most prevalent access network technology in most dense urban locations as well as being often the only access network option in rural locations, but the limits of copper-based access networks are being reached, especially in dense urban areas. In the case of both unshielded twisted pair and coaxial cable the solution for upgrading existing access networks is to push the fiber deeper towards the home while keeping the copper portion as the last mile access technology. Very high bit rate digital subscriber line (VHDSL) technology and DOCSIS 3.1 take advantage of pushing the fiber deeper by offering even higher bit loading and/or higher spectral utilization over the existing copper last mile access wires when the distance to the home is reduced.

### 3.2. Microwave

Microwave is another widely deployed connectivity media. It is ideal for point-to-point connections where it is physically impractical to construct a wired network. However, microwave networks can be costly, they are climate dependent, they require line-of-sight locations, and they do not deliver the bandwidth of fiber.

Microwave is subject to availability of spectrum in the location where it is to be used. The availability of spectrum is dependent upon governmental licensing which can permit or prohibit the use of microwave. All microwave signals are subject to interference from weather. Rain or any impediment to the line-of-sight required for a clean signal can temporarily reduce throughput.

### 3.3. Cellular

Cellular radio is another very important and rapidly growing connectivity media. It is the media of choice for mobile last-mile connections, but the bandwidth is limited by the radio spectrum, even with the spectral efficiency of long term evolution (LTE) and LTE-advanced cellular technologies, and because it is a shared media and spectrum is limited. Nevertheless, the way to increase the capacity of cellular networks is to increase the density of cellular base stations and that means more fiber must be used for the cell backhaul links to the network backbone. So, even wireless cell phone service is transmitted over fiber optic cable soon after it leaves the cell tower.

### 3.4. Fiber Optic Cable

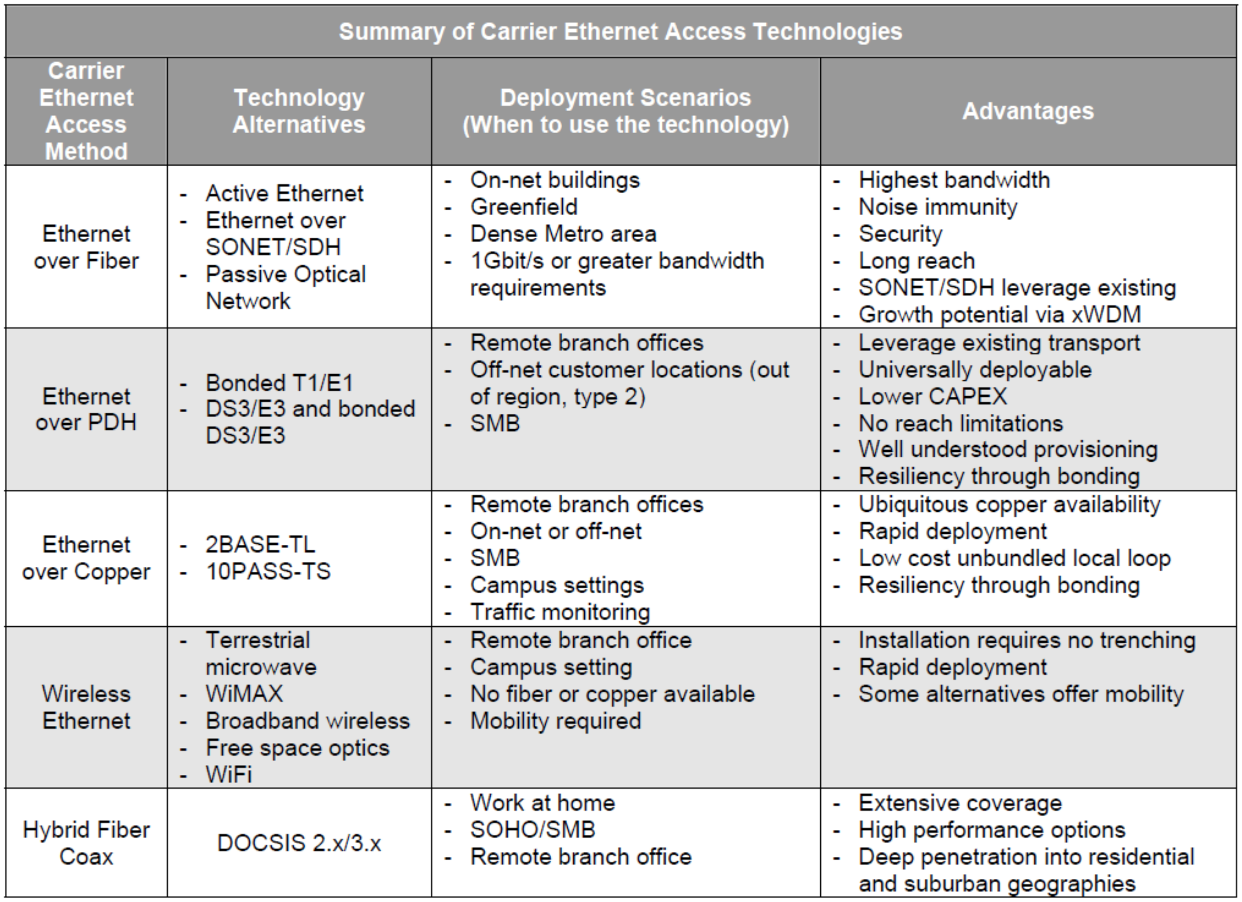
Fiber is the media of choice for most new network installations and increasing for greenfield access network deployments because 1) it has orders of magnitude greater capacity than alternative access network technologies, and 2) it is actually less expensive nowadays to deploy in new construction than the copper used in coax or twisted pair wire.

Fiber-optic cable is so suitable to new high-bandwidth requirements that technology has developed to make even greater use of the media. For example, wavelength division multiplexing (WDM) creates many virtual connections (using multiple wavelengths) within each fiber cable. These virtual connections can transmit at 100 Gbps data rates and more for thousands of miles with amplification. Insatiable demand for data, the cost effectiveness of fiber, and the much greater ultimate capacity of fiber are driving this revolution in fiber network construction.

Individual fiber optic networks intersect at strategic locations to create larger networks that are capable of connectivity to any other point on any other network. No matter who owns or uses them, optical networks use single modem fiber and WDM technology to interconnect. It is useful to think of them in categories: backbone networks, metro networks, and local networks. These distinctions have more to do with who owns and maintains the network than with differences in the fiber or connectivity equipment.

Table 1 summarizes the key features and characteristics of the main copper, fiber and wireless technologies used in access networks.

**Table 1 – MEF Access Technology[4]**



| Summary of Carrier Ethernet Access Technologies | | | |
|---|---|---|---|
| **Carrier Ethernet Access Method** | **Technology Alternatives** | **Deployment Scenarios (When to use the technology)** | **Advantages** |
| Ethernet over Fiber | - Active Ethernet<br>- Ethernet over SONET/SDH<br>- Passive Optical Network | - On-net buildings<br>- Greenfield<br>- Dense Metro area<br>- 1Gbit/s or greater bandwidth requirements | - Highest bandwidth<br>- Noise immunity<br>- Security<br>- Long reach<br>- SONET/SDH leverage existing<br>- Growth potential via xWDM |
| Ethernet over PDH | - Bonded T1/E1<br>- DS3/E3 and bonded DS3/E3 | - Remote branch offices<br>- Off-net customer locations (out of region, type 2)<br>- SMB | - Leverage existing transport<br>- Universally deployable<br>- Lower CAPEX<br>- No reach limitations<br>- Well understood provisioning<br>- Resiliency through bonding |
| Ethernet over Copper | - 2BASE-TL<br>- 10PASS-TS | - Remote branch offices<br>- On-net or off-net<br>- SMB<br>- Campus settings<br>- Traffic monitoring | - Ubiquitous copper availability<br>- Rapid deployment<br>- Low cost unbundled local loop<br>- Resiliency through bonding |
| Wireless Ethernet | - Terrestrial microwave<br>- WiMAX<br>- Broadband wireless<br>- Free space optics<br>- WiFi | - Remote branch office<br>- Campus setting<br>- No fiber or copper available<br>- Mobility required | - Installation requires no trenching<br>- Rapid deployment<br>- Some alternatives offer mobility |
| Hybrid Fiber Coax | DOCSIS 2.x/3.x | - Work at home<br>- SOHO/SMB<br>- Remote branch office | - Extensive coverage<br>- High performance options<br>- Deep penetration into residential and suburban geographies |

### 3.4.1. National Fiber Backbone Networks

Continent-wide fiber backbones are operated by service providers, a few large content delivery networks, and some governmental agencies. These networks use single mode fiber cables with hundreds of strands per cable and optical amplification. They are designed to transmit data over long distances with fewer data entry and exit locations. Access points are at transoceanic landing points, or in major metropolitan areas that service many customers. The cost of building transcontinental networks makes them scarce. Metro networks, service providers, and organizations of all types and sizes use these long-haul backbone networks to interconnect between regions.

### 3.4.2. Metro Fiber Networks

Creation of the national fiber backbones was the focus of over-investment, prior to the tech bubble bursting in 2000. More than a decade and a half later, the market has caught up to the investment. Backbone and metro network routes are now in hot demand and short supply in some markets, which is fueling the construction of regional and metro fiber routes. Millions of homes and perhaps 25% of US urban office spaces are located within a few miles of a fiber network. These fiber installations are being built by a diverse set of organizations including: public companies, telecommunications service providers such as telcos, cable operators and Internet companies such as Google, city governments, and even real estate investment trusts (REITs). Also built with single-mode fiber, they may use amplification if greater link distance is required. Compared to national fiber backbones, they are designed with many more access points for connections to local customers.

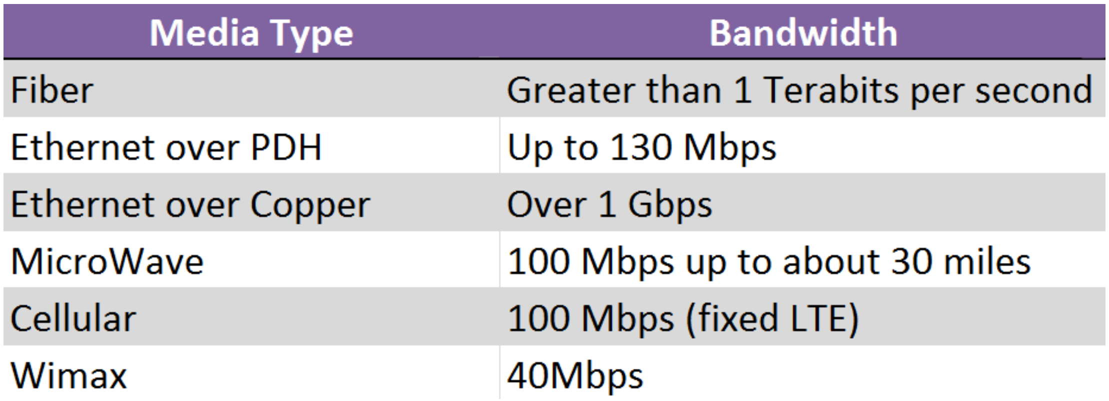
These new metro fiber networks are the basis for an emerging connectivity market in dark fiber. When fiber networks are nearby, organizations can more easily connect to it for lower costs and higher bandwidth. The metro fiber network connection can be easy, fast, and relatively inexpensive, if a building already has a fiber network connection or is in close proximity to the access point. If it is close, a fiber spur must be built from the existing fiber splicing point to the new location. Fiber is often run along the utility easements, streets, and highways. Fiber construction costs can range from less than $2,000 per mile to more than $50,000 per mile, depending on the urban density and right-of-way issues involved. These costs may be paid directly by the user, or amortized over time by obtaining an indefeasible fight-to-use (IRU) to lease the fiber from the network builders or owners. If the fiber is older and already amortized, the construction fees may not exist, leaving only the leasing fees to pay. These dark fiber assets are more widely available now than ever and new construction continues at a rapid pace.

## 4. Comparison of Bandwidth by Physical Media

Organizations typically procure their first wide area network (WAN) connectivity with services through a traditional telecommunications service provider. Service providers have the expertise and infrastructure to connect subscribers in their service area over a variety of physical media, with a selection of data rates and plans from the legacy asynchronous transfer mode (ATM) or frame relay services to newer carrier Ethernet with connections provided at layer 2 (L2) or layer 3 (L3). This connectivity has been sufficient for most network requirements, but they are increasingly inadequate for leading high-growth organizations leveraging their business models with connectivity in an always-on, rich media driven world.

Table 2 compares the bandwidth from the typical service types available in most worldwide markets.

**Table 2 - Bandwidth Capacity by Media Type**



| Media Type | Bandwidth |
|---|---|
| Fiber | Greater than 1 Terabits per second |
| Ethernet over PDH | Up to 130 Mbps |
| Ethernet over Copper | Over 1 Gbps |
| MicroWave | 100 Mbps up to about 30 miles |
| Cellular | 100 Mbps (fixed LTE) |
| Wimax | 40Mbps |

## 5. The Proliferation of Connectivity Options

The incentive to build a WDM network instead of buying a lit service or a wavelength service is driven by a number of factors including: higher bandwidth demands, the requirement for lower cost, the need for control, network flexibility requirements, and the need for security. Typically, the demand for greater bandwidth creates the need for more fiber links. Along with the proliferation of devices that consume bandwidth and increasing number of wired and wireless methods of accessing bandwidth, there is a commensurate increase in the numbers and types of service providers. To fill this need, new service provider business models are evolving. In addition to traditional telecommunications service providers, there are companies that sell or lease dark fiber; others offer co-location facilities for servers and storage; others offer the ability to interconnect many networks, and yet others offer only applications and services. This expanding service provider environment, along with increasing fiber accessibility, enables organizations large and small to build their own networks.

## 6. Considerations for Dark Fiber vs. Wavelength Services

Organizations that are in fiber connected buildings or in buildings that could connect to the fiber network often consider the following factors in their analysis.

### 6.1. Bandwidth requirements

As a rule of thumb dark fiber leasing may provide benefits over lit services when network bandwidth requirements exceed approximately 4 Gbps as we will see in subsequent analysis.

### 6.2. Bandwidth growth requirements

Dark fiber could yield a quick return on investment for networks with rapidly growing bandwidth requirements. If you expect to continually upgrade bandwidth then the case for dark fiber becomes compelling. Many leading organizations are leveraging connectivity in their business models. The bandwidth and speed offered by fiber connectivity create new business models and yield competitive advantage. This can be illustrated by the download times offered by the access media described in Figure 2 that shows the time required to download a 5 gigabyte (GB) file over fiber compared to various copper and wireless media.

### 6.3. Length of time the service is needed

The case for dark fiber becomes more compelling over longer service contracts. If an organization has at least a five-year time horizon, it is likely that dark fiber will save on network costs.

### 6.4. Additional monthly fees

Moving to dark fiber could reduce costs in additional ways. Many lit services require cross-connect fees to interconnect locations required by the organization. These fees can go up unpredictably after the initial contract period expires. Corporate finance departments dislike unknown future costs and value the fixed cost structure of dark fiber. Reliance upon lit services creates unknown future liabilities due to growing bandwidth demand and inevitable price increases. Dark fiber connections directly between locations may reduce or eliminate these additional recurring fees. See Figure 2.

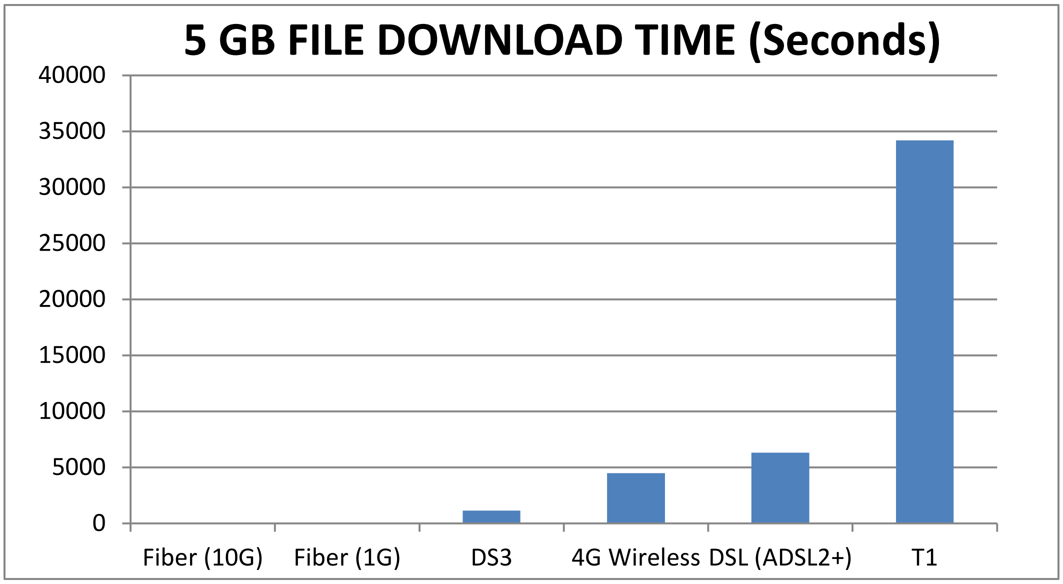


**Figure 2 – Time to Download a 5 GB file**

## 6.5. The Cost of Wavelength Services

Pricing carrier Ethernet services involves many variables including how many service providers are involved in creating the service, the number of locations, virtual private network (VPN) type, quality of service parameters, resilience and many other factors. Pricing carrier Ethernet services varies from one scenario to the next, and between service providers. Pricing for complex products or services like these is not often widely published but we can develop an idea of pricing ranges for various service bandwidths from recent announcements and public statements. Gigabit services over fiber are now marketed to both business and residential markets. A number of service providers have recently announced 1 Gbps residential Internet service.

- When announcing their Austin, TX service, AT&T indicated a price of $95 per month for a 1 Gbps service with a terabyte (TB) cap and an additional $10 for every 50 Gbps above the cap, up to a maximum of $30 additional monthly.
- At the other end of the spectrum in Maine, local service provider GWI offers a 100 megabits per second (Mbps) service for $69 a month, which competes with Time Warner Cable in Maine that offers a 50 Mbps for about the same monthly cost per Mbps.
- Birch Communications addresses a similar market with an asymmetrical service with 24 Mbps downstream and 3 Mbps upstream for $119 per month. These prices are not used in the break-even analysis shown below because they normally do not offer QoS guarantees or other features required by businesses. They are typically residential best effort services.
- In the metropolitan commercial market where service guarantees are required, Global Capacity recently announced a 100 Mbps service for $1,000. However, the cost per bit drops substantially for larger bandwidth contracts. They also offer a 200 Mbps service for $1,200, which doubles the bandwidth for only 20% additional cost.

Surveys conducted at the GEN14 event presented by the MEF in November 2014[5] offered additional insight into service pricing from Allstream, Cox, XO Communications, and other service providers.

The cost for a 1 Gbps service between data centers in a metro area with existing fiber and multiple competing dark fiber providers was estimated at $800 to $1,500 per month. The same 1 Gbps service from a data center to a subscriber building in the same metro area would range from $1,500 to $2,500 per month.

A 10 Gbps service between data centers in a metro area, again, with existing fiber and some degree of competition among dark fiber providers would range from about $4,000 to $6,000 per month. The same 10 Gbps service from the data center to a subscriber location in the metro area would be in the range of $6,000 to $8,000 per month.

These figures suggest that the price for business services ranged approximately from a low of $0.70 per Mbps per month for 10 Gbps service to a high of $10.00 per Mbps per month for 100 Mbps service. This equates to about $7000 per month for 10 Gbps and $1000 per month for 100 Mbps service. Besides bandwidth, two other important factors affect price: the QoS guarantees associated with the service, and the number of competing service providers on the link. Our pricing analysis assumes business services offer QoS guarantees and are priced as such.

## 6.6. Cost of Dark Fiber IRUs

The cost for acquiring dark fiber varies building by building, state by state, country by country, and among markets and providers. Pricing depends on the route and the location, and is sometimes a function of the financial structure of the provider. Dark fiber pricing is dependent upon market competition, customer demand, and the cost of fiber construction in that area.

Construction of metro fiber is usually more expensive per mile than long haul fiber. Building urban links are often higher in cost on a per-linear-foot basis than costs for rural or suburban links because of the significant structural impediments to running fiber in dense urban areas. However, in some metro areas there is better inventory of installed fiber on popular metro links, and such competition can reduce metro fiber.

Dark fiber costs are typically divided into upfront fees and monthly fees. The content of those fees depends on the fiber provider. Upfront fees are more frequently associated with network construction costs and monthly fees are often associated with maintenance. However, the composition of these fees varies depending on the provider of the dark fiber IRU.

Upfront fees for a 20-year IRU for dark fiber may range from approximately $2,000 per mile per strand to more than $50,000 per mile per strand. The variance depends on the complexity of the fiber build in question and the access to right-of-way. These numbers equate to $15 to $275 per month per mile, if the terms require a monthly payment and not an initial lump sum payment. If the cost of the construction is amortized into the fiber, then the price can range can from $350 to $6,000 per strand per month, depending on the length of the lease and the construction costs[6]. Many dark fiber leases do not require fees to cover construction if the fiber build costs have been amortized in other ways. For our analysis we used a cost of $7000 annually for a strand of dark fiber on a 5 year IRU.

Burbank Water and Power[7] is a municipality that leases existing dark fiber to organizations within their city boundaries to promote local and regional business development. Their charges are based on the link distance and the length of the contract. To lease from one to six fibers on a 5-year IRU, the cost is $175 per month per fiber. The price decreases on a 15-year lease to $135 per month per fiber.

Other charges for metro fiber from various utility and government organizations with existing fiber show per-month, per-strand charges of approximately $300 for 1 to 10 miles, $180 for 11 to 20 miles, and $120 for 21 to 30 miles.

For construction of new fiber in 2013, a leading dark fiber construction and leasing firm, Allied Fiber[8], indicated charges of approximately $759 per fiber mile on a 20-year IRU. So the cost for dark fiber varies depending on the location, the supplier and the distance. Next we will consider the bandwidth capacity of the dark fiber.

## 7. Capabilities of the WDM Equipment

Dark fiber has the capacity to transmit terabits of data.  In order to access this capacity, WDM equipment is required at each location. A point-to-point link requires a pair of devices, one at each end, with a pair of dark fiber strands connecting them and for longer distances optical amplification may be required. One chassis of WDM equipment can provide up to 196 channels at 10 Gbps each with current standard technology and 100 Gbps links are becoming more common, although one chassis full of 100 Gbps links would be significantly lower density. For our analysis we use the more common 10 Gbps WDM specifications to determine dark fiber and equipment costs for the breakeven analysis. All wavelengths will be assumed to pass through each location, and they can be added or dropped at each location as necessary.

For this analysis the model network proposes four buildings connected in a metro ring as shown in Figure 3 with four wavelengths of 10 Gbps each between each of the four buildings. They connect in a ring architecture with a 5-mile link distance between each building. The WDM equipment can monitor and diagnose service performance on each wavelength for each link.

We use $250,000 for the cost of the WDM network for this scenario. This estimate is conservative for the WDM equipment needed to create the network over dark fiber and it could likely be done for less. There is one significant difference between the services we compare in this scenario. We calculate connecting the buildings with 4 x 10 Gbps WDM over dark fiber and the lit service pricing is for 4 x 1G between the buildings.  So the dark fiber and WDM scenario provides ten times the bandwidth from day one.  If we compared 10 Gbps WDM over dark fiber to 10 Gbps lit service the breakeven would be even faster. See Figure 3.

Figure 3 – Four Node WDM Ring with Four 10 Gbps Links Each

The red line in Figure 4 uses a cost of $20,000 per link per year for each of the four links for an annual total of $80,000 for the dark fiber IRU. It also includes the $250,000 one-time charge for the WDM equipment required for these connections. The blue line shows the cost of the 1 Gbps lit service estimated at $1,125 per month, with four services between each of the four buildings over the same 10-year period.

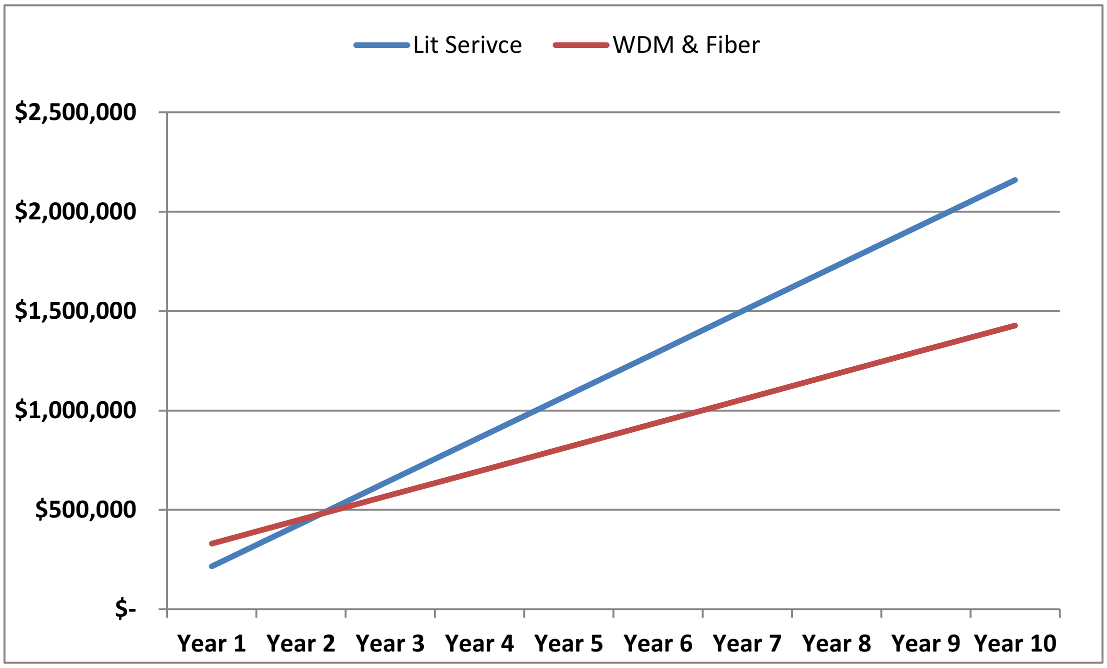


Figure 4 – Breakeven Time for WDM Savings

This analysis shows that breakeven for our scenario to four buildings connected in a redundant ring is less than two years for dark fiber versus subscribing to lit services. In addition to offering 10 times more bandwidth than the lit service in this configuration, the dark fiber approach also offers savings of more than $732,000 over a 10-year time horizon.

## 8. Conclusions

Physics and technology make fiber connectivity the best media for high bandwidth future oriented telecommunications. The financial markets are supporting organizations that build and lease dark fiber, which indicates a successful and growing market for these companies. Organizations that require more than approximately 4-6 Gbps between multiple metro locations have the opportunity reduce costs by switching from purchasing lit services and moving to dark fiber with WDM equipment. Our analysis shows that breakeven can be less than 24 months and therefore over a 5-10 year time horizon significant savings can accrue to organizations that make the switch to dark fiber. Therefore, service providers that have very high bandwidth metro enterprise customers should understand in which metro markets dark fiber IRUs could be a competitive threat to their existing or prospective customer base.

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# Fiber Backhaul and Demarcation for Wi-Fi Access Points and Small Cells

A Technical Paper Prepared for the
Society of Cable Telecommunications Engineers
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# 1. Introduction

## 1.1. Executive Summary

Cable operators are deploying carrier Wi-Fi and small cells as part of the mobile network operator (MNO) heterogeneous network (HetNet) strategy to complement macro cell towers to meet the growing bandwidth demands of smart phones and tablets.

Cable operators are generating revenue by providing hosted small cell services for MNOs, as they can address all three legs of the small cell deployment stool, which include site acquisition (starting with aerial plant), power, and backhaul. These hosted small services provide fourth generation/long term evolution (4G/LTE) wireless coverage in high usage areas within cell tower coverage (“Hotspot”) and in areas outside of the cell tower coverage (“Notspot”), as illustrated in Figure 1.

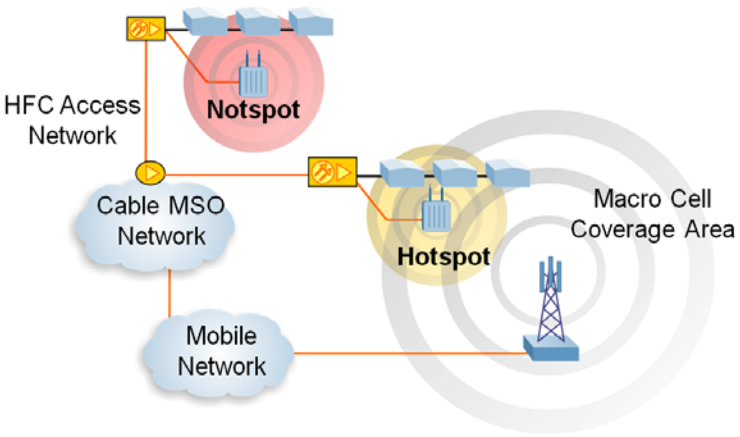


**Figure 1 – Example of cable operator HetNet backaul services**

In addition, cable operators are deploying millions of Wi-Fi access points (AP) as a cost-effective method to offload data and video traffic from third generation (3G) and 4G networks, as well as to offer subscribers value added services or premium content services. The recent advances in Wi-Fi technology augment the deployment of 4G/LTE services using cost-efficient wireless access points in unlicensed spectrum.

Both carrier Wi-Fi and small cells require carrier Ethernet backhaul circuits with demarcation devices, and the cable operator fiber plant provides the backhaul connectivity. This paper reviews the challenges cable operators face when providing backhaul services to MNOs, and how fiber optic demarcation devices can provide solutions to deliver service level agreements (SLA), reduce wireless backhaul operating costs, and reduce capital expenditures when deploying small cells and Wi-Fi APs in a variety of network topologies.

## 1.2. Scope

This paper reviews challenges and solutions for cable operators deploying small cells and Wi-Fi APs that are specifically related to carrier Ethernet demarcation for backhaul services.

## 1.3. Background

### *1.3.1. Carrier Wi-Fi*

According to Cisco's Visual Networking Index, the escalating number of Wi-Fi deployments will reach 53 million Wi-Fi hotspots globally by 2018. The report also predicts that this will lead to more data traffic being delivered over Wi-Fi networks than wired networks by 2018, noting that both cable companies and wireless carriers are extending their reach by employing Wi-Fi hotspot strategies. Juniper Research predicts that 60% of mobile data traffic will run over Wi-Fi by 2019, compared to just over 50 percent estimated in 2014.

Wireless carriers are embracing Wi-Fi. Sprint and T-Mobile have launched Wi-Fi calling, and AT&T and Verizon have announced availability of Wi-Fi calling by the end of 2015, according to a Fierce Wireless special report.

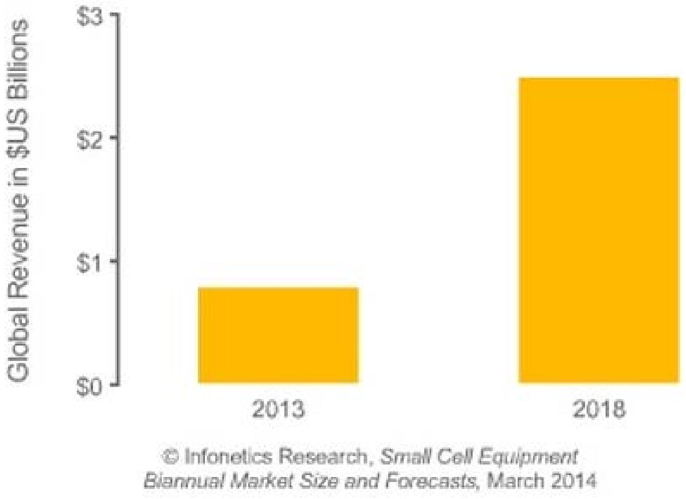
Cable operators and MNOs are leveraging advances in Wi-Fi technology such as Hotspot 2.0, next generation hotspot (NGH), and 802.11ac that enables 4G/LTE services with roaming capabilities.

Cable operators are collaborating to provide ubiquitous carrier Wi-Fi coverage to provide value added services and reduce churn. Cable WiFi® is the wireless network collaboration of Bright House Networks, Cox Communications, Optimum, Time Warner Cable and XFINITY that allows subscribers access to 400,000 Wi-Fi hotspots nationally. In April this year Time Warner Cable rolled out "TWCWiFi Passpoint," a national Wi-Fi network. The company considers Hotspot 2.0 Wi-Fi APs as complementary to a cellular contract, but not likely as a replacement.

*Light Reading* estimates that cable operators in the United States and Canada have already deployed 10 million carrier Wi-Fi hotspots, and millions more on the way.

### *1.3.2. Small Cells*

Deployment of small cell hosted sites by cable operators and MNOs will grow dramatically in the coming years. Infonetics Research forecasts the small cell market to grow from a very small base to $2.8 billion by 2018, as illustrated in Figure 2:



© Infonetics Research, *Small Cell Equipment Biannual Market Size and Forecasts*, March 2014

**Figure 2 – Small Cell Global Revenue Forecast from Infonetics**

Small cells are converging with Wi-Fi, and the research firm Mobile Experts projects that 70% of small cells will have integrated Wi-Fi by 2017, as illustrated in Figure 3.

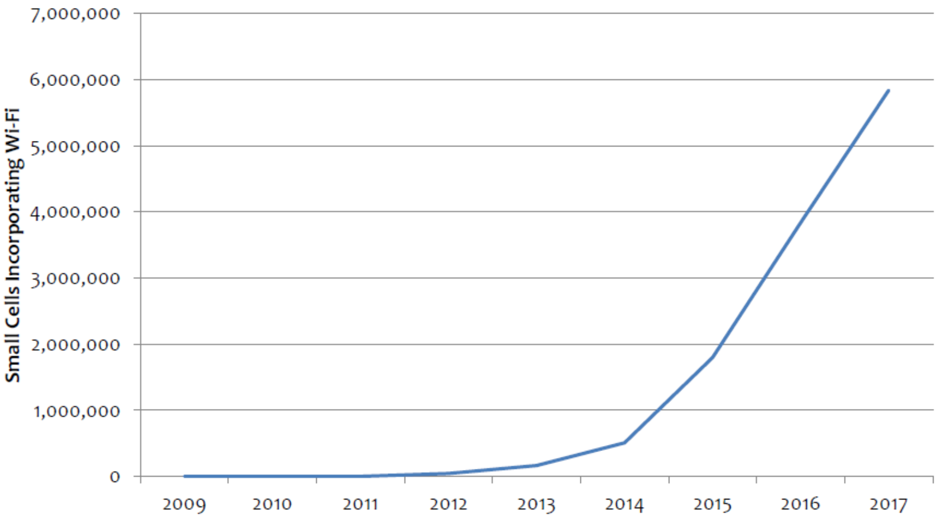


**Figure 3 – Small Cell and Wi-Fi Convergence**

A comparison of Wi-Fi APs and small cells is shown in Table 1.

Table 1 – Comparison of Wi-Fi and Small Cells

| Characteristic | Wi-Fi | Femtocell | Pico/Metrocell |
|---|---|---|---|
| Maximum Power Output | <100 mW | <250 mW | <250 mW - <5 W |
| Maximum Simultaneous Users | 4-8 | 4-8 | 4-64 |
| Licensed Spectrum | No | Yes | Yes |
| Maximum Range | 50 m – 100 m | 50 m – 100 m | 750 m |

### 1.3.3. Carrier Ethernet Backhaul – The Protocol of Choice

The simplicity, ubiquity and low cost of Ethernet have driven global network adoption, including mobile backhaul. Ethernet is a well-understood technology, and offers comprehensive operations, administration and maintenance (OAM) tools to ensure backhaul services meet or exceed SLAs.

The Metro Ethernet Forum and carrier Ethernet 2.0 certification makes Ethernet the protocol of choice for mobile backhaul services.

### 1.3.4. Carrier Ethernet Demarcation

The carrier Ethernet demarcation device is commonly referred to as a network interface device (NID). It is also called an Ethernet demarcation device (EDD), an Ethernet access device (EAD), and as an Ethernet demarcation device (DEMARC).

The NID is required in carrier Ethernet services, and provides a user to network interface (UNI) that manages one or more "flows" of traffic. The NID provides rate-limiting, traffic classification, and forwards the traffic to another UNI over an Ethernet virtual connection (EVC).

There are a variety of NID devices available on the market that support different functionality, feature sets, and form factors.

## 2. Hetnet Deployment Challenges and Solutions

Fiber backhaul and carrier Ethernet demarcation provide long distance connectivity, quality of experience (QoE) and low-latency data traffic, but there are still physical challenges with installations, providing service level agreements, and keeping operating costs under control. Table 2 lists these challenges that will be reviewed in detail in the following sections.

**Table 2 – HetNet Backhaul Services: Challenges and Solutions**

| HetNet Backhaul Service Challenge | NID Solution |
|---|---|
| SLAs for backhaul services | Carrier Ethernet 2.0 Certified demarcation, TWAMP, and protection switching |
| Diverse network topologies: Active Ethernet, HFC, WDM, EPON/DPoE | NID with pluggable transceivers support all topologies and streamlines inventory |
| Reduce OPEX | NID supports automated provisioning, testing and DOCSIS |
| Power: PoE, AC, DC | NIDs with 60 W PoE and AC/DC power |
| Timing Synchronization | NID with Sync-E & 1588v2 |
| Temperature & Small Enclosures | Hardened compact NID |
| **Wi-Fi Specific Challenges:** Lower CAPEX and 802.11ac backhaul bandwidth | Low-cost NIDs with upgrade path and high-bandwidth backhaul |

### 2.1. Providing Backhaul Service Level Agreements

### *2.1.1. SLAs for Carrier Ethernet 2.0 Multi-CoS*

The Metro Ethernet Forum (MEF) announced carrier Ethernet 2.0 as the next generation in the evolution of Ethernet services. This next generation is defined as “networks and services that enable multiple classes of service and manageability over interconnected provider networks”.

The carrier Ethernet 2.0 multiple classes of service (Multi-CoS) enables services within an EVC to be differentiated, prioritized and assigned unique bandwidth profiles (rate limiting). The MEF further defines Multi-CoS as standardized classes of service that are associated with MEF-defined performance objectives and performance tiers.

The MEF 23.1 specification introduced the industry’s first standardized Multi-CoS performance objectives (MPOs) with new metrics for specific applications, including mobile backhaul. In addition to the International Telecommunication Union (ITU) Y.1731 performance metrics of frame delay (latency), inter-frame delay variation (jitter) and frame loss ratio; MEF 23.1 adds mean frame delay and frame loss range. These MPOs are defined to enable precise SLA metrics for application-specific delivery.

In Figure 4, a 4G/LTE backhaul service is transported over EVC 100 with four classes of service (CoS). Each class of service flow is differentiated with a priority and bandwidth profile for a backhaul service, with ITU-T Y.1731 performance monitoring (PM) and 802.1ag connectivity fault management (CFM) per CoS, as described below and illustrated in Figure 4.

- CoS 7 is for synchronization data, which has the lowest data rate, or committed information rate (CIR), but the highest CoS priority because it requires the lowest possible latency.
- CoS 5 is for voice data, which has a lower data rate, or committed information rate (CIR), but a higher CoS priority because it requires low latency for voice quality.
- CoS 3 is for video data, which requires a higher CIR for streaming video and a higher CoS priority because latency and dropped frames can impact video quality.
- CoS 1 is for web and background email data. This has a high CIR and low priority.

The CE 2.0 certified compliant NID enables Multi-CoS SLAs within a service Figure 4, and flows to different devices can be assigned to the appropriate ports. The NID supports Y.1731 performance monitoring, that monitors delay, delay variation, frame loss, mean frame delay and frame loss range for each CoS to enable value added services with SLA assurance.

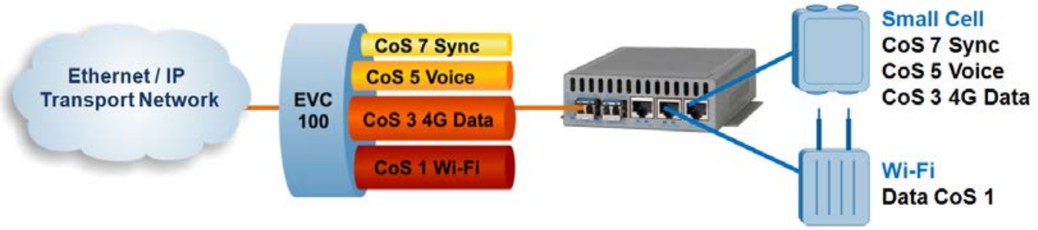


**Figure 4 – Carrier Ethernet 2.0 Multi-CoS Performance Monitoring**

The CE 2.0 certified compliant NID also supports the Institute of Electrical and Electronics Engineers (IEEE) 802.1ag connectivity fault management and 802.3ah link OAM standards. 802.3ah link OAM with dying gasp monitors the access link to the small cell or wireless AP, and sends out a fault notification just before a loss of power in a demarcation device failure. 802.1ag proactively monitors the service and isolates faults.

802.1ag CFM is the foundation for service OAM. 802.1ag is referred to as connectivity fault management because it has the capability to proactively monitor and provide fault detection of the entire EVC. 802.1ag fault monitoring functions across all domains and maintenance associations. The tools used by 802.1ag are:

- Continuity check message (CCM) to monitor service availability
- Loopback to confirm service faults
- Linktrace to isolate service faults

cable operators can use 802.1ag to monitor for faults from UNI to UNI, while each operator along the service path can monitor for faults across their service responsibility from external network to network interface (ENNI) to ENNI or from an ENNI to a UNI.

Connectivity fault management improves customer satisfaction with rapid service restoration, and reduces costs associated with truck rolls.

### 2.1.2. TWAMP for Layer 3 and Layer 4 networks

The IETF two-way active measurement protocol (TWAMP) defines a standard for measuring layer 3 and layer 4 round-trip two-way network performance metrics between any two devices that support the TWAMP protocols. NIDs that support TWAMP deliver a flexible method for accurately measuring performance between two end-point devices, regardless of device type or vendor. The TWAMP-control protocol is used to set up performance measurement sessions, and to send and receive performance-measurement probes.

The TWAMP architecture is composed of the following four logical entities that are responsible for starting a monitoring session and exchanging packets:

- The control-client sets up, starts, and stops TWAMP-test sessions.
- The session-sender instantiates TWAMP-test packets that are sent to the session-reflector.
- The session-reflector reflects a measurement packet upon receiving a TWAMP-test packet.
- The TWAMP server manages one or more TWAMP-test sessions and configures per-session end points ports. The session-reflector and server make up the TWAMP responder in IP SLAs.

Although TWAMP defines the different entities for flexibility, it also allows for logical merging of the roles on a single device for ease of implementation. Figure 5 depicts the TWAMP architecture.

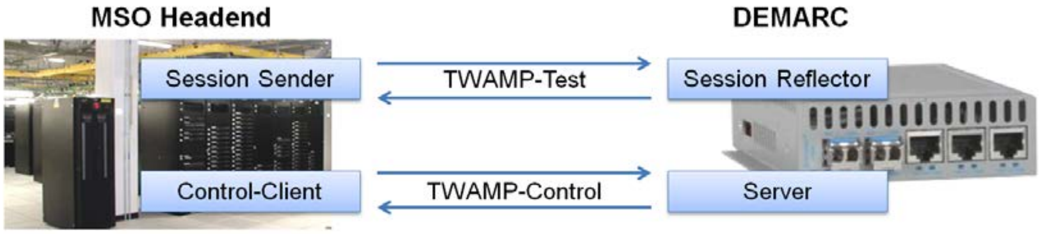


**Figure 5 – TWAMP Test and Control**

TWAMP protocol has two different modes, TWAMP full and TWAMP lite. The TWAMP full mode works in a client-server relationship. TWAMP lite works similar to TWAMP full except the TWAMP-Control protocol is eliminated and the session-sender, control-client and server are combined into one controller node. The session-reflector node performs the responder functionality.

TWAMP enables testing of both periodic and continuous traffic. The continuous traffic test injects test traffic evenly at user-defined intervals and enables a more granular and uniform measurement of performance compared to the periodic test method. Some NIDs provide a complete solution for service delivery and service assurance using the TWAMP extended capabilities:

- Y.1564 service activation and RFC2544 for trouble shooting using TWAMP encapsulation, eliminating truck rolls.

- In SLA Management, TWAMP lite and full modes perform SLA testing to any endpoint in the network.

### *2.1.3. SFP Demarcation for Active Ethernet and HFC*

The SFP NID is a small form-factor pluggable (SFP) gigabit optical NID that enables cable operators to deliver low-latency, SLA-guaranteed backhaul services.

The SFP NID can be installed directly into a small cell, and saves capital expenditures (CAPEX) by eliminating the need for a standalone demarcation device, as illustrated in Figure 6. It also reduces operating expenditures by decreasing power consumption, space, installation and maintenance costs.

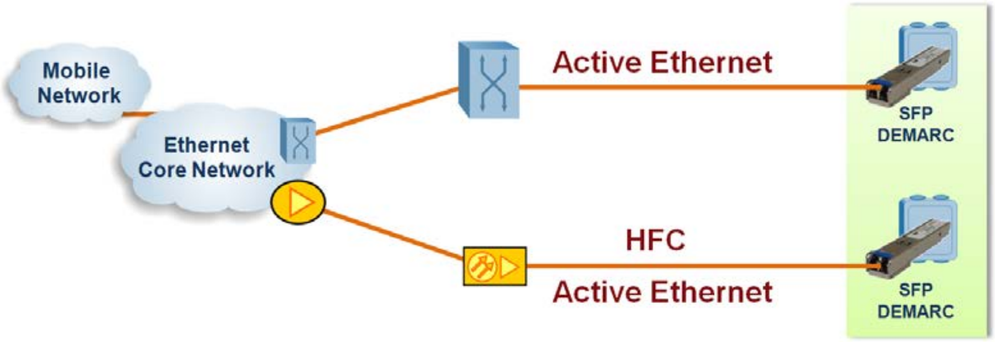


**Figure 6 – SFP NID Demarcation for Active Ethernet and HFC Networks**

The SFP NID supports ITU-T Y.1731 performance monitoring and IEEE 802.1ag connectivity fault management. When the SFP NID is plugged into existing network equipment, these features enable low-cost monitoring of carrier Ethernet functionality, operation and performance.

Integrated ITU-T Y.1564 and RFC 2544 test heads provide multi-flow service activation testing (SAT) of throughput, latency, jitter and frame loss at full wire speed. Service testing is reviewed in section 3.3.

There are some SFP NIDs that also support 1588v2 and synchronous Ethernet (Sync-E) for backhaul timing synchronization. Synchronous timing is reviewed in section 2.5.

## 2.2. Unified Demarcation for Diverse Network Topologies

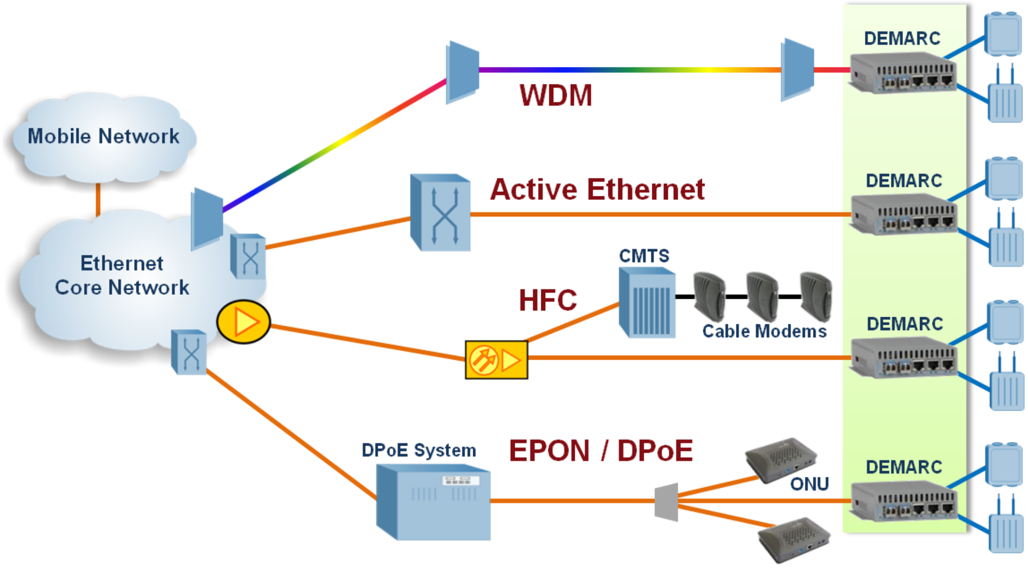


Figure 7 – Unified Demarcation for Diverse Network Topologies

Cable operators operate several disparate network topologies, including coarse and dense wavelength division multiplexing (CWDM or DWDM), active Ethernet, hybrid fiber-coax (HFC), and EPON/DPoE networks, as illustrated in Figure 7. The ability to deploy a single NID device across all these network topologies simplifies deployments and streamlines equipment inventories. By installing different types of SFP transceivers, the NID can be installed in active and passive networks, and support data rates from 10 megabits per second (Mbps) to 10 gigabits per second (Gbps).

### *2.2.1. WDM Demarcation*

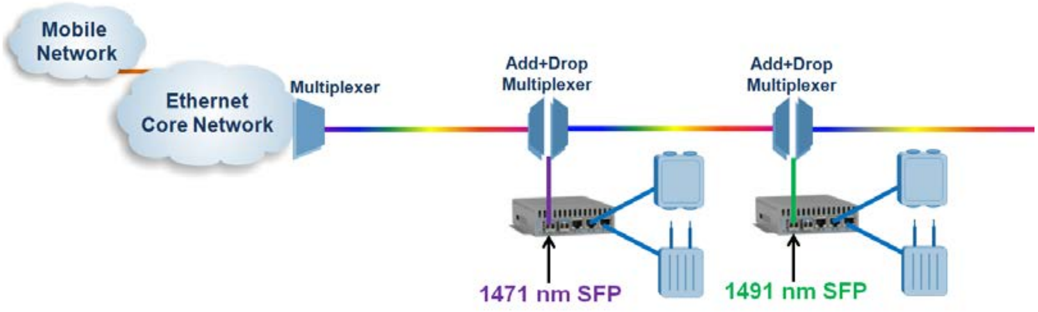


Figure 8 – Demarcation for WDM Networks

WDM access networks utilize several wavelengths transported over fiber, and are deployed where multiple fiber links are not available. There are a variety of WDM topologies deployed by cable operators to preserve fiber infrastructure. Figure 8 shows a CWDM multiplexer installed at the head of a single-mode fiber run to insert up to 16 wavelengths. Each wavelength transports a backhaul EVC. Add+drop multiplexers are installed at small cell/Wi-Fi locations along the CWDM fiber run to filter out (drop) one wavelength and transparently pass the other wavelengths to other locations. At each location, a NID is installed with a CWDM SFP that matches the wavelength being dropped off by the add+drop multiplexer. One or two wavelengths can be dropped off at each location, and the longer wavelengths (numerically higher nanometer [nm] value) are used for the longer distances on the fiber run.

### *2.2.2. Active Ethernet Demarcation and Protection Switching*

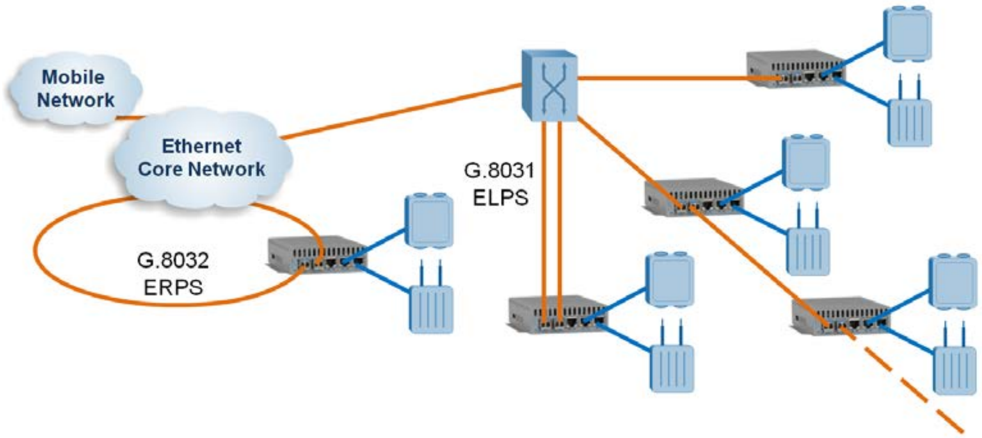


**Figure 9 – NID Deployments in a Variety of Ethernet Topologies**

Active Ethernet NIDs are the most commonly deployed demarcation devices due to the ubiquity of active fiber networks. NIDs that support dual SFP fiber ports can be deployed in a variety of active Ethernet network topologies, including rings, redundant links, and daisy chains, as illustrated in Figure 9. In point-to-point fiber access links only one SFP is installed in the NID.

NIDs with dual fiber ports deployed in daisy chain configurations is similar to the WDM add+drop architecture. Instead of segregating traffic with WDM wavelengths, EVCs are segregated with Ethernet service multiplexing for Ethernet virtual private lines (EVPL) and Ethernet private LANs (EVP-LAN), in which multiple services are aggregated from a single user-to-network interface (UNI) to multiple UNIs. Each service is distinguished from the others by using 802.1q VLAN tag identification. Since the access links share bandwidth of the small cell/Wi-Fi sites, the total aggregate bandwidth of the antennas cannot exceed the bandwidth of the access link.

NIDs installed on fiber rings that support ITU-T G.8032v2 Ethernet ring protection switching (ERPS) provide resiliency to protect network services, and multiple EVCs. G.8032 ERPS supports complex ring architectures with multi-ring and sub-ring protection that enables cable operators to build scalable Layer 2 networks.

G.8032 ERPS works with active ring links and standby ring protection links. The NIDs installed on the ring monitor the active links with fast CCM at 3.3 ms rate, and provide failover protection in less than 50 milliseconds (ms). If a fault is detected on an active link, the NIDs switchover to the standby protection links. When the network fault is resolved, the NIDs can be configured to automatically revert to the normal state, or the link can be restored manually.

NIDs that support ITU-T G.8031 Ethernet linear protection switching (ELPS) provide resiliency to protect network services in point-to-point topologies with redundant fiber links with sub-50 ms failover protection.

ITU-T G.8032v2 ERPS and G.8031 ELPS provide deterministic performance and protection for SLA service guarantees, improves customer satisfaction with guaranteed up time, and saves the cost of SLA penalties for service availability, excessive outage time and outage recurrences.

Another redundant link protection method supported by NIDs is the legacy IEEE 802.1ax/802.3ad link aggregation group (LAG) with link aggregation control protocol (LACP).

### *2.2.3. HCF Demarcation*

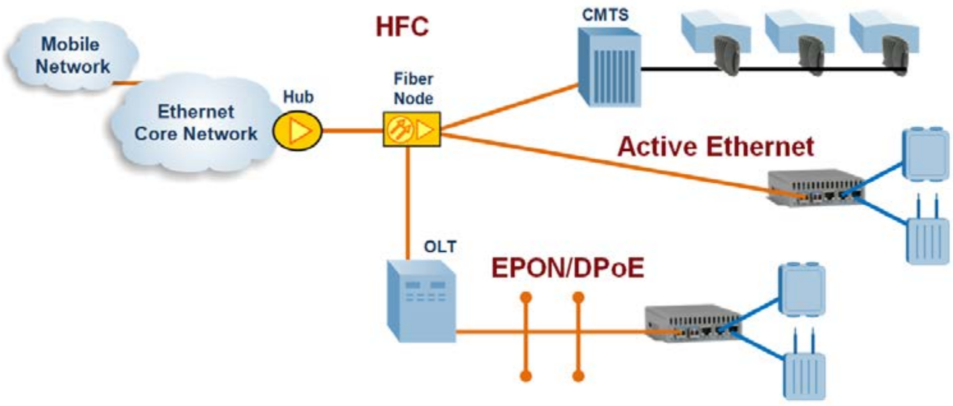


**Figure 10 – NID Deployment in an HFC Network**

In HFC networks, active Ethernet or passive fiber links can be distributed from a fiber node, as illustrated in Figure 10. For active Ethernet, NIDs can be deployed as described in the previous section. For EPON or the imminent DOCSIS provisioning of EPON (DPoE) network, a passive pluggable optical network unit (ONU) EPON SFP is installed in the NID.  DPoE and the pluggable ONU EPON SFP are reviewed in the following section.

### *2.2.4. EPON and DPoE Demarcation*

The EPON network architecture delivers dedicated, high-speed, symmetrical bandwidth, but the provisioning and management of EPON networks is not standardized. DOCSIS provisioning of EPON (DPoE™) networks enables the delivery of carrier Ethernet services over EPON with DOCSIS management and provisioning.

Similar to HFC, EPON uses a point to multi-point topology, where a headend hub services multiple subscriber endpoints. But unlike HFC, EPON can be provisioned to provide dedicated symmetrical throughput for specific services or subscribers, while also supporting carrier Ethernet 2.0 Multi-CoS and service OAM.

EPON is designed for the telecommunications market and EPON systems typically use a proprietary management interface. Conventional EPON systems force cable operators to maintain proprietary operations support systems (OSS) in addition to the DOCSIS OSS. The addition of proprietary management increases the complexity of the network, which in turn increases back office OPEX.

As a solution to this management system disparity, CableLabs introduced the DPoE specifications, which allows the EPON system to be transparently managed and provisioned by the DOCSIS OSS. The DPoE specifications define the DPoE system, which is analogous to the cable modem termination system (CMTS), and together with a DPoE ONU (D-ONU) mimic the actions of a traditional DOCSIS cable modem, as illustrated in Figure 11. The resulting management scheme allows cable operators to leverage the existing DOCSIS OSS to provision Ethernet services, and automatically configure the EPON D-ONU.

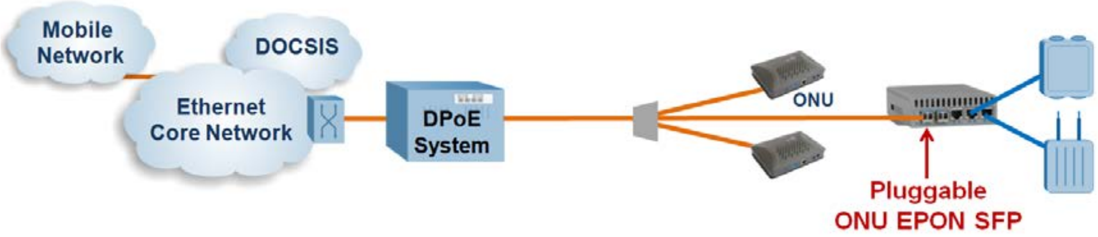


**Figure 11 – Demarcation for EPON and DPoE Networks**

Typically, the customer-facing interface on the standalone ONU device is connected to a NID which provides a demarcation point connecting the operator and the subscriber network, or in this case, a small cell and Wi-Fi AP.

The D-ONU is typically a standalone modem-like box, with a network-facing port and a customer-facing port. The network-facing port connects to the fiber line and the customer-facing port connects to the subscriber's network, usually as an Ethernet port. When the standalone D-ONU is deployed in conjunction with a NID to provide carrier Ethernet services over the DPoE Network, the two-box configuration requires extra mounting space, cabling and power source at the customer premise. This bulky configuration adds cost and additional points of failure to the network.

**Figure 12 – Pluggable ONU**

An alternative to the two-box configuration and EPON-specific NID is to use a pluggable D-ONU, as illustrated in Figure 12. A pluggable D-ONU is an EPON SFP transceiver with a standalone ONU chip/capability built-in according to the DPoE specifications. When installed directly into the SFP port of a NID, the pluggable D-ONU is powered by the NID through the SFP interface. The pluggable D-ONU eliminates the requirement for additional space, cabling, and power source.

## 2.3. Reducing Costs of HetNet backhaul

### *2.3.1. Reducing OPEX with DEMARC Auto-Configuration (DAC) of DPoE*

The concept of automatically provisioning Ethernet services is further extended to the NID with the release of the CableLabs® DPoE$^{TM}$ DEMARC auto-configuration (DAC) specification. The specification defines the DAC process that automatically provisions the DEMARC (or NID) after installation, requiring little or no interaction from the installer; similar to the installation of a cable modem.

The DAC process with a pluggable D-ONU and a NID that is compliant with the DPoE DEMARC specification. The DAC process starts when the pluggable D-ONU is installed in the NID, it identifies itself to the NID through the SFP diagnostic interface. Then the D-ONU sends information provided by the DPoE System to the NID using the IEEE link layer discovery protocol (LLDP). Information sent through the LLDP includes management path (the NID acquires the VLAN ID to establish management communication) and authentication information.

The NID connects to the dynamic host configuration protocol (DHCP) server, which assigns an IP address to the NID, and the NID downloads the configuration file from the file server. The NID automatically provisions itself based on the configuration file and turns up the EVC. At this point the DAC process is complete. The service is then ready to be tested and validated for SLA assurance.

The DPoE specification enables carrier Ethernet services to be delivered over EPON with DOCSIS management and provisioning. The DAC process with pluggable ONUs further streamlines deployments by automating provisioning of the NID. cable operators can now leverage the existing DOCSIS OSS, the scalability of EPON, and the service OAM functionality of the NID to accelerate revenue growth from HetNet backhaul services with SLA assurances.

- NIDs with pluggable D-ONUs shorten deployment time, reduce human error, improve customer satisfaction and provide tangible operational cost savings.
- DAC enables plug-and-play installation like a cable modem
- Use existing DOCSIS OSS management system
- Reduces truck rolls

### *2.3.2. Reducing OPEX with ZTP for Active Ethernet and HFC*

Carrier Ethernet enables flexible mobile backhaul, with different service types that have both port-based and VLAN-based (multiplexed) services. In addition, there are a wide variety of service attributes and Service OAM parameters. Configuring NIDs with these complex parameters can make provisioning and turning up carrier Ethernet services costly and time consuming. This complexity also creates issues with human error and mis-configuration that can further delay service activation, and require additional testing and troubleshooting.

Zero touch provisioning (ZTP) enables quick and easy service turn-up, and reduces costs associated with expert technicians having to manually provision demarcation devices. It also reduces expertise required by installers and technicians and centralizes management at the network operations center (NOC).

ZTP automatically loads configuration files to demarcation devices on the network, and eliminates the need for manual configuration. The ZTP process utilizes DHCP and TFTP.

- NID requests IP address and IP address of TFTP from the DHCP server
- NID requests configuration files from TFTP server
- TFTP Server sends configuration to NID (service attributes, , etc.)
- NID loads configuration file and reboots

After reboot, the NID is fully provisioned for EVCs, bandwidth profiles, class of service management and Ethernet service OAM probes. The service is then ready to be tested and validated for SLA assurance.

### 2.3.3. Reducing OPEX with Service Testing

Carrier Ethernet mobile backhaul services deliver sync, voice, video and data. Service activation testing provides the methodologies to quickly test and validate SLA metrics prior to handing off the backhaul service to the MNO. Current methods of testing services are time consuming, and require truck rolls with expensive test equipment.

NIDs with integrated ITU-T Y.1564 and RFC 2544 service testing quickly and easily verify the configuration and performance of Ethernet services.

ITU-T Y.1564 service activation testing (SAT) is a comprehensive carrier Ethernet testing standard that tests all CE 2.0 data flows with application-oriented Multi-CoS. Y.1564 SAT tests all service attributes, including multi-flow information rate and traffic policing, and tests all performance attributes simultaneously so testing is run quickly and efficiently, and can detect potential interaction between data flows.

RFC 2544 provides per-flow testing of key performance indicators (KPI), such as throughput, latency, jitter and frame loss up to full wire speed.

NIDs can also support generation/reception of L2, L3 and L4 test frames, and hardware-based delay and loopback measurement provide nanosecond testing resolution.

NIDs with ITU-T Y.1564 and RFC 2544 eliminate the CAPEX of test equipment and the OPEX of truck rolls, expedite service activation testing and turn up, and enable validation of CE 2.0 service assurance with application-oriented Multi-CoS.

### 2.3.4. Reducing OPEX and CAPEX with Power over Ethernet

Power over Ethernet (PoE) is a technology that enables the safe transfer of DC electrical power along with data over standard unshielded twisted pair (UTP) network cabling. Both the data and the power may share the same wire, and each is independent and unaffected by the other.

PoE is deployed where access to electrical power is inconvenient, expensive or infeasible to supply; which applies to many indoor/outdoor small cell and Wi-Fi deployments. The cost of bringing electrical power to each device is eliminated by powering the equipment through the UTP cable. This is why many small cells and Wi-Fi APs are powered by PoE. But this requires the installation of PoE power injectors, such as PoE switches or midspans, which increase equipment costs and the footprint of the antenna site.

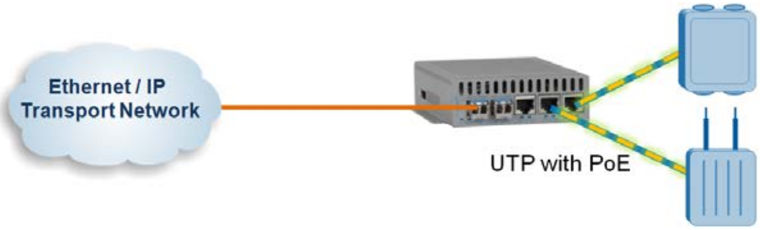


Figure 13 – NID with Power over Ethernet

NIDs with power over Ethernet are classified as power sourcing equipment (PSE) that power multiple powered devices (PDs), including Wi-Fi APs and small cells, as illustrated in Figure 13. NIDs with PoE provide fiber connectivity to the backhaul link and inject PoE through the RJ-45 ports. This lowers CAPEX by eliminating the need for midspans or bulky PoE switches, and resolves the power and size issues.

NIDs with PoE also feature dual fiber ports for deployment on ITU-T G.8032v2 protected rings, as illustrated in Figure 14. NIDs that support multiple PoE RJ-45 ports can power small cells, Wi-Fi APs and other devices like surveillance cameras at one location. The PDs can be installed up to 100 m away from the NID (the maximum distance of copper UTP cabling), and two small cells or Wi-Fi APs can be installed up to 200 m apart from each other using the same NID.

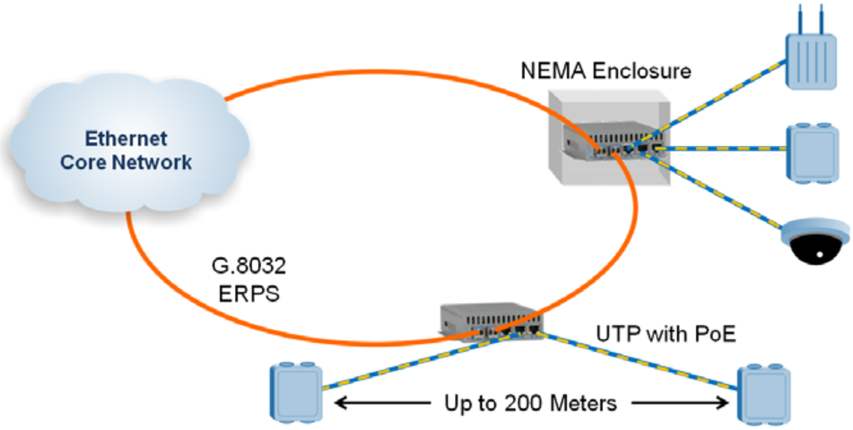


Figure 14 – NID with Multiple PoE Ports

NIDs support a variety of PoE power levels; up to 60W PoE per RJ-45 port for multi-stream wireless access points.

- IEEE 802.3af  PoE (15.4 W)
- IEEE 802.3at PoE+ (34.2 W)
- IEEE 802.3bt (60 W PoE) – ratification expected in 2017.

In addition to the upcoming IEEE 802.3bt 60 W PoE standard, Telecommunications Industry Association (TIA) and International Organization for Standardization  (ISO) are also currently updating standards that address cabling to support higher power levels that provide power over all four pairs of wires in Cat5 and higher cabling.

One of the issues that can affect data performance over copper cabling is heat generation in cable bundles. When power is added to twisted-pair cabling, the copper conductors generate heat and the temperature of the cable bundle stabilizes at a higher temperature than the surrounding ambient temperature. High temperatures create greater insertion loss and shorten data transmission distances. As PoE standards allow for higher power transmissions, temperature concerns will likely become even more prevalent.

Cable temperatures should not exceed the temperature rating for the cable, and cables for commercial typically have a maximum temperature rating of 60 degrees Celsius. The TIA recommends 15 degrees as the maximum allowed temperature rise above ambient as a result of power over the cabling.

Suggestions from TIA to help lower cabling temperature include: reducing the number of cables per bundle from 96 to 24, using higher category cabling and shielded cabling

Although copper cable bundles are typically not needed in small cell and Wi-Fi deployments, it is important to note the potential safety issues, especially as PoE power levels increase to 100 W.

## 2.4. Challenges Specific to Wi-Fi Deployments

### *2.4.1. Reducing Best Effort Wi-Fi Deployment Costs*

Cable operators are rolling out millions of Wi-Fi hotspots to provide best-effort internet access as a value-added service and to reduce churn. Although some revenue is generated by providing 3G and 4G offloading for MNOs, Wi-Fi has not been fully monetized by cable operators so it is critical to reduce deployments costs. One way to reduce CAPEX is to deploy low-cost fiber media converters that provide power over Ethernet. In this sports arena Wi-Fi example, as illustrated in Figure 15, PoE media converters provide SFP ports for fiber access, and inject PoE, PoE+ or 60 W PoE through the RJ-45 ports. Carrier Ethernet is not required for these applications, and the basic media converter is sufficient since there is no need for QoE.

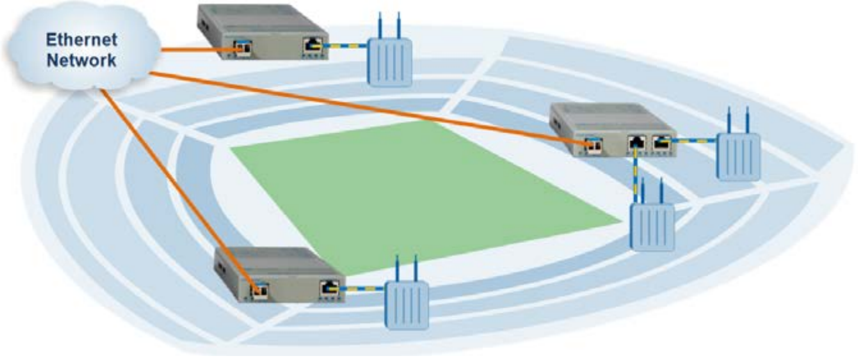


**Figure 15 – Best Effort Wi-Fi Backhaul with PoE Media Converters**

### *2.4.2. Reducing Carrier Wi-Fi Deployment Costs*

As cable operator Wi-Fi deployments evolve to transport voice calls, QoE and carrier Ethernet backhaul will be required. This can be achieved by installing SFP NIDs in the media converters, as illustrated in Figure 16. This provides a low-cost initial equipment investment and a low-cost upgrade path to carrier Wi-Fi with voice calling.

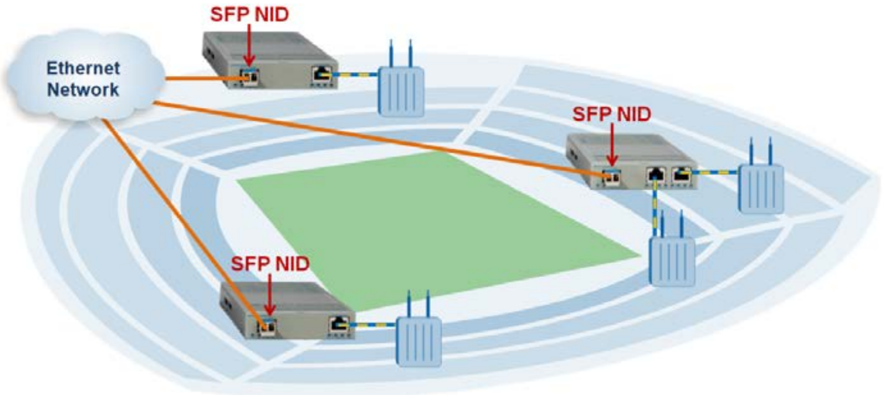


**Figure 16 – Carrier Ethernet Backhaul with PoE Media Converters + SFP NIDs**

### *2.4.3. IEEE 802.11ac Backhaul Bandwidth Challenges*

The IEEE 802.11ac Wi-Fi standard nearly triples bandwidth over its predecessor 802.11n (1.3 Gbps compared to 450 Mbps), and doubles the wireless spectrum (20/40 MHz compared to 20/40/80 MHz). 802.11ac compliant APs are launched to the market in two phases, called Wave 1 and Wave 2, as shown in Table 3.

Wave 1 supports single-user multiple input multiple output (SU-MIMO), where a single client at a time talks to the AP. Wave 2 nearly doubles the performance of Wave 1, and adds multi-user MIMO (MU-MIMO) that enables a Wave 2 AP to talk with multiple Wave 2 clients concurrently, specifically in the downstream direction, AP to client.

**Table 3 – The Evolution of 802.11ac**

| Characteristic | 802.11n | 802.11ac Wave 1 | 802.11ac Wave 2 |
|---|---|---|---|
| Megahertz | 20/40 MHz | 20/40/80 MHz | 20/40/80/160 MHz |
| Bandwidth | 450 Mbps | 1.3 Gbps | 2.34 Gbps |
| Modulation | SU-MIMO | SU-MIMO | MU-MIMO |

The challenge for cable operators is the data rates of Wave 1 and Wave 2 devices exceed the 1 Gbps backhaul capacity of the typical cable operator access network.

One solution is to use two fiber links with link aggregation to double the fiber backhaul capacity from 1 Gps to 2 Gbps. This requires two 1 Gpbs copper links on the AP side of the NID, and with link aggregation the two logical flows are aggregated to one flow over two fiber ports. If the access link is dual fiber, then two single-fiber SFPs can be deployed to convert the dual fiber strand into two single-fiber strands.

Looking forward, there are two proprietary industry groups developing competing NBASE-T and MGBASE-T standards for 2.5 Gbps and 5 Gbps BASE-T standards that can support 802.11ac data rates over copper lines.

The IEEE is currently working on creating 10 Gbps, 40 Gbps, and 100 Gbps Ethernet standards and has not yet addressed the market need for 2.5 Gbps and 5 Gbps, so only time will tell if the NBASE-T or the MGBASE-T standard will be ratified by IEEE, or some combination of the two. Some form of the 2.5 Gbps and 5 Gbps technology will be integrated into 802.11ac Wi-Fi APs, which will in turn need to be integrated into the NID.

## 2.5. Timing Synchronization

Cellular base stations and small cells require synchronization. This may be frequency synchronization, phase alignment to other base stations, or in the case of code division multiple access (CDMA) and CDMA2000, time synchronization, detailed in Table 4. There are a number of different technologies available to allow frequency, phase and time synchronization between base stations. Some of these are network based, while others are satellite or radio based techniques, and do not impact the backhaul network.

There are several deployment scenarios that are possible to provide synchronization. It should be noted that while synchronization as a service is a new concept that is not well defined, MEF 22.1 has included frequency synchronization as part of its definition of Ethernet services for mobile backhaul.

NIDs that support Sync-E, network time protocol (NTP) and IEEE 1588v2 will enable cable operators to deliver timing synchronization to MNOs. Combining the various synchronization methods will help improve reliability and accuracy, while addressing the weakness of each individual technique.

**Table 4 – Comparison of Timing Techniques**

| Technique | Frequency Synchronization | Phase Synchronization | Time Synchronization |
|---|---|---|---|
| IEEE 1588 Precision Time Protocol | Yes | Yes | Yes |
| Network Time Protocol | Yes | Yes | Yes |
| Synchronous Ethernet | Yes | No | No |

## 2.6. Space Constraints and Outdoor Environments

Small cells and Wi-Fi APs are designed for indoor and outdoor deployments, but most NIDs and the associated power equipment are designed for indoor deployments.  Outdoor enclosures that meet the National Electrical Manufacturers Association (NEMA) ratings for protecting equipment from liquids, rain, ice, corrosion and contaminates such as dust are used to house equipment at the small cell site or Wi-Fi AP, as illustrated in Figure 17. The size of NEMA enclosures is limited by installation sites such as aerial poles, and many cities have codes that limit the size of enclosures on buildings, especially in historic districts.

**Figure 17 – Compact NEMA Enclosures**

Compact NIDs with integrated power over Ethernet eliminate the need for midspan equipment and are ideal for deployments in small NEMA enclosures. Temperature hardened NIDs are designed to withstand the high and low temperatures inside NEMA enclosures.

## 3. Conclusions and Recommendations

Cable operators are spending billions to deploy millions of Wi-Fi APs and small cells to provide value added services, offload 3G and 4G data, and supplement MNO wireless networks with hotspots and notspots.

Cable operators have to deliver SLAs to MNOs, install equipment and provide power, and provision services; all while keeping costs in check to maintain profitability.

Ethernet NIDs enable carrier Ethernet 2.0 backhaul for small cells and Wi-Fi APs with Multi-CoS SLAs by supporting industry standards for performance monitoring, fault management and protection:

- IEEE 802.1ag end-to-end connectivity fault management
- ITU-T Y.1731 end-to-end performance monitoring
- IETF two-way active measurement protocol
- ITU-T G.8031 and G.8032v2 Ethernet protection switching with sub-50 ms failover
- IEEE 802.1ax/802.3ad LAG with LACP
- ITU-T G.8262 sync-E and IEEE 1588v2 timing

The cable operator can simplify inventories and reduce CAPEX by deploying the same NID for WDM, HFC, active Ethernet and EPON/DPoE access networks. Only one NID needs to be inventoried for use in all networks by installing different pluggable SFP interfaces. CAPEX is also reduced with integrated power over Ethernet eliminates the cost and footprint of midspans, and can power multiple small cells and Wi-Fi APs.

Cable operators can reduce operating costs by automating provisioning and streamline service testing to enable plug-and-play installations.

- IETF RFC 2544 Ethernet service activation testing with built-in test-head
- ITU-T Y.1564 Ethernet service activation testing
- DEMARC auto-configuration (DAC) for DPoE networks
- Zero-touch provisioning for automated service activation

As cable operators monetize Wi-Fi services, media converters with PoE can reduce deployment costs of best effort Ethernet backhaul, and upgrade to carrier Ethernet with SLAs for carrier Wi-Fi voice services by installing an SFP NID in the media converter.

The wide variety of carrier Ethernet demarcation devices support a variety of industry standards to reduce operating costs and capital expenditure costs to enable profitable small cell and Wi-Fi backhaul services.

## 4. Abbreviations

| | |
|---|---|
| 3G | third generation |
| 4G | fourth generation |
| AC | alternating current |
| AP | access point |
| CAPEX | capital expenditure |
| CCM | continuity check message |
| CDMA | code division multiple access |
| CFM | connectivity fault management |
| CIR | committed information rate |
| CMTS | cable modem termination system |
| CoS | class of service |
| CWDM | coarse wavelength division multiplexing |
| DAC | DEMARC auto configuration |
| DC | direct current |
| DEMARC | demarcation |
| DHCP | dynamic host configuration protocol |
| DOCSIS | Data-Over-Cable Service Interface Specifications |
| D-ONU | DPoE optical network unit |
| DPoE | DOCSIS provisioning of EPON |
| DWDM | dense wavelength division multiplexing |
| EAD | Ethernet access device |
| EDD | Ethernet demarcation device |
| ELPS | Ethernet linear protection switching |
| ENNI | external network to network interface |
| EPON | Ethernet passive optical network |
| ERPS | Ethernet ring protection switching |
| EVC | Ethernet virtual connection |
| EVPL | Ethernet virtual private line |
| EVP-LAN | Ethernet private local area network |
| Gbps | gigabits per second |
| HetNet | heterogeneous network |
| HFC | hybrid fiber coax |
| IEEE | Institute of Electrical and Electronics Engineers |
| IETF | Internet Engineering Task Force |
| IP | Internet protocol |
| ISO | International Organization for Standardization |
| ITU | International Telecommunication Union |
| KPI | key performance indicator |
| LACP | link aggregation control protocol |
| LAG | link aggregation group |
| LLDP | link layer discovery protocol |
| LTE | long term evolution |
| m | meter |
| Mbps | megabits per second |

| | |
|---|---|
| MEF | Metro Ethernet Forum |
| MHz | megahertz |
| MIMO | multiple input multiple output |
| MNO | mobile network operator |
| MPO | multi-CoS performance objectives |
| multi-CoS | multiple classes of service |
| mW | milliwatt |
| NEMA | National Electrical Manufacturers Association |
| NGH | next generation hotspot |
| NID | network interface device |
| nm | nanometer |
| NOC | network operations center |
| NTP | network time protocol |
| OAM | operations, administration, and maintenance |
| ONU | optical network unit |
| OPEX | operational expenditure |
| OSS | operations support systems |
| PD | powered device(s) |
| PoE | power over Ethernet |
| PSE | power sourcing equipment |
| QoE | quality of experience |
| SAT | service activation testing |
| SFP | small form-factor pluggable |
| SLA | service level agreement |
| Sync-E | synchronous Ethernet |
| SU-MIMO | single user multiple input multiple output |
| TIA | Telecommunications Industry Association |
| TWAMP | two-way active measurement protocol |
| UNI | user to network interface |
| UTP | unshielded twisted pair |
| W | watt |
| WDM | wavelength division multiplexing |
| ZTP | zero touch provisioning |

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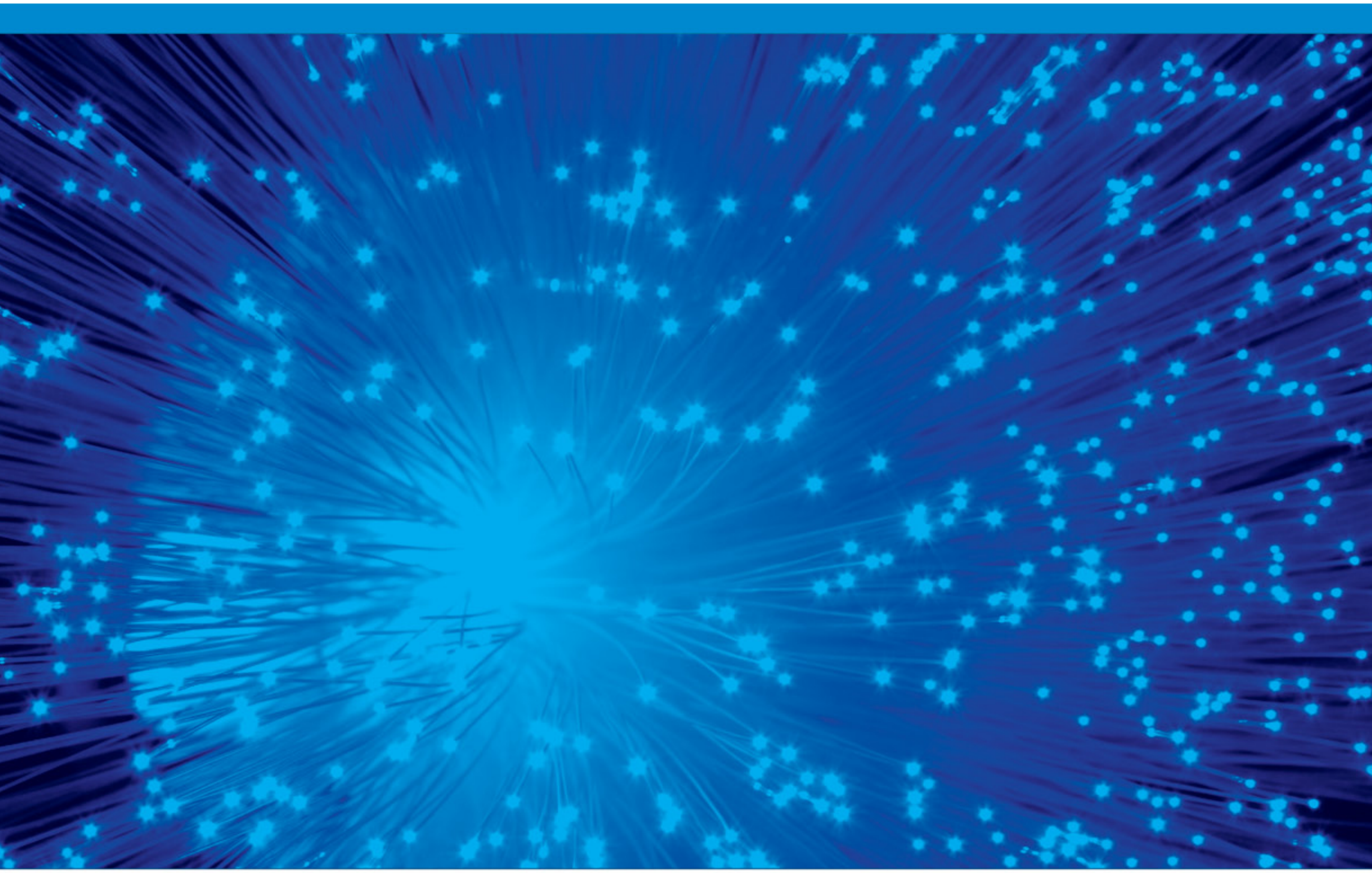

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