



***Society of Cable  
Telecommunications  
Engineers***

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**ENGINEERING COMMITTEE  
Network Operations Subcommittee**

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**SCTE Technical Report**

**SCTE 209 2015**

**Technical Report  
UHF Leakage, Ingress, Direct Pickup**

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## NOTICE

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## 1. Scope

Until recently, cable system signal leakage monitoring and repair activities were necessarily focused on preventing interference to aeronautical navigation and communication systems in the 108 megahertz (MHz) to 137 MHz and 225 MHz to 400 MHz very high frequency (VHF) and ultra high frequency (UHF) bands.<sup>1</sup> Although Section 76.605(a)(12) of the Federal Communications Commission (FCC) Rules contains leakage limits for frequencies above 400 MHz, cable signals in the UHF spectrum were generally unobserved because (1) there were no explicit FCC requirements to monitor leakage on those frequencies, and (2) there were few if any complaints of interference.

Consequently, cable signal leakage monitoring devices were designed and manufactured to cover the VHF spectrum, particularly in and near the 108 MHz to 137 MHz aeronautical frequencies, but not the UHF spectrum.

Even though frequencies above 806 MHz have been used for land mobile and cell phone communications for many years, cable signal leakage had never been recognized as a problem at those frequencies because there were few cable systems operating in that part of the spectrum.

Today circumstances have changed. Frequencies in the 700 MHz range that had been used for over-the-air television (TV) broadcasting have been reallocated for land mobile communications. Some of those frequencies are licensed to cellular phone companies. These new licensees have the technical ability to detect interference to their radio services, and to determine that the interference is coming from cable signal leakage.

Moreover, in recent years cable engineers have determined that the leakage characteristics of cable plant vary substantially by frequency, and that monitoring for VHF leaks does not detect UHF leaks.

This document provides guidance and recommendations to cable operators on monitoring and measurement practices and procedures for mitigating cable signal leakage, ingress, and direct pickup in the UHF band.

## 2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of the standard. At the time of Subcommittee approval, the editions indicated were valid. All standards are subject to revision; and while parties to any agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents *may not* be compatible with the referenced version.

- None are applicable

## 3. Informative References

The following documents *may* provide valuable information to the reader but are not required when complying with this standard.

- None are applicable

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<sup>1</sup> The VHF spectrum encompasses 30 MHz to 300 MHz, and the UHF spectrum encompasses 300 MHz to 3000 MHz.

## 4. Compliance Notation

<i>shall</i>	This word or the adjective “ <i>required</i> ” means that the item is an absolute requirement of this specification.
<i>shall not</i>	This phrase means that the item is an absolute prohibition of this specification.
<i>should</i>	This word or the adjective “ <i>recommended</i> ” means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
<i>should not</i>	This phrase means that there <i>may</i> exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
<i>may</i>	This word or the adjective “ <i>optional</i> ” means that this item is truly optional. One vendor <i>may</i> choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor <i>may</i> omit the same item.

## 5. Abbreviations and Definitions

### 5.1. Abbreviations and Acronymns

$\mu\text{s}$	microsecond
$\mu\text{V/m}$	microvolt per meter
$A_{\text{em}}$	maximum effective aperture
BER	bit error ratio
BLER	block error rate
BTS	base transceiver station
CEA	Consumer Electronics Association
CENELEC	European Committee for Electrotechnical Standardization
CEPT	European Conference of Postal and Telecommunications Administrations ( <i>Conférence Européenne des Administrations des Postes et des Télécommunications</i> )
CLI	cumulative leakage index
CNR	carrier-to-noise ratio
CPE	customer premises equipment
CQI	call quality index
CR	code rate
CW	continuous wave
dB	decibel
dBi	decibel isotropic
dBm	decibel milliwatt
dB/m	decibel per meter
dBmV	decibel millivolt
$\text{dB}\mu\text{V/m}$	decibel microvolt per meter
DOCSIS	Data Over Cable Service Interface Specifications
e.g.	for example ( <i>exempli gratia</i> )
eMTA	embedded multimedia terminal adapter
ETSI	European Telecommunications Standards Institute

E-UTRA	evolved UMTS terrestrial radio service
FBC	Full-Band Capture
FSC	Full-Spectrum Capture
FCC	Federal Communications Commission
FM	frequency modulation
GHz	gigahertz
GPS	Global Positioning System
HFC	hybrid fiber coax
ISM	industrial, scientific, and medical
JWG	Joint Working Group
km	kilometer
LPDA	log periodic dipole array
LTE	long term evolution
m	meter
Mbps	megabits per second
MDU	multiple dwelling unit
MER	modulation error ratio
MHz	megahertz
MIMO	multiple input multiple output
MVPD	multichannel video programming distributor
mW	milliwatt
NFP	near-field probe
NOS	[SCTE] Network Operations Subcommittee
NOS WG1	[SCTE] Network Operations Subcommittee Working Group 1
NPRM	Notice of Proposed Rulemaking
PC	personal computer
$P_d$	power density
$P_t$	source power
QC	quality control
QAM	quadrature amplitude modulation
QP	QAM power
QPSK	quadrature phase shift keying
RF	radio frequency
RP	[SCTE] Recommended Practice
RS-EPRE	reference signal energy per resource element
RSSI	received signal strength indication
SCTE	Society of Cable Telecommunications Engineers
SISO	single input single output
SNMP	simple network management protocol
SNR	signal-to-noise ratio
TBSI	transport block size index
TDOA	time difference of arrival
TNO	Netherlands Organisation for Applied Scientific Research ( <i>Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek</i> )
TR	[SCTE] Technical Report
TV	television
UE	user equipment
UHF	ultra high frequency
VHF	very high frequency

V/m	volt per meter
8-VSB	eight-level vestigial sideband

## 6. FCC Leakage-Related Rules

### 6.1. Brief History of Cable Television Leakage Regulations

In 1972, after several years of consideration, the FCC adopted a broad range of regulations applicable to cable systems.<sup>2</sup> These included the technical standards that are incorporated in §76.605 of the FCC Rules. In particular, the leakage requirements in §76.605(a)(12) were adopted at that time. One leakage value was applied to the frequency band 54 MHz to 216 MHz, and a less stringent limit was applied outside that range. The basis for those values was the limit that already existed for unintentional radiators in Part 15 of the FCC Rules.<sup>3</sup>

The FCC took note of a request by the Office of Telecommunications Policy (at that time an office within the White House) to prohibit from use by cable systems the frequency bands 108 MHz to 137 MHz and 225 MHz to 400 MHz, in order to avoid the possibility of interference to air traffic control communications. The FCC declined on the basis that this would be a “rather remote interference possibility.”<sup>4</sup>

However, in 1976 the FCC reported that cable leakage interference had occurred to an airport approach control service operating on 118.25 MHz. Consequently, in 1977 the FCC adopted the aeronautical cable signal leakage rules in §76.610 and §76.611. §76.613, known as the harmful interference clause, and which prohibits interference to radio services, was revised to explicitly include protection of radionavigation services. The detailed technical rules to protect the aeronautical radio services, which included signal level limits, frequency avoidance and regular monitoring, were based in part on the bandwidths and other technical specifications of those radio services, and in part on the analog cable signal formats. Revised aeronautical leakage rules were adopted in 1984.<sup>5</sup>

In 2012, the FCC began considering whether the cable signal leakage rules needed to be revised to take into account use of digital modulation methods on cable systems.<sup>6</sup>

### 6.2. Current FCC Signal Leakage Rules

The following paragraphs in Part 76 of the FCC Rules include regulations applicable to cable television signal leakage:

§76.605(a)(12): Maximum allowable signal leakage field strength-versus-frequency

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<sup>2</sup> Cable Television Report and Order, 36 FCC 2d, 143 (1972); see generally, <http://www.nctatechnicalpapers.com/Paper/1983/1983-cable-signal-leakage-where-is-it-all-going>

<sup>3</sup> Id.

<sup>4</sup> Id. at para. 162.

<sup>5</sup> Amendment of Part 76, Docket No. 21006, 65 FCC 2d 813 (1977); Second Report and Order, 99 FCC 2d 512 (1984).

<sup>6</sup> Cable Television Technical and Operational Requirements, Notice of Proposed Rulemaking, 27 FCC Rcd 9678 (2012).

§76.609(h)(1) through (5): How to perform signal leakage measurements

§76.610: Describes the sections of rules that apply when cable signals are carried on aeronautical band frequencies (§§76.605(a)(12), 76.611, 76.612, 76.613, 76.614, 76.616, 76.617, 76.1803 and 76.1804)

§76.611: Cumulative leakage index calculation, drive-out and flyover measurements<sup>7</sup>

§76.612: Frequency offset requirements

§76.613: Harmful interference clause

§76.614: Quarterly monitoring and leakage repair

§76.616: Cable network operation near certain emergency frequencies

§76.617: Describes who is responsible for leakage inside and outside of the home

§76.1803: Form 320 content and submission

§76.1804: Form 321 content and submission

### 6.3. FCC Signal Leakage Field Strength Limits

The aforementioned §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 follows:

<b>Frequencies</b>	<b>Signal leakage limit (micro-volt/meter)</b>	<b>Distance in meters (m)</b>
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 microvolts per meter ( $\mu\text{V/m}$ ) 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.

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<sup>7</sup> A commonly misused leakage-related term is *cumulative leakage index*, or CLI, which is not the same as signal leakage. Cumulative leakage index 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; one must measure signal leakage in order to calculate CLI.

The signal leakage limit applicable to the UHF spectrum is 15  $\mu\text{V}/\text{m}$  measured 30 meters (approximately 100 feet) from the plant. The 30 meters leakage limit can be correlated on a free-space basis to a field strength value at 3 meters using the following formula:

$$E_{\mu\text{V}/\text{m}} \text{ at 3 meters} = E_{\mu\text{V}/\text{m}} \text{ at 30 meters} * (30/3)$$

where  $E_{\mu\text{V}/\text{m}}$  is field strength in microvolts per meter

Converting the 30 meters field strength limit of 15  $\mu\text{V}/\text{m}$  to an equivalent field strength limit at 3 meters gives 150  $\mu\text{V}/\text{m}$ . If a cable network just meets the leakage limits-versus-frequency (or has even lower levels of leakage) defined in §76.605(a)(12), does that mean the cable network complies with the requirements in Part 76? Not necessarily.

Part 76 also includes the previously mentioned harmful interference clause (§76.613), which says, in effect, if leakage of any field strength causes harmful interference, the leakage must be fixed regardless of its actual field strength. The following is from §76.613:

§ 76.613 Interference from a multichannel video programming distributor (MVPD)

- a) Harmful interference is any emission, radiation or induction which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radiocommunication service operating in accordance with this chapter.
- b) An MVPD that causes harmful interference *shall* promptly take appropriate measures to eliminate the harmful interference.
- c) If harmful interference to radio communications involving the safety of life and protection of property cannot be promptly eliminated by the application of suitable techniques, operation of the offending MVPD or appropriate elements thereof *shall* immediately be suspended upon notification by the District Director and/or Resident Agent of the Commission's local field office, and *shall not* be resumed until the interference has been eliminated to the satisfaction of the District Director and/or Resident Agent. When authorized by the District Director and/or Resident Agent, short test operations *may* be made during the period of suspended operation to check the efficacy of remedial measures.
- d) The MVPD *may* be required by the District Director and/or Resident Agent to prepare and submit a report regarding the cause(s) of the interference, corrective measures planned or taken, and the efficacy of the remedial measures.

Complying with just the signal leakage field strength limits in §76.605(a)(12) is not enough. If signal leakage of any field strength at any frequency causes harmful interference, that is a violation of §76.613.

## 7. Recommendations To Minimize Signal Leakage In The UHF Spectrum<sup>8</sup>

As discussed earlier in this document, the FCC has for many years required cable operators to monitor for signal leakage in or near the 108 MHz to 137 MHz VHF aeronautical band. Leakage detection and repair

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<sup>8</sup> The material in this section is adapted from Hranac (2014), and is used here with the permission of the author.

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 long term evolution (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, their field engineers have 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).

What, then, can cable operators do to guard against signal leakage affecting LTE and other services operating in the UHF spectrum?

### **Step 1. Learn about the causes of leakage in the UHF spectrum**

The causes of UHF leakage are for the most part the same as the causes of VHF leakage. UHF leakage tends to be more common in the hardline plant, in part because signal levels there are greater than they are in the subscriber drop, and because tilted active device outputs elevate signal levels in the upper end of the downstream spectrum relative to lower frequencies. That said, UHF leakage can originate in both the hardline plant and subscriber drops. A few examples of the typical causes of UHF leakage include loose, improperly installed, or damaged connectors and adapters; radial cracks in the cable shield; loose passive device faceplates; damaged or missing gaskets in actives and passives; and rodent chews.

### **Step 2. Learn about leakage characteristics at different frequencies**

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.

### **Step 3. Use the right tools**

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. In the event that the newer commercial leakage detection equipment is not yet readily available at the system level, so-called

"homebrew" methods using a combination of high-gain UHF antenna, bandpass filter, preamplifier, and spectrum analyzer can be used to at least confirm the presence of UHF leakage.

#### **Step 4. Develop an effective signal leakage program that includes both VHF and UHF leakage monitoring**

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  $\mu\text{V}/\text{m}$  limit at 30 meters, as well as for harmful interference to LTE services.

#### **Step 5. Prevent future leakage**

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 the previously mentioned 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.

#### **Step 6. Understand what to do when contacted by LTE field engineers about a potential leakage-related interference problem**

- 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.
- 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.
- 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.

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.

## 8. UHF 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 *may* happen anywhere 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 UHF 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 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, frequency modulation (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 – both analog and digital – and more recently, LTE signals in the 698 MHz to 806 MHz band.

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.

Radio frequency (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-store 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 customer premises equipment (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.

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 *may* exist when there is little or no VHF leakage. In short, there is little or no correlation. VHF ingress *may* enter the plant through some shielding defects, UHF ingress *may* enter through others, and both *may* 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 *may* 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.

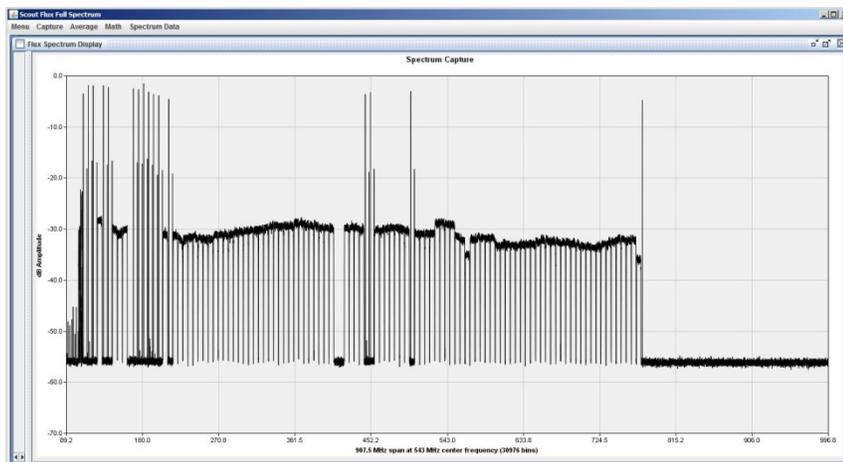
A spectrum analyzer or spectrum monitor *may* be used to troubleshoot ingress by first locating points in the service area where the ingress does and does not exist, such as an affected subscriber's premises and the node serving that subscriber. The divide-and-conquer method is then used to isolate where 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 quadrature amplitude modulation (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. As of the date this report was written, some manufacturers have equipment with this feature available, variously called QAM Ingress (JDSU), i-QAM (Sunrise Telecom/VeEx), and QAM Error Vector Spectrum (Trilithic).

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 carrier-to-noise ratio (CNR), modulation error ratio (MER), bit error ratio (BER), and signal constellation for a given QAM signal have been degraded by the ingress, and where the QAM signal is unimpaired.

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 1) for indications of the presence of downstream ingress.



**Figure 1: Spectrum capture with FM ingress visible on far left edge of the display, from a Broadcom FBC silicon-equipped cable modem**

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<sup>9</sup>, and use an external test point even if it must be created using a permanent tap installation.

## 9. 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 *may* 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, *may* 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. The interference manifests itself as tiling,

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<sup>9</sup> 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.

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.

Direct pickup interference by LTE user equipment (UE) causes the same symptoms. LTE UE supports a maximum transmit power of up to +23 dBm (decibel milliwatt) ( $\pm 2$  dB) (European Telecommunications Standards Institute, 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 2,000,000  $\mu$ V/m. Refer to Appendix C for a step-by-step procedure to calculate the field strength produced by LTE UE.

Cable modems experiencing direct pickup interference *may* suffer mild to severe packet loss and degraded data throughput. Embedded multimedia terminal adapters (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.

## 10. Commercial UHF Leakage Detection and Measurement

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 this paper was written (July 2014). Appendix A includes descriptions of most of the following 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 the Appendix 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: JDSU

Products: QAM Egress Option, DSAM

Web site: [www.jdsu.com/go/DSAM](http://www.jdsu.com/go/DSAM)

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>

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 a 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 JDSU product also provides spectrum analyzer-like functionality, automatically indicating when a QAM signature is detected in the spectrum scan.

## 11. “Homebrew” UHF Leakage Detection Solutions

As discussed in Section 7.0 of this document, several manufacturers now have available UHF- and digital-compatible signal leakage test equipment. Cable operators *should* understand that commercially-manufactured products are recommended as the first choice for detecting and accurately measuring UHF leakage, and ensuring compliance with FCC Rules.

Given the reality of budget cycles and the purchasing process in most cable companies, it will take time for the new products to be as ubiquitous at the system level as existing VHF leakage detection equipment. What can be done in the short-term if, for example, an LTE service provider contacts system personnel about leakage-related interference in the 698 MHz to 806 MHz LTE spectrum, and commercial UHF leakage equipment is not yet available locally?

One option that *may* work to confirm the presence of UHF leakage is “homebrew” solutions using a combination of an existing spectrum analyzer, high-gain antenna, bandpass filter, and external preamplifier. Two sets of field tests were conducted to determine the viability of homebrew solutions.

The first field test, completed in mid-2013, evaluated a limited combination of antennas, spectrum analyzer, and preamplifier in preparation for a paper presented at SCTE’s 2013 Cable-Tec Expo (Hranac, Segura 2013)<sup>10</sup>. While the Cable-Tec Expo paper was being finalized and edited for publication in the conference proceedings, SCTE’s NOS WG1 completed additional field tests of homebrew solutions, summarized in this section as Field Test 2. The results of the second round of testing corroborated the results of the testing in Field Test 1.

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<sup>10</sup> The equipment combination was configured with the intent of detecting and measuring leakage from a calibrated leak in the 700 MHz spectrum. The calibrated leak’s signal source included a modulator configured for 703.25 MHz, and a local cable drop connected to a bandpass filter, variable attenuator, and antenna.

### 11.1. Field Test 1

The following is excerpted from the aforementioned 2013 Cable-Tec Expo paper:

The authors performed some very preliminary tests comprising limited combinations of antennas, a spectrum analyzer, and preamplifier. Antenna types included a resonant half-wave dipole, a 400-1000 MHz printed circuit board-type log-periodic antenna,<sup>11</sup> and an older consumer-grade UHF broadcast television antenna.<sup>12</sup> The spectrum analyzer was Sunrise Telecom's (now VeEx) AT2500RQv,<sup>13</sup> and the preamplifier an Antronix 1 GHz drop amplifier.<sup>14</sup>

The following is a summary of the first field test results, which were mixed:

- A resonant half-wave dipole and spectrum analyzer combination does not have sufficient sensitivity to detect the presence of low- to-moderate field strength UHF leakage. This is in large part because of the antenna factor difference between VHF and UHF dipoles and the corresponding effective loss of sensitivity at higher frequencies. The combination of a dipole and spectrum analyzer was able to detect a CW carrier at 703.25 MHz that produced a field strength of approximately 150  $\mu\text{V/m}$ , but the CW carrier was too close to the spectrum analyzer's noise floor for reliable measurements at field strengths much below about 75  $\mu\text{V/m}$ .
- At a field strength of approximately 75  $\mu\text{V/m}$  using the dipole/spectrum analyzer combination, leaking QAM haystacks were just visible above the noise floor on the analyzer display, but their amplitude was too low to allow measurement of full-channel field strength.<sup>15</sup> When the field strength was decreased by 6 dB to approximately 37  $\mu\text{V/m}$ , the QAM haystacks were buried in the spectrum analyzer's displayed noise floor.
- The small log-periodic antenna provided about 3 dB of additional sensitivity compared to the dipole. When combined with just the spectrum analyzer, sensitivity was still insufficient for low- and moderate-field strength leak detection.
- The UHF TV antenna provided about 5 dB of additional sensitivity compared to the dipole. When combined with just the spectrum analyzer, sensitivity was still insufficient for low- and moderate-field strength leak detection.
- The UHF TV antenna, preamplifier, and spectrum analyzer combination provided sufficient sensitivity to detect the presence of moderate- and some low-field strength leakage. Because the actual gain of the antenna was unknown, this combination could not be used for accurate field

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<sup>11</sup> Kent Electronics 400-1000 MHz printed circuit board antenna. <http://www.wa5vjb.com/products1.html>

<sup>12</sup> Make/model and specifications unknown. Boom length 5'9".

<sup>13</sup> <http://www.veexinc.com/en-us/Products/AT2500RQvPlus>

<sup>14</sup> Antronix FRA1-1510, 15 dB gain, 3 dB noise figure. [http://www.antronix.net/uploads/specs/DS-1030-AR-A04\\_FRA%20Serie\\_51\\_0.pdf](http://www.antronix.net/uploads/specs/DS-1030-AR-A04_FRA%20Serie_51_0.pdf)

<sup>15</sup> The amplitude of the QAM signals had been measured at a much higher field strength from a calibrated leak, then a precision lab-grade variable attenuator was adjusted to achieve the desired lower leakage field strengths.

strength measurements. It could, however, be used to confirm the *presence* of UHF leakage before repairs, and the presence or absence of leakage after repairs. Note that this equipment combination is too unwieldy to be used in a vehicle, and is recommended only for fixed testing after a possible leakage location has been identified by other means (e.g., an LTE service provider). Note that portable AC power *may* be necessary for some of the equipment, depending on make/model. A bandpass filter *may* be necessary to prevent preamplifier overload by strong out-of-band signals.

- If a CW carrier is available for UHF leakage detection using home-brew equipment configurations, ensure that the carrier's placement in the cable network's downstream spectrum does not overlap existing over-the-air LTE signals, UHF TV signals, etc. When leakage does occur, a CW carrier will be less likely to cause interference to over-the-air services if it is in an unused part of the over-the-air spectrum. Likewise, a CW carrier will be easier to see on the test equipment display if an over-the-air signal is not covering it. A challenge here is that most cable operators are reluctant to give up the channel slot necessary to support a CW carrier dedicated to UHF leakage monitoring.

The NOS WG1 field tests corroborate the authors' preliminary test results. While the NOS WG1 results were still being analyzed as this paper was being finalized, the data confirm that a combination of high-gain antenna, preamplifier, bandpass filter, and spectrum analyzer is necessary to reliably detect the presence of UHF leakage.

## 11.2. Field Test 2

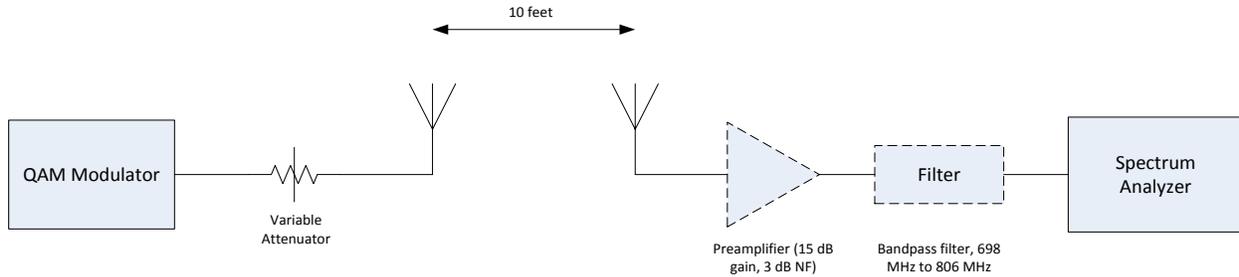
Following the first field test, additional testing was conducted by members of SCTE's NOS WG1 on August 8, 2013, in Littleton, Colorado.

A calibrated leak was created on CEA (2013) channel 112 (720 MHz to 726 MHz) after first determining that there were no over-the-air signals present within that 6 MHz-wide frequency range. A headend QAM modulator was connected to an external lab-grade variable attenuator<sup>16</sup> via suitable length quad-shield 11-series coax jumpers, and then to a printed circuit board 400 MHz to 1000 MHz log periodic dipole array (LPDA) antenna. The variable attenuator allowed setting Ch. 112's RF level to the antenna in 1 dB increments.

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<sup>16</sup> JFW Industries, Inc., Model 75DA-003, S/N 215060 9720

The calibrated leak’s LPDA antenna was placed on top of a 10 feet tall PVC support, oriented to provide horizontal polarity and aimed at a second 10 feet tall support about 10 feet away for the receive antennas under evaluation. Each of the test receive antennas was connected via quad-shield coax to either a standalone spectrum analyzer, or a combination of an external 15 dB gain preamplifier, bandpass filter, and spectrum analyzer. Figure 2 shows a block diagram of the test setup.



**Figure 2: Block diagram of equipment setup for Field Test 2**

Five different receive antennas were evaluated in the field test, and are listed in Table 1.

**Table 1: Characteristics of the antennas evaluated in Field Test 2**

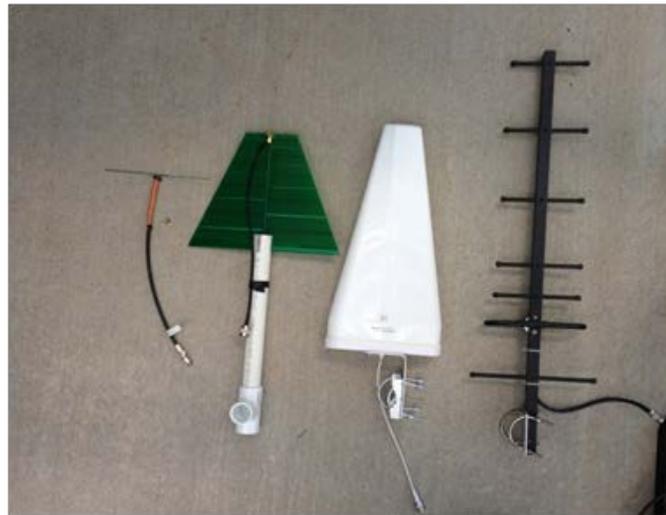
Antenna Number	Antenna Type	Manufacturer	Model Number	Published Gain
A1	Homemade 723 MHz half-wave dipole with quarter-wavelength coaxial sleeve balun	R. Hranac	N/A	2.15 dBi
A2 <sup>17</sup>	Printed circuit board 400 MHz to 1000 MHz log periodic dipole array	Kent Electronics	NTMS	Antenna factor 700 MHz: 21.2 800 MHz: 22.3 (Approximate gain calculated from antenna factor vs. frequency is 5.9 dBi)
A3	Log periodic dipole array, 698-960/1710-2700 MHz 10/11 dBi Directional Antenna with N-Style Jack (F) Connector	Terrawave Solutions	M3100110D11206	10 dBi in the 698 MHz to 960 MHz range
A4	Yagi, 700 MHz 4G LTE Cellular Antenna	Digital Antenna	477-YB	9 dB (dBi versus dBd not specified)

<sup>17</sup> Two of the 400 MHz to 1000 MHz printed circuit board log periodic dipole array antennas were used in Field Test 2. One was set up as the calibrated leak’s transmit antenna to provide improved front-to-back ratio and directivity performance (compared to a dipole) in order to minimize the possibility of interference to over-the-air services, and the second was one of the receive antennas under evaluation.

A5	UHF broadcast TV antenna (est. 20 years old), boom length 5' 9"	Unknown	Unknown	Unknown
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Antennas A1 through A4 were tested with a CW carrier at 723 MHz [center frequency of CEA (2013) channel 112], followed by a 6 MHz-wide QAM signal on the same channel. Antenna A5 was tested with only the CW carrier. Two ham radio handheld transceivers with wideband receive capability were tested with the CW carrier to determine whether they could be used in a scanner-like mode to detect UHF leakage in the LTE band.

Figure 3 is a photo of antennas A1-A4 (left to right), and Figure 4 is a photo of antenna A5 on its support mast, with the calibrated leak's LPDA antenna visible in the background.



**Figure 3: Left to right, antennas A1-A4**



**Figure 4: Antenna A5 on right**

Table 2 is a summary of calculated power in dBmV at the terminals of a resonant half-wave dipole versus a given field strength, and the calculated RF input to the spectrum analyzer after the 1.78 dB of receive antenna-to-spectrum analyzer feedline loss. The calculations were done prior to starting the field tests, and the information in Table 2 was then used to ensure that the calibrated leak was indeed calibrated. This was done with a CW carrier, which could be seen at the moderate and higher field strength values. The lower field strength leakage couldn't be seen on a spectrum analyzer with just a dipole connected to the analyzer, which is why 37.5  $\mu\text{V/m}$  was chosen as the lowest field strength value in subsequent testing.

**Table 2: Leakage field strength values versus calculated dipole levels**

Field strength at 723 MHz	Calculated RF level at dipole terminals	Coax feedline loss	RF input to spectrum analyzer
150 $\mu\text{V/m}$	-40.11 dBmV	1.78 dB	-41.89 dBmV
100 $\mu\text{V/m}$	-43.63 dBmV	1.78 dB	-45.41 dBmV
75 $\mu\text{V/m}$	-46.13 dBmV	1.78 dB	-47.91 dBmV
50 $\mu\text{V/m}$	-49.65 dBmV	1.78 dB	-51.43 dBmV
20 $\mu\text{V/m}$	-57.61 dBmV	1.78 dB	-59.39 dBmV
10 $\mu\text{V/m}$	-63.63 dBmV	1.78 dB	-65.41 dBmV

The calibrated leak was first configured with a CW carrier at 723 MHz, antenna A1 – a resonant half-wave dipole – installed on the receive antenna mast, and the feedline connected directly to a spectrum analyzer. The CW carrier was able to be measured with the spectrum analyzer at the higher field strength values, but was in the noise at 37.5  $\mu\text{V/m}$ .

The remaining tests were conducted at three field strength values: 150  $\mu\text{V/m}$ , 75  $\mu\text{V/m}$ , and 37.5  $\mu\text{V/m}$ . Tables 3 through 9 summarize test results when measuring the CW carrier and QAM signal<sup>18</sup> on CEA (2013) channel 112, with the various antennas connected directly to the spectrum analyzer, followed by use of a combination of preamplifier, bandpass filter, and spectrum analyzer. Antenna A5 was tested only with a direct connection to the spectrum analyzer.

**Table 3: Antenna A2 connected directly to analyzer**

Field Strength	CW carrier level	QAM digital channel power	Comments
150 $\mu\text{V/m}$	-37.2 dBmV	-36 dBmV	QAM haystack about 12 dB above analyzer noise
75 $\mu\text{V/m}$	-42 to -43 dBmV	-41.2 dBmV	QAM haystack about 6 dB above the analyzer noise

<sup>18</sup> The digital channel power of the QAM signal and the power of the CW carrier were identical.

37.5 $\mu$ V/m	-48 dBmV	Could not measure	QAM haystack barely visible above analyzer noise
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**Table 4: Antenna A2 with preamp and filter**

Field Strength	CW carrier level	QAM digital channel power	Comments
150 $\mu$ V/m	-26 dBmV	-25.4 dBmV	N/A
75 $\mu$ V/m	-32 to -33 dBmV	-31.4 dBmV	QAM haystack about 12 dB above the analyzer noise
37.5 $\mu$ V/m	-38 dBmV	-36 dBmV	QAM haystack about 6 dB above analyzer noise. Can see the QAM signal, but close to noise.

**Table 5: Antenna A3 connected directly to analyzer**

Field Strength	CW carrier level	QAM digital channel power	Comments
150 $\mu$ V/m	-35 dBmV	-35 dBmV	QAM haystack about 14 dB above analyzer noise
75 $\mu$ V/m	-40 dBmV	-40.4 dBmV	QAM haystack about 8 dB above analyzer noise
37.5 $\mu$ V/m	-45 dBmV	-44 dBmV	QAM haystack too close to analyzer noise for accurate measurement.

**Table 6: Antenna A3 with preamp and filter**

Field Strength	CW carrier level	QAM digital channel power	Comments
150 $\mu$ V/m	-24 dBmV	-23.7 dBmV	QAM haystack about 20 dB above analyzer noise
75 $\mu$ V/m	-29.8 dBmV	-29.4 dBmV	QAM haystack about 14 dB above analyzer noise
37.5 $\mu$ V/m	-35 dBmV	-34.7 dBmV	QAM haystack about 8 dB above analyzer noise

**Table 7: Antenna A4 connected directly to analyzer**

<b>Field Strength</b>	<b>CW carrier level</b>	<b>QAM digital channel power</b>	<b>Comments</b>
150 $\mu\text{V/m}$	-33.7 dBmV	-33.7 dBmV	QAM haystack about 16 dB above analyzer noise
75 $\mu\text{V/m}$	-39.3 dBmV	-39 dBmV	QAM haystack about 10 dB above analyzer noise
37.5 $\mu\text{V/m}$	-44 dBmV	-43.2 dBmV	QAM haystack about 4 dB above analyzer noise, very close to noise floor.

**Table 8: Antenna A4 with preamp and filter**

<b>Field Strength</b>	<b>CW carrier level</b>	<b>QAM digital channel power</b>	<b>Comments</b>
150 $\mu\text{V/m}$	-22.7 dBmV	-22.3 dBmV	QAM haystack about 21 dB above analyzer noise
75 $\mu\text{V/m}$	-28.5 dBmV	-28.1 dBmV	QAM haystack about 15 dB above analyzer noise
37.5 $\mu\text{V/m}$	-34 dBmV	-33.5 dBmV	QAM haystack about 9 dB above analyzer noise, very close to noise floor.

**Table 9: Antenna A5 connected directly to analyzer**

<b>Field Strength</b>	<b>CW carrier level</b>	<b>QAM digital channel power</b>	<b>Comments</b>
150 $\mu\text{V/m}$	-34.5 dBmV	-33.8 dBmV	QAM haystack about 14 dB above analyzer noise
75 $\mu\text{V/m}$	-40.5 dBmV	-39.1 dBmV	QAM haystack about 9 dB above analyzer noise
37.5 $\mu\text{V/m}$	-46.5 dBmV	-43.2 dBmV	QAM haystack about 4 dB above analyzer noise, too close to noise floor for accurate measurement.

Two handheld ham radio transceivers (“handi-talkies”) with wideband receive capability also were evaluated using a CW carrier as the calibrated leak’s test signal, the respective manufacturer-supplied rubber duck whip antennas and an external LPDA antenna. The first radio, a Yaesu VX-7R, was able to tune to 723 MHz, but could not receive the CW carrier with a whip antenna or the LPDA at any field strength up to and even above 150  $\mu\text{V/m}$ . An Icom IC-92AD was able to receive the CW carrier with both

antennas, but its signal strength meter provides only relative indications<sup>19</sup>, and as such cannot be used to measure the field strength of the CW carrier.

### 11.3. Discussion

One of the challenges that occurs when measuring UHF signal leakage is the antenna factor difference at higher frequencies compared to lower frequencies.<sup>20</sup> For example, the antenna factor of a half-wave dipole resonant at 121.2625 MHz is about 8.12 dB/m, while the antenna factor of a half-wave dipole resonant at 782 MHz is about 24.31 dB/m, a difference of 16.19 dB. The latter translates directly to an effective 16.19 dB loss of sensitivity at 782 MHz compared to 121.2625 MHz. Another way to look at it is to assume identical leakage field strengths at the two frequencies. For a 20  $\mu\text{V/m}$  leak, the RF power at the terminals of the 121.2625 MHz dipole will be -42.1 dBmV, while the RF power at the terminals of the 782 MHz dipole will be -58.29 dBmV for a 20  $\mu\text{V/m}$  leak. Here the difference in power at the two dipoles' terminals is 16.19 dB, the same as the antenna factor difference.

In order to have the same overall sensitivity at 782 MHz when using a dipole to measure leakage compared to using a dipole to measure leakage at 121.2625 MHz, a low-noise preamplifier with at least 16.19 dB of gain would be necessary with the 782 MHz equipment lashup. Alternatively, one could use a combination of high-gain antenna and preamplifier to improve overall sensitivity when performing UHF leakage measurements.

The results from Field Test 1 and Field Test 2 clearly show that low field strength UHF leaks are difficult or impossible to measure accurately without the use of at least a high-gain UHF antenna, preferably in conjunction with a low-noise preamplifier and bandpass filter (the field tests showed that a filter was necessary when using a preamp because of analyzer overload from nearby LTE signals). Such a combination of equipment is too unwieldy to use for routine leakage monitoring while driving, and is far better suited for detecting the presence of leakage at known problem locations – for example, where an LTE field engineer notes likely signal leakage.

Homebrew equipment combinations also cannot be used to accurately measure the field strength of UHF leaks. One major problem is that the actual antenna gain is uncertain or unknown. Published gain figures for some antennas *may* be questionable, or in some instances vague (dBi versus dBd not specified). Because of this, homebrew equipment combinations *should* only be used to confirm the presence of leakage at suspected problem locations, and to confirm that leakage can no longer be observed on the test equipment once a repair has been made. To the extent possible, commercial leakage detection and measurement solutions *should* be the first choice.

## 12. LTE Downlink Interference Testing

### 12.1. Objective

This section of the document summarizes the results of tests that were conducted to determine the impact of cable leakage on LTE downlink performance. The objective of the testing was to determine cable leakage field strengths that would affect performance of the LTE downlink. Testing was performed on October 4, 2013 at Charter Communication's facilities in Greenwood Village, CO.

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<sup>19</sup> Scanners and handheld ham radio transceivers often have a received signal strength indicator in the form of a bar graph or similar, but are not calibrated and provide only relative indications of received signal strength.

<sup>20</sup> See Hranac (2012, July)

## 12.2. Introduction

The term “downlink” refers to the communication link between a base transceiver station (BTS) at the cellular tower and the end user’s device such as a smart phone or tablet. The testing focused on the impact that cable leakage interference has on the LTE downlink.

The challenge with conducting such tests in the field is that there are a large number of variables that influence the resulting measurements. These variables include environment, terrain, physical obstructions, number of active users, and even other interference sources. Consequently, in order to minimize the effects of these variables, tests were conducted in a controlled environment.

## 12.3. Test Equipment

Rohde & Schwarz graciously provided the following equipment for the tests:

- Rohde & Schwarz CLG - Cable Load Generator: used to generate QAM “interference” channels (upper instrument in Figure 5).
- Rohde & Schwarz CMW500 - Wideband Radio Communications Tester used to simulate the LTE downlink to UE (lower instrument in Figure 5).
- R&S CMW-Z10 Portable RF Shielding Box (denoted as 1 in Figure 6).
- Mini Circuits Splitter-Combiner ZAPDJ-2-S to mix QAM Channels with LTE signaling (denoted as 2 in Figure 6).
- LG V600 User Equipment Simulator (denoted as 3 in Figure 6).

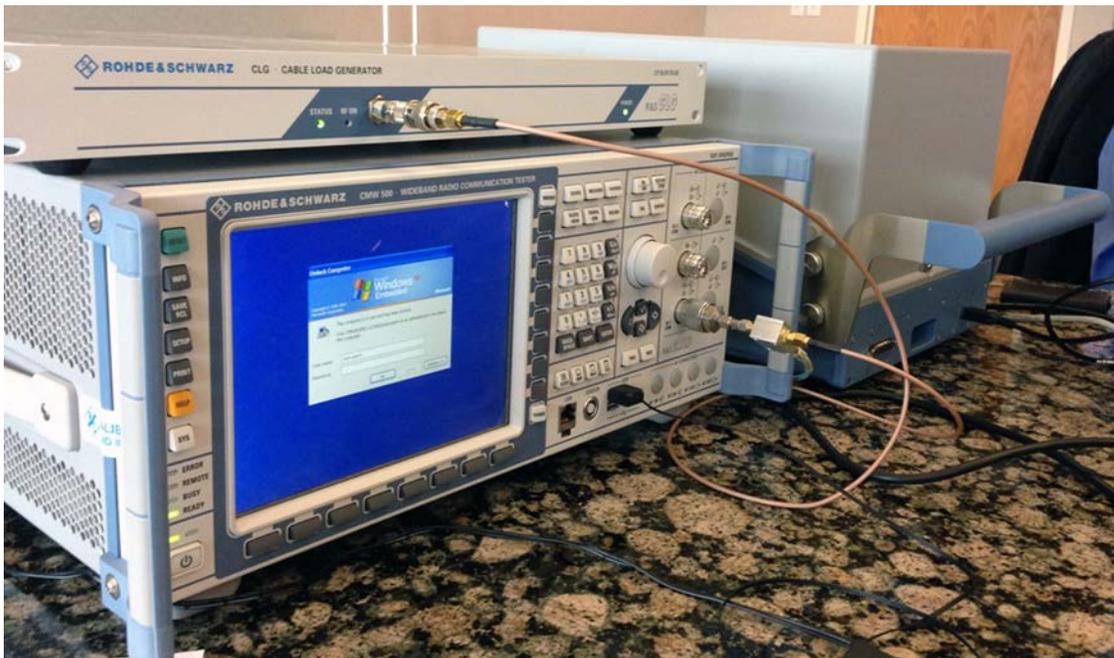
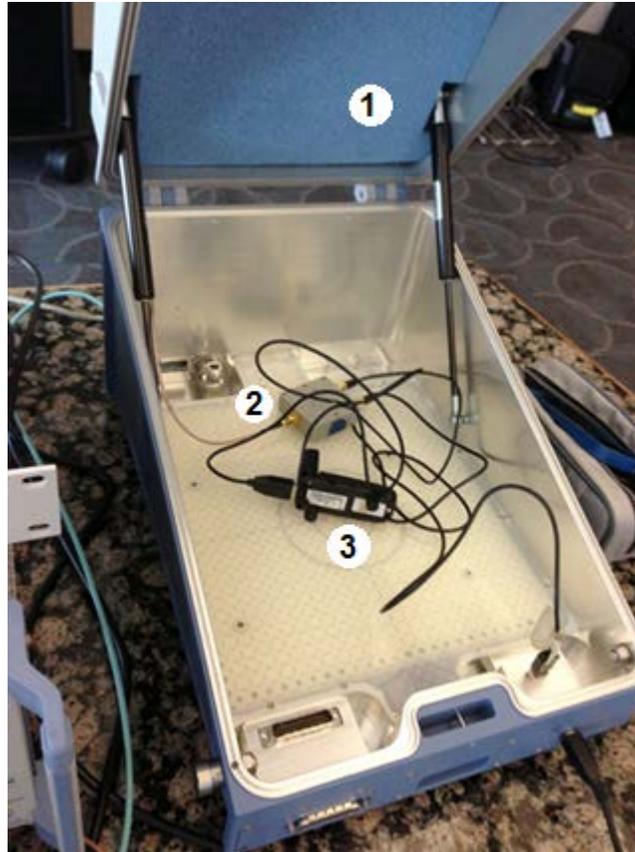
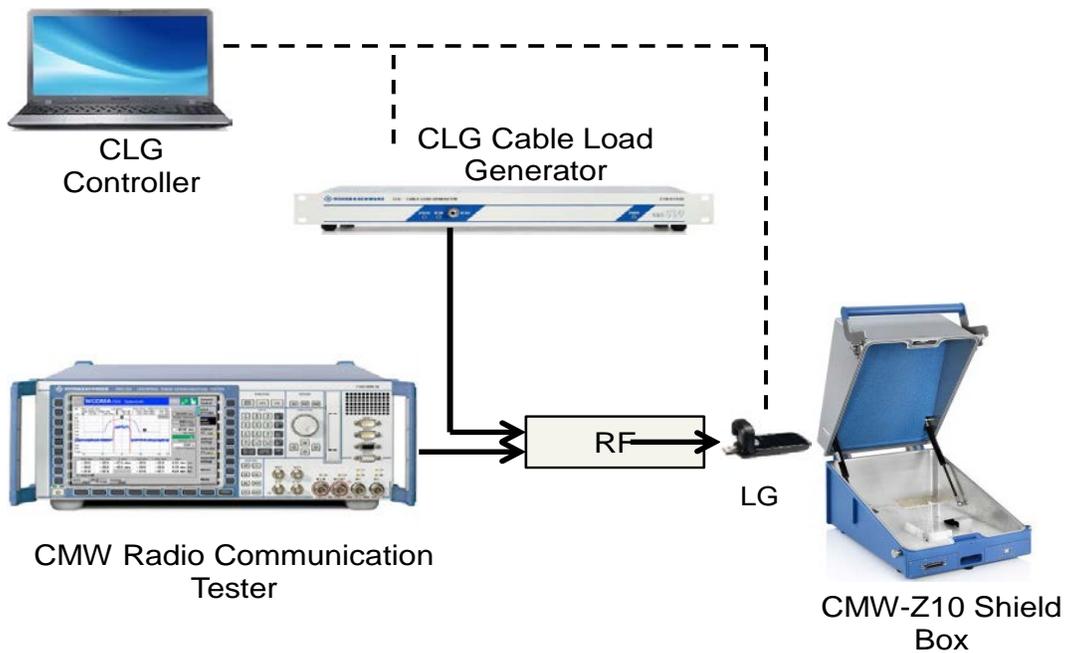


Figure 5: Rohde & Schwarz cellular and cable signal generating equipment



**Figure 6: Controlled testing environment**

A block diagram of the test setup is shown in Figure 7.



**Figure 7: Test setup for downlink test**

The CLG was configured to generate QAM signals on CEA (2013) channels 107-126 which overlap the 698 MHz to 806 MHz LTE spectrum, including channels 116-117 that directly overlap the LTE Band 13 downlink (746 MHz to 756 MHz). These channels were combined with the LTE downlink signaling from the CMW500 to act as the cable interference. The combined signals were then fed into the LG V600 UE simulator controlled using Verizon Access Manager software.

## 12.4. Defining the Test Parameters

Two UE device parameters were measured during the testing and used as indicators of downlink performance changes:

- CQI: Call quality index that ranges from 0 (worst) to 14 (best)
- Data throughput in megabits per second (Mbps)

The LTE downlink signal was controlled and varied by the Rohde & Schwarz CMW500. An explanation of the various modes and signal variables follows:

### Modes of Operation

- The User Defined Mode allows manual adjustment of LTE parameters such as the modulation order and the transport block size. The CQI Mode automatically scales the modulation order and transport block size based on connection conditions. This is the default mode for consumer devices.
- Most of the testing done was in the User Defined Mode because it allowed precise control over the modulation order and the transport block size.

Two primary downlink control parameters were varied during the testing:

- RS-EPRE - Reference signal energy per resource element, equivalent to the signal strength received at the UE device.
- TBSI - Transport block size index, ranges from 0 (most robust) to 26 (least robust). TBSI controls the amount of error correction and overhead that is applied to the downlink signal. As the TBSI is increased, a smaller percentage of error correction is applied, thus increasing the possible data throughput rate. A high TBSI would be used in cases when there is little interference resulting in a good signal-to-noise ratio (SNR). This parameter normally auto adjusts based on the quality of the link between the base station and the UE device.

Other measurement parameters that provide information about the call connection quality are:

- CR - Code rate, the percentage of data payload versus amount of error correction overhead. A higher percentage equals more payload versus overhead. This is directly tied to the TBSI.
- BLER - Block error rate, the percentage of errors detected per block.

In order to get a better feel for how the modulation order, TBSI, CR, and data rate relate to each other, here are some examples:

- Using a 64-QAM constellation and a TBSI of 26 enables a maximum data rate of 36.7 Mbps with 5.9% overhead for error correction (CR = 0.9411). This represents the smallest amount of error correction, thus the highest possible data rate.
- If the TBSI is lowered to 24 with the same 64-QAM constellation, the maximum data rate is reduced to 30.6 Mbps with 21.3% overhead for error correction (CR = 0.787). If the TBSI is further lowered to 21, the maximum data rate drops to 25.46 Mbps with 34.4% overhead (CR = 0.656).

- Jumping to the lowest possible combination of QPSK with a TBSI = 0, the data rate falls to 1.3 Mbps with 80% overhead (CR = 0.2). This represents the most robust signal type traded for a minimal data rate.

### 12.5. Test Methodology and Results

The QAM power (QP) leakage levels were adjusted, starting from low to high, to determine the impact on the downlink using different RS-ERPE (signal strength) and TBSI (error correction) levels. The testing started with a baseline test using the following settings:

- RS-ERPE = -52.2 dBm
- Mode = CQI
- Auto QAM
- TBSI = Auto

This represents a typical real-world scenario where the downlink will auto adjust based on the quality of the connection. The RS-ERPE of -52.2 dBm represents fairly good signal strength.

The QAM power was started at -30 dBmV (decibel millivolt) representing an equivalent 497  $\mu$ V/m leak at 750 MHz and was combined with the downlink signal. The measured impact on the connection quality was as follows:

- CQI=14 (best)
- Data Rate of 23.6 Mbps

The QAM constellation and TBSI were set to auto so the actual numerical parameters were not available. A reasonable guess would be QAM = 64, TBSI = 20. The QAM power was then systematically increased to observe the change in the CQI and/or the data rate.

Test results appear in Table 10. The first noticeable change in data rate occurred at -5 dBmV (8,836  $\mu$ V/m) where the data rate dropped to 15 Mbps. At -4 dBmV (9,914  $\mu$ V/m), the connection totally dropped. Note that: (1) It takes a very large leak to impact the downlink performance at a signal strength of -52.2 dBm and (2) instead of slowly degrading the connection quality as the QAM power was increased, there was a cliff effect: perfectly good at -7 dBmV, then completely gone at -4 dBmV. This *may* be a function of the CMW500's ability to rapidly auto adjust to the connection conditions, but this is only a hypothesis.

**Table 10: Auto QAM results**

RS-ERPE = -52.2 dBm		
Mode = CQI		
Auto QAM, TBSI: Auto		
QP (dBmV)	CQ	Rate (Mbps)
-30	14	23.6
-10	14	23.6
-9	14	23.6
-8	14	23.6
-7	14	23.6
-5	14	15
Connection Dropped at -4		

In the next stage of testing, the CQI auto adjustment setting was turned off allowing better control and gaining knowledge of numerical values of all parameters.

Stage 2: Change from CQI Mode to User Defined Mode. Keeping RS-ERPE the same (-52.2 dBm), QAM = 64, and TBSI = 21, the tests were repeated starting at a QP of -10 dBmV (4,969  $\mu$ V/m). Table 11 summarizes the test results.

**Table 11: User defined results**

RS-ERPE = -52.2 dBm		
Mode = User Defined, 64-QAM		
TBSI = 21, CR = 0.656		
QP (dBmV)	CQ	Rate (Mbps)
-10	14	25.5
-8	14	25.5
-7	14	25.5
-6	13-14	25.5
-5.5	13	25.5
-5	13	25.5
-4.5	13	25.5
-4	13	23
-3.5	13	21
Connection Dropped at -3		

At -6 dBmV, there was a slight shift in the CQI, but no apparent change in the data rate. It took an equivalent leak level >9,900  $\mu$ V/m to noticeably impact the connection quality. The same cliff-effect connection drop occurred, however this is to be expected since the QAM and TBSI values were fixed.

In the next series of tests, the RS-ERPE and/or the TBSI values were significantly adjusted to worst case values to determine if lower leakage levels would impact the connection quality. Results are shown in Table 12. Boldface text indicates the parameters that were changed in each test run.

**Table 12: Results with various parameter changes**

RS-ERPE = -80 dBm			RS-ERPE = -100 dBm			RS-ERPE = -100 dBm		
Mode = User Defined, 64-QAM			Mode = User Defined, 64-QAM			Mode = User Defined, 64-QAM		
TBSI = 26, CR = 0.9411			TBSI = 25, CR = 0.81			TBSI = 24, CR = 0.787		
QP (dBmV)	CQ	Rate (Mbps)	QP (dBmV)	CQ	Rate (Mbps)	QP (dBmV)	CQ	Rate (Mbps)
-20	14	36.7	-30.0	13	27-28	-100	14	30.6
-15	14	36.7	-29.5	13	25	-50	14	30.6
-13	14	36.7	-29.0	13	24	-45	13	30.6
-10	14	33-35	-28.5	13	24	-40	13	27.0
-9.5	14	32.0	-28.0	13	23	-39	13	25.0
-9.0	14	30.0	-27.5	13	23	-38	13	20.0
-8.5	14	29.5	Connection Dropped at -27 Connection was unstable at Start TBSI too high for reliable results Data Rate should have been 31.7			Connection Dropped at -37		
-8.0	14	27.0						
-7.5	14	5 to 8						
Connection Dropped at -7 BLER = 8.5% at -8.0; 13% at -7.5								

Using a weaker signal strength of an RS-ERPE = -100 and a TBSI of 24, the connection was dropped at -38 dBmV which is approximately 198  $\mu$ V/m. Note that the CQI and data rate did start to deteriorate slightly at -40 dBmV (157  $\mu$ V/m). Thus in a scenario where a UE has a weaker signal strength, a fixed

64-QAM constellation, and a moderate amount of fixed error correction (TBSI = 24, CR = 0.787), the connection quality would be affected by a 157  $\mu\text{V/m}$  leak and completely dropped by 198  $\mu\text{V/m}$ . This scenario is unlikely to occur in the field because the TBSI would auto adjust downward to compensate for the poor SNR and to maintain the best possible connection quality. However, these levels of interference did cause a change in the connection performance levels.

For reference purposes, there was a need to determine the lower limit of the RS-ERPE signal strength before a connection was dropped with minimal leakage present ( $<1 \mu\text{V/m}$ ). Using QPSK and a TBSI = 0 (80% error correction), the connection was lost at an RS-ERPE of -126 dBm. This result correlates to the minimum received signal strength of -124 dBm specified in ETSI (2011, January) for the LTE Bands 12, 13, 14, and 17 which cover 698 MHz to 806 MHz. Based upon the performance noted earlier, this identifies a RS-ERPE range (-100 dBm to -126 dBm) in which a leak measuring 198  $\mu\text{V/m}$  can degrade the downlink performance.

The FCC NPRM currently proposes a leakage limit of 13.1  $\mu\text{V/m}$  at 30 meters (equivalent to 131  $\mu\text{V/m}$  at 3 meters) for digital leakage above 216 MHz. Test results reveal that this limit appears to be within a reasonable range that will minimize performance impact on the downlink for most of the useable RS-ERPE. At lower limits of the RS-ERPE range ( $<-100 \text{ dBm}$ ) the TBSI will likely auto-adjust to compensate for the lower SNR and provide improved interference immunity. With a lower TBSI, it is possible that 131  $\mu\text{V/m}$  *may* have a negligible effect on the downlink at a RS-ERPE of -100 dBm. That said, it is important for cable operators to understand that harmful interference *may* occur when signal leakage field strength is below the maximum limits stated in §76.605 of the FCC Rules, or below the proposed maximum limit in the NPRM. In other words, low field strength leaks *may* cause harmful interference depending on the distance between the leakage source and the affected receiver. At lower RS-ERPE of -113 dBm to -126 dBm, the likelihood of degrading LTE performance will depend on the separation distance between a leak of 131  $\mu\text{V/m}$  at 3 meters and the victim receiver. The resulting field strength of a leak is reduced by 6 dB with every doubling of the distance between the leak and receiver. For example, if the field strength 3 meters from a leak is 150  $\mu\text{V/m}$ , the field strength 6 meters from the leak will be 75  $\mu\text{V/m}$ , a 6 dB difference (Note: This relationship assumes unobstructed free-space path loss. Reflections and path obstructions *may* affect the actual field strength variation versus distance.) The level of impact of a given leak on LTE performance will also vary with distance between the leakage source and the affected LTE equipment.

## 13. LTE Uplink Interference Testing

### 13.1. Objective

This section of the document summarizes the results of lab tests that were performed to determine the impact of digital cable leakage on LTE uplink performance. The objective of the testing was to determine the power levels of QAM signal leakage that would cause measurable interference to an LTE uplink.

### 13.2. Introduction

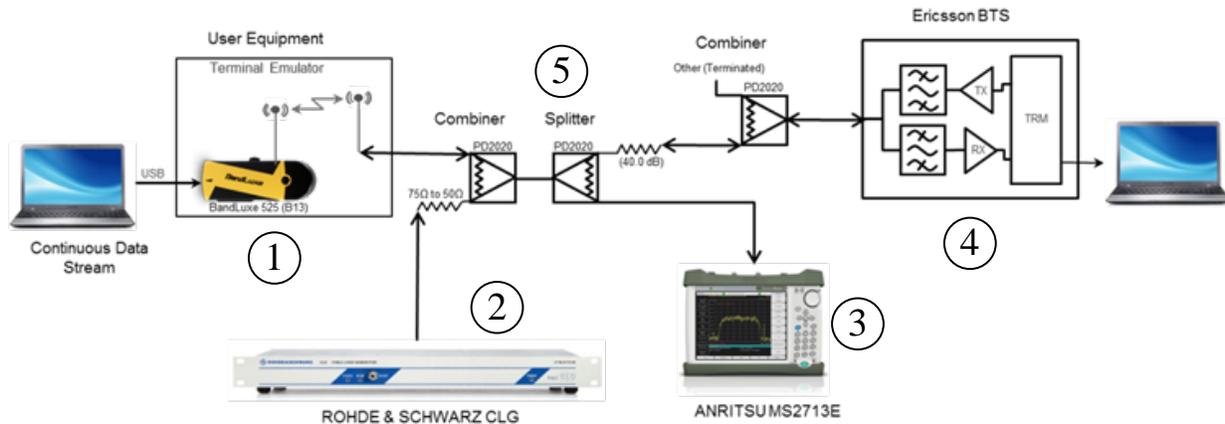
The term “uplink” as used in this section refers to the cellular communication link between the LTE UE and a LTE cellular tower's BTS. The testing focused on the impact that digital cable leakage can have on the LTE uplink which provides high-speed upstream data services to the UE (smart phones, tablets, etc).

The uplink testing is very difficult to perform in the field because of several variables that influence the measurements. These variables include environmental factors, terrain, number of active users, antenna configurations, and various interference sources. In order to minimize the effects of these variables, tests

were conducted in a controlled environment. Working in cooperation with Ericsson, the tests were performed in their Advanced Technology Lab in Plano, TX.

### 13.3. Test Environment

The cable leakage interference testing was performed using the setup shown in Figure 8. The following is a description of the primary elements used in the test setup.



**Figure 8: Test setup for uplink test**

- 1) A UE device was used to establish a cell phone connection to a live LTE BTS that was continuously transmitting data. A personal computer (PC) was used to generate the data stream which was connected to the UE for transmission.
- 2) Cable leakage was simulated by using a Rohde & Schwarz CLG to generate QAM “interference” signals. The CLG was configured to generate QAM signals on CEA (2013) channels 107-126 (690 MHz to 810 MHz), which overlap the 698 MHz to 806 MHz frequency band, designated for use in the U.S. by LTE and other services. The QAM signals were combined with the UE cellular signaling using a lab-grade combiner.
- 3) The combined signals were monitored using an Anritsu 2713E spectrum analyzer. This was done by using a splitter/combiner to split the signal between the analyzer and the feed to the LTE BTS.
- 4) The combined UE and QAM signaling was directly fed into a live LTE BTS via a coaxial cable connection to the BTS’s antenna port.
- 5) The path loss between the UE and CLG to the BTS was carefully measured in order to properly calculate the actual levels of signaling that were reaching the BTS antenna port.

### 13.4. Defining the Test Parameters

Two base station parameters were used to monitor the uplink performance changes:

- Received signal strength indication (RSSI)
- Data throughput in Mbps.

The BTS element management system captured hundreds of different measurement parameters during the lab tests, however, for the purposes of this document, only the RSSI measurements were used to detect the presence of interference. RSSI was used in order to simulate the same monitoring parameter used by LTE service providers. The RSSI represents the signal plus cumulative noise floor measurement at the cellular site and has a direct correlation with LTE service performance. Another point worth noting is that the BTS measurements are only reported in 15 minute intervals, thus any effects on the BTS caused by changes to the QAM signal power were only available after a 15 minute lag time.

### 13.5. Test Methodology and Results

The QAM signal power levels were adjusted, starting from low to high, to determine the impact on the LTE uplink. The only real time measurement parameter available was the data throughput which could be acquired via a PC from the UE device. The initial round of testing used the data throughput parameter as an initial method to determine what QAM signal power started to interfere with system performance. This was an important step prior to running the BTS interference testing to help determine a general starting point for the QAM signal power and to help overcome the 15 minute reporting limitation from the BTS. Once a known QAM signal power was established that impacted the data throughput, this was used to determine a general starting point for the QAM signal power for the RSSI testing. The actual starting point was lowered to ensure the start point was below detectable interference levels. Prior to starting the test, the base station RSSI was checked at this initial QAM signal power level to ensure no measureable interference was occurring.

The next step was to increase the QAM signal power in 6 dB steps every 15 minutes. At each QAM signal power level, both a time stamp and a data throughput measurement were recorded. This process continued for several hours until the QAM signal power reached a point where the interference was severe enough that it caused the UE connection to drop.

A full report containing all parameters from the BTS element management system was then provided which included the 15 minute time stamps for all measurements. This data was matched with the QAM signal power time stamps to determine what levels of QAM signal power had a corresponding impact on the BTS.

A summarized set of results is provided in Table 13, and shows the QAM signal power (and equivalent leakage field strength) reaching the antenna with 12 dBi of gain, the data throughput level, and the corresponding time stamp. An examination of the data shows that at an equivalent leakage field strength of 5.1217  $\mu\text{V}/\text{m}$  at the plane of the antenna, the data throughput started to show signs of impact.

**Table 13: QAM power test data**

BTS Interference Test										
CLG QP	QAMPwr	Uplink	QP 6MHz BW	QP 10MHz BW	QP at BTS	QP at 12dBi Ant	Leak at Ant	Through Put		Time
dBmV	dBmV	dBmV	dBmV	dBmV	dBmV (6MHz)	dBmV	$\mu\text{V}/\text{m}$	min	max	
-38	-40.5	-4	-28.0	-25.3	-87.3	-99.3	0.1776	12.8	13.5	2:00
-32	-40.5	-4	-28.0	-25.3	-87.3	-99.3	0.1776	12.8	13.5	2:15
-26	-40.5	-4	-28.0	-25.3	-87.3	-99.3	0.1776	12.8	13.5	2:30
-20	-40.5	-4	-28.0	-25.3	-87.3	-99.3	0.1776	12.8	13.5	2:45
-14	-38.3	-4	-25.8	-23.1	-85.1	-97.1	0.2288	12.8	13.5	3:00
-8	-34.6	-4	-22.1	-19.4	-81.4	-93.4	0.3503	12.8	13.5	3:15
-2	-29.1	-4	-16.6	-13.9	-75.9	-87.9	0.6598	12.8	13.5	3:30
4	-23.2	-4	-10.7	-8.0	-70.0	-82.0	1.3014	12.8	13.5	3:45
10	-17.2	-3.5	-4.7	-2.0	-64.0	-76.0	2.5967	12.8	13.5	4:00
16	-11.3	-3.5	1.2	3.9	-58.1	-70.1	5.1217	10.5	11.8	4:15
22	-5.2	-1.8	7.3	10.0	-52.0	-64.0	10.3375	3.5	4.2	4:30
27	-0.5	1	12.0	14.7	-47.3	-59.3	17.7589	0.3	1	4:45

The graph in Figure 9 shows the RSSI output from the BTS. A small red circle is shown on the graph at the time stamp when the equivalent leakage level at the antenna was clearly causing an increase of the RSSI which corresponds to a leakage field strength of the previously mentioned  $5.1217 \mu\text{V}/\text{m}$ . This graph clearly shows that each QAM signal power increase after this point had a dramatic effect on the RSSI values. It is interesting to note that both of the parameters, RSSI and data throughput, started to show signs of deterioration at the same level of interference.

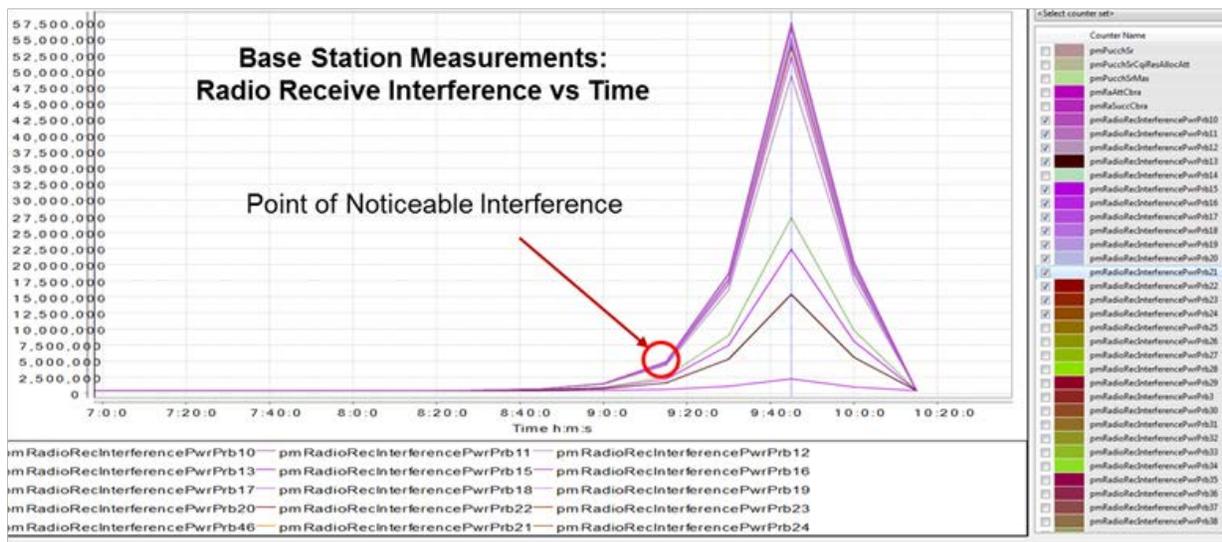


Figure 9: RSSI output from BTS over time

The next step in the process was to convert the  $5.1217 \mu\text{V}/\text{m}$  into useable information. The  $5.1217 \mu\text{V}/\text{m}$  value represents the field strength of a leak directly at the LTE tower antenna. Since sources of cable leakage will not occur directly adjacent to these antennas, it is necessary to convert the leakage field strength to an equivalent leakage level at some distance away from the LTE antenna. In other words, what leakage level would it take at distance "x" from the antenna to reach the base station antenna at a level of  $5.1217 \mu\text{V}/\text{m}$ ?

Based upon free-space loss, the graph in Figure 10 plots the distance from the leak to the BTS antenna versus the equivalent leak level that represents the  $5.1217 \mu\text{V}/\text{m}$  leakage field strength at the antenna. This graph can now be used to represent the equivalent leak levels that would cause detectable change in the RSSI at the BTS at a known distance from the tower. The numerical values shown represent the field strength of the leakage measured at 10 feet from the cable network. This data is extremely useful for cable operators since it provides a general guide to determine which leaks *may* cause LTE interference detected by an increase in the BTS RSSI.



**Figure 10: Equivalent leakage levels versus distance from tower**

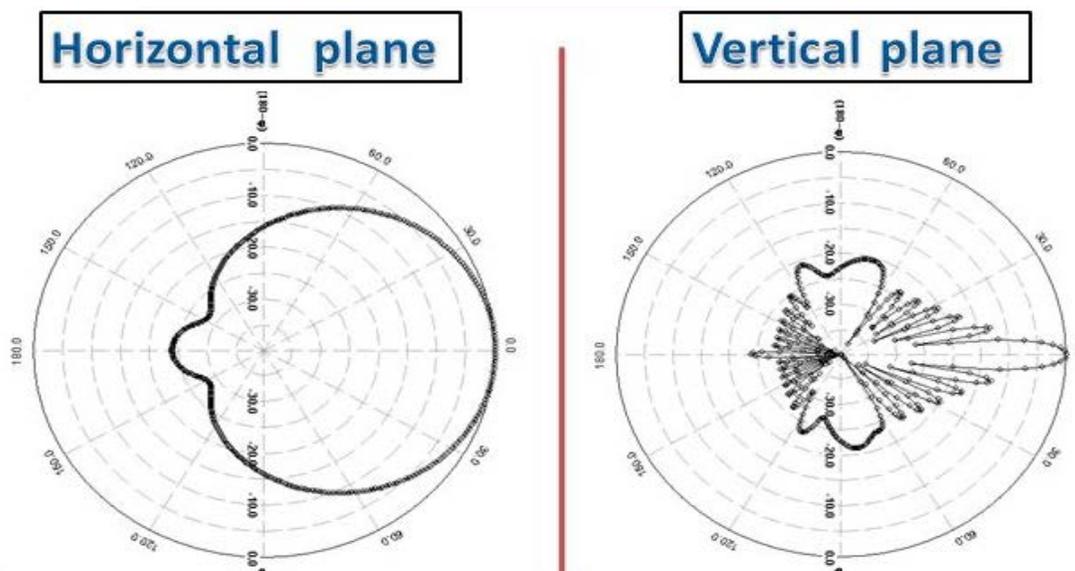
There are a few caveats that need to be brought to light in order to qualify the data represented in these test results. The data shown here are representative of measurements taken in a controlled lab environment and under fixed conditions. A real world environment has many variables that will impact the measured data. These variables include such factors as:

- Multiple-input / multiple-output (MIMO) vs single-input / single-output (SISO) antennas. The lab testing at Ericsson simulated the equivalent of a SISO antenna configuration. A MIMO configuration, which is commonly used in LTE deployments, provides the added benefit of better interference rejection.
- BTS antenna gain and down tilt (mechanical and electrical). The reduction of antenna gain due to variances in vertical antenna pattern near the cellular tower *may* lessen the impact of QAM signal leakage that falls underneath the antenna pattern's main lobe.
- Terrain variance, physical obstructions and reflective surfaces between the tower and UE. Physical obstructions such as trees and building can have a dramatic effect on the QAM signal field strength that reaches the BTS that is not accounted for in a free-space loss model.

All of these factors will have a significant impact on how leakage levels impact RSSI. However, the testing performed in the Ericsson lab still has value in that it represents a worst case scenario, and establishes a usable baseline to work from.

The current FCC signal leakage limit of 15 µV/m at 30 meters in the LTE spectrum is equivalent on a free-space basis to 150 µV/m at 3 meters. Looking at the graph in Figure 10, at a distance of 600 feet from the BTS tower, the leakage level is 154 µV/m which is very close numerically to the current FCC limit of 150 µV/m. At distances greater than 600 feet, the leakage levels shown on the graph are higher than the FCC limit, and therefore, the current limit of 150 µV/m *may* provide protection for leaks of 150 µV/m and lower that are beyond 600 feet from the tower.

What about the leaks that are less than 600 feet from the tower? Per the test data, these leaks can be less than the 150  $\mu\text{V}/\text{m}$  limit and still cause interference to the BTS equipment. However, there is another aspect that needs to be considered: the antenna tilt and radiation pattern. The antenna radiation pattern is fairly narrow in the vertical direction and is typically not wider than 15 degrees as shown in Figure 11.



**Figure 11: Antenna tilt and radiation pattern**

The proximity of a leak under the antenna’s main lobe *may* have a reduced impact on the BTS depending on its field strength in combination with its proximity in the radiation pattern. The vertical antenna pattern can impact the sensitivity gain by 20 dB or more depending on the location of a leak with respect to the side lobes. In addition, there are many other variables that can impact the actual signal strength of the leak that reaches the BTS. Variables such as physical obstructions (buildings, trees, etc.), terrain, and elevation are some examples that will impact the amount of leakage that reaches the cellular antenna. This means that we cannot use fixed guidelines to determine what leakage levels will cause known harmful interference to a BTS. There is an increased probability that leakage underneath the main lobe of a cell tower will have a reduced effect depending on field strength, however it is not quantifiable using generalized assumptions.

In a cellular tower configuration in which the LTE antennas are greater than 100 feet in height from the ground level, a distance of 600 feet from the tower would fall under the main antenna lobe. However, there are cases where the LTE antennas are not located on towers, but rather in close proximity to cable infrastructure. One example is microcells placed on the sides of buildings or on utility poles. In these cases, even smaller amounts of leakage could have a higher potential of causing LTE interference.

Additional field testing was performed in cooperation with Verizon Wireless in order to validate the Ericsson field testing. Controlled leakage was produced at various distances from a live cell tower and the resulting RSSI measurements were collected. The results confirm the Ericsson testing data although with variances in the leakage levels as they related to the amount of impact on the RSSI. These variances were expected due to the external environmental variables and the use of a MIMO antenna as described previously. The Verizon test data generally showed that the use of a MIMO antenna helped to reduce the impact of QAM signal leakage as compared to the use of the SISO antenna in the Ericsson testing. However, it is not possible to quantify a generalized impact because of the influence of the many variables that were not controllable during the test. Figure 12 shows the captured RSSI data from the BTS element management system during the field testing.

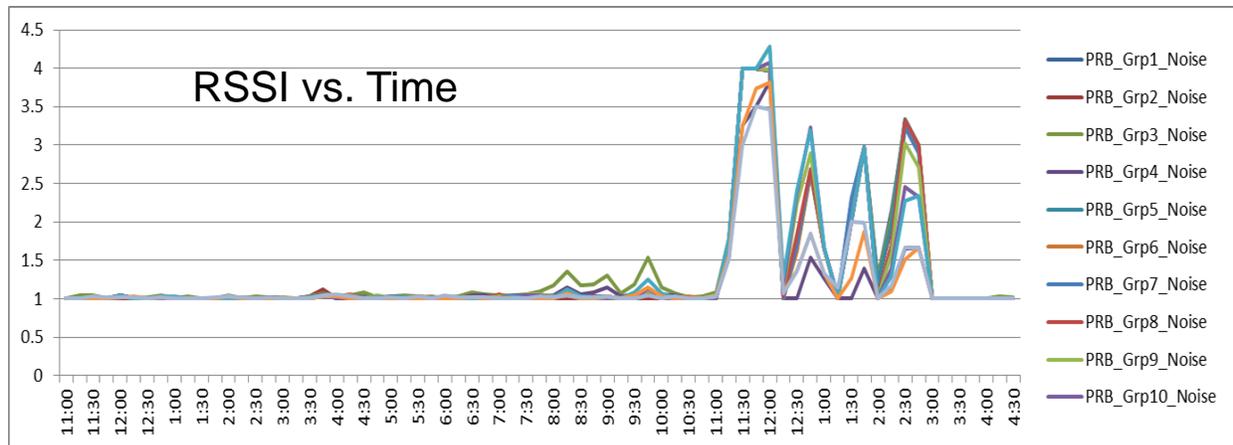


Figure 12: RSSI data from Verizon field test

### 13.6. Summary

Based on the test data in the Ericsson lab and further validated by the field testing with Verizon, this study clearly indicates that QAM signal leakage can have a definitive impact on the LTE uplink performance. A field strength as low as 5  $\mu$ V/m at the plane of the antenna was shown to cause interference. A practice using an effective VHF and UHF leakage management program is recommended to help mitigate potential LTE interference along with the need to cooperate with LTE service providers when interference occurs.

## 14. Summary and Conclusions

UHF leakage, ingress, and direct pickup are solvable challenges. UHF leakage was identified as a problem once wireless service providers started to deploy LTE technology, and is far more common than many assumed. This is largely because of the lack of correlation between VHF and UHF leakage field strengths from the same leak source. 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.

The cable industry has experience with UHF ingress, mostly from UHF TV signals and now from LTE towers and equipment. Direct pickup interference to older set-tops and other CPE from cell phones has been a known problem for a few years, and LTE UE is now on the list of devices that can cause ingress and direct pickup interference. More recently, some cable operators have experienced direct pickup interference to certain types of headend and hub site equipment, typically requiring the manufacturer to modify or replace the affected equipment.

UHF leakage has become important for the cable industry. Since legacy leakage detection equipment was designed to operate in or near the VHF aeronautical band, cable operators have had little or no visibility into their networks' leakage performance at higher frequencies. Fortunately, test equipment manufacturers have introduced digital-compatible leakage detection products that operate in the UHF spectrum, so technology is now widely available allowing cable operators to implement UHF leakage monitoring programs. There are some homebrew combinations of test equipment that *may* be usable as short-term solutions to confirm the presence of moderate- to high-level UHF leakage at known problem locations, until commercially-manufactured UHF detectors are obtained locally. However, the homebrew methods are not suitable for widespread monitoring or accurate field strength measurements. To the

extent possible, the commercial solutions *should* be the first choice. It is strongly recommended that all cable systems implement a UHF leakage program in conjunction with their existing VHF leakage program as soon as possible.

In addition, ingress and direct pickup can interfere with cable services, causing subscriber dissatisfaction and increased churn. UHF ingress *may* affect the ability to reliably deploy next-generation DOCSIS technology, or obtain the highest spectral efficiency (bits per hertz) from it.

The industry needs to approach the challenges of UHF leakage, ingress, and direct pickup from several directions: One is to implement UHF leakage management programs in conjunction with existing VHF leakage management programs. Another is to make sure future leakage problems are avoided, which can be done with training, good craftsmanship, quality control, and effective maintenance programs. Understanding the causes of UHF leakage, ingress, and direct pickup, how to deal with them when they occur, and how to prevent them going forward are critical. Adopting best practices strategies for today and the future are key.

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## Appendix A: current test equipment and procedures

### A.1 Arcom Digital Solutions

#### Measuring Digital Leakage

A technique to directly detect and measure QAM channel signal egress from hybrid fiber coaxial (HFC) network is the correlation method. Simplified, the correlation method looks at two signal sets to determine if they are the same. The first signal set is a reference signal that is acquired by connecting to the cable network; and depending upon the product, this reference is captured either at the headend or in the field. The second signal set is a leakage signal captured using an antenna at a field location. The signal sets are then analyzed using a correlation detector, and if there is correlation and the two signals contain the same components, then with certainty the signal detected at the leakage antenna is the exact same signal that originated from the network – and we know QAM egress is being measured.

The leakage detector output is the correlation function as graphed in Figure 1. Time delay is displayed on the x-axis and magnitude of the detected leak is displayed on the y-axis. Peaks of the correlation function indicate that leakage has been detected at the corresponding time delay. In the example shown, the marker at the peak indicates the detected leak field strength of 31.6  $\mu\text{V}/\text{m}$ , at a time delay of 98.217 microseconds ( $\mu\text{s}$ ). This time delay information is further utilized in a time difference of arrival (TDOA) location technique that exactly calculates the GPS coordinates of the leak source location and leak level adjusted to a 3 meter (approximately 10 feet) measurement distance.

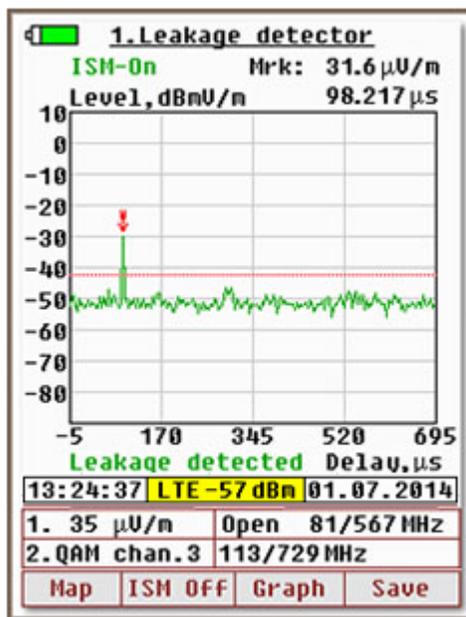


Figure 1: Navigator signal display

This correlation technology is sold under the QAM Snare® name. QAM Snare comprises several product implementations that range from simple stand-alone units intended to troubleshoot locations where LTE interference is known to exist, to fully integrated, mobile leakage detection and location platforms, as well as aircraft based systems.

Common to all implementations is the need to capture reference samples for the desired channel, the need to establish common timing of the reference samples in relation to the leakage samples, and the need

to deliver the reference sample set and timing to the device that performs the correlation. The previously mentioned QAM Snare products and implementations handle these processes in several different fashions.

### **Product Implementations**

The simplest implementation is for stand-alone detection. Here, two small low-cost handheld devices are utilized – with the first device performing the function of acquiring and transmitting samples (the transmitter), and the second device performing the function of detector and correlator (the detector). No equipment of any sort needs to be installed in the headend. The transmitter is connected via a coaxial cable to any convenient connection point – an open multi-tap port, a splitter, a test point, etc. The transmitter takes reference samples of the desired QAM signal, and though a simple industrial, scientific, and medical (ISM) band chipset which also manages the timing, transmits the samples over the air to the companion detector unit. The detector receives the samples and correlates with samples it has acquired from its leakage antenna. The leak level is displayed, and the user simply points and moves in the direction of increased level to identify and resolve the leaking device or connector. Multipath signal components have historically proven to complicate the final identification step and have made leakage detection challenging, described as somewhat of an art. With the correlation method just described, multipath would manifest as additional lower amplitude peaks of the cross-correlation function. In software this is overcome by filtering out all but the main peak, thereby inherently eliminating multipath as an issue and significantly simplifying the location step. Additionally, correlator technology-based detection utilizes the full 6 MHz QAM channel bandwidth, providing a much more stable leakage signature that in itself is inherently less prone to multipath. This described product is referred to as an Isolator Set and its implementation has applications for use in the field to resolve locations of LTE problems or complaints, applications for MDUs, within the home for troubleshooting or certification, as well as applications in the headend as a quality control (QC) and troubleshooting tool.

A second implementation of the correlator technology is for installation in a leakage patrol vehicle. In this implementation, the reference signals from the desired QAM signal(s) is captured at the headend. Simultaneously, a time stamp is also recorded utilizing the GPS reference clock. The reference signal and time stamp form a small data packet which is transmitted over a wireless network to the field unit each second. To ensure common timing, the field unit also utilizes the GPS reference clock to time stamp the leakage samples it records from the over-the-air antenna.

Prior to the correlation process, time stamps from both sample sets are automatically coordinated and aligned, compensating for any delays in the transmission. As the vehicle drives around the plant it continuously and in real time searches for leakage, and when detected it calculates the GPS coordinates of the leak and instantly updates the database with the leak information. When the technician wants to fix or resolve a leak, he or she simply pulls the unit from the cradle and is able to walk about freely. This implementation is split into several product variants optimized for the method being used – one variant is the Monitor Plus, which is a black box type of device that is intended to be installed in a vehicle collecting data without any user interaction; a second is a product called the Navigator Plus that is intended to be used by the technician tasked with fixing leaks. The Navigator Plus has a display and contains maps which show the flagged detection point, simplifying the process for the technician. And a third variant is called the Isolator Plus, which is optimized for the fulfillment technician for use with the home and drop.

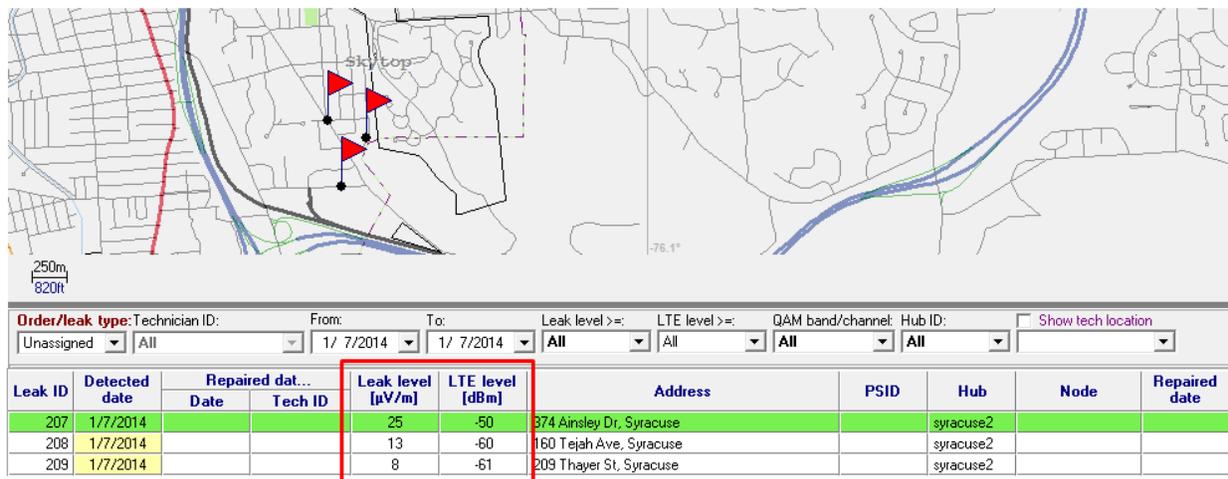
An additional implementation of the technology is an adaptation suitable for leakage flyovers. Here, all processing is performed off-line, and no real-time communication with the aircraft is necessary. While flying, the leakage detector continuously stores leakage samples as well as GPS time stamps and coordinates. After landing, the device in the aircraft establishes a wireless connection with a server that

has stored the corresponding reference samples taken at the headend. The samples are then transmitted to the device and the flight path is recreated off-line – this time with the correlation process being performed and leakage recorded.

### **How to operationally use QAM Snare, and which QAM Snare product to use**

There are a few approaches that can be taken for leak mitigation that depend upon the goals and strategies of the particular operating entity. If the intent is to solely react to locations where an LTE provider has posted notification of a problem, then the recommended product would be an Isolator Set described in the first implementation. Go to the address that the LTE provider has indicated, tune the unit to an LTE frequency such that leak frequency response variations are accounted for and to ensure the technician is searching for the correct leak, connect the transmitter to any open tap or test point – and point and move around with the detector unit in the direction of increasing leak amplitude until the deficient network component is found, and then repair the leak.

If the intent is to be proactive and to find and repair leaks that are most likely to affect LTE providers, then a more systematic approach is required, based upon intelligent prioritization not solely reliant upon leak level. Two factors determine whether egress from given leak will adversely affect LTE transmission: The most dominant factor is the distance and beam path from the leak to tower, followed by the amplitude of the leak at the LTE transmission frequency. If a mitigation approach is taken where the technician simply starts with the highest level leaks and ignores the distance element, then significant cost and time will be spent mitigating leaks that aren't causing a problem to the LTE provider, while at the same time many smaller amplitude leaks that are actually causing LTE problems might be ignored. QAM Snare has a solution to this significant operational problem implemented into the platform in two ways. Simultaneous to the leakage detection, an approximation of determining distance and beam path is realized in the form of measuring the LTE signal level and recording the result in the leak database. Since the correlation process is realized in a fraction of a second, when not correlating the device tunes to and scans through the LTE downlink and public safety frequencies and measures the LTE signal level. Secondly, since QAM Snare is frequency agile, it allows for measuring LTE egress exactly at the LTE band. Field testing has proven that UHF leaks can have significant frequency response variations and radiate differently at different frequencies. If leak detection is not configured within or very near the LTE band, there is a high likelihood that the recorded measurement *may* be at a very different level from the level within the LTE band, and additionally a large number of leaks that do exist in the LTE band *may* not exist if the measurement is made at 100+ MHz away. Together, the information on LTE egress and LTE signal level provides for a process such that automated rules can be established that prioritize the repair of leaks at those locations with the strongest LTE signal strength, and repair for those locations where there is very low LTE signal strength can have a much lower priority. As an example, multiple level threshold rules could be established where leaks are scheduled for repair when the detected level in the LTE band is  $> 125 \mu\text{V/m}$  at those locations where the LTE signal level is  $> -50 \text{ dBm}$  – and additionally lower level leaks  $> 75 \mu\text{V/m}$  are scheduled for repair only at those locations where the LTE signal level is stronger, for example locations with LTE signal level  $> -40 \text{ dBm}$ . This methodology allows for fewer locations needing repair therefore minimizing operating expenses, while simultaneously minimizing the overall potential of LTE affecting egress.



**Figure 2: Database software showing both leak and LTE levels**

This last described process also has benefit if the operational goals are additionally to proactively combat downstream ingress from LTE signals getting into the plant. In cases of downstream ingress, the two most dominant factors are the LTE signal level and the signal level of the QAM channels in the plant. Actual leak level is of less importance. If the QAM level is very high, say immediately after an amplifier, then regardless of LTE signal level there is very little chance of that leak location being a source of downstream ingress impairment – and that leak can be therefore assigned a very low repair priority. Conversely, at locations with the lowest QAM signal level – even leaks as small as 5 µV/m have the potential for negatively affecting transmission quality if the LTE ingress signal is strong. As such, a database containing the combination of LTE signal level plus the addition of electronic network maps containing QAM signal level can provide a means to establish rules that intelligently decrease the quantity of leaks to repair, and better focus on those leaks most likely to be the source of network impairments. Of course, it will not be possible to distinguish signal level at all locations where there is a leak (for example, at an amplifier containing both low signal level at the input and high signal level at the output), but any eliminated locations manifest in operational savings. Over time, as more data is acquired as to what the actual cutoff threshold is regarding leak level and LTE levels corresponding to adversely affecting LTE transmission and LTE ingress, the allowable threshold numbers can be altered and optimized for operational efficiency – therefore ensuring that repair resources are only allocated to those leaks actually causing a problem.

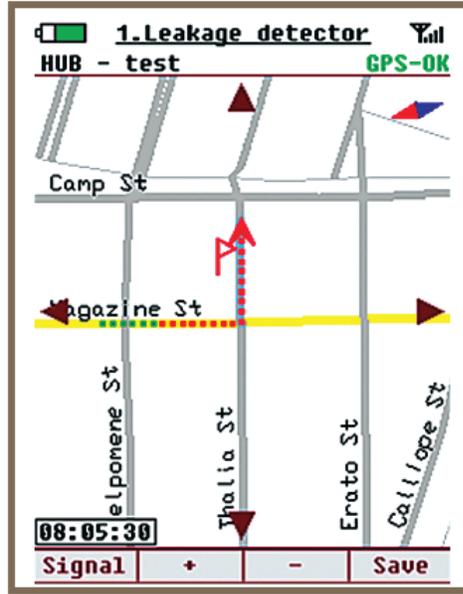


Figure 3: Navigator Plus map display

### The Final Identification Step

With legacy leakage equipment, technicians have historically been trained to go to an area and walk around. Multipath issues and the varying signal levels at different locations, as well as the capabilities of the software location algorithm necessitated this approach. QAM Snare is different, and as such the training on how to use the equipment is different. The correlation detection process inherently utilizes time delay as an additional parameter that is available to use in the location algorithm. This allows for the use of the previously mentioned TDOA location technique where the exact GPS coordinates of the leak are calculated. The software calculates the location, and in real time a flag is placed on a map. If a Navigator Plus is being used, the flag immediately shows up on the device display. As such, instead of walking around – the final identification steps start by teaching the technician to simply go to the mapped flag location.



**Figure 4: Cradled Navigator Plus**

At the identified location, the technician stands still and orients the loop dipole antenna as one would a magnifying glass, and points the antenna until the detected signal is at a maximum. Then the technician moves in the direction of increasing signal level. For vertical plant typically this requires going up in a bucket at the flagged location, and once at the device a close proximity scan is performed to identify which exact connector or device is deficient.

## **A.2 ComSonics Solutions**

### **Introduction**

The ComSonics' QAM leakage solution set allows detection of cable TV leakage in an all-digital system (all QAM signals) without the need for an analog TV or dedicated continuous wave (CW) carrier in the downstream spectrum. It is a leakage detection system made up of three general parts: The first is a "marker" signal source that is installed at a headend or hub. The second is a fleet-based GPS leakage detection platform. The third are the handheld devices.

- The QAM Marker is a signal source typically installed at a headend or hub site, configurable to support up to three co-located cable systems in an overbuild area, to distinguish leaks between the cable systems.
- The Genacis QS platform is a vehicle-based solution that is best used in a fleet type application. It uses a fully automated "black box" approach requiring no technician interface for broad-coverage leakage detection/monitoring.
- The QAM Sniffer and QAM Shadow are handheld cable leakage detectors used for locating and isolating the leakage source. The QAM Sniffer is oriented towards the

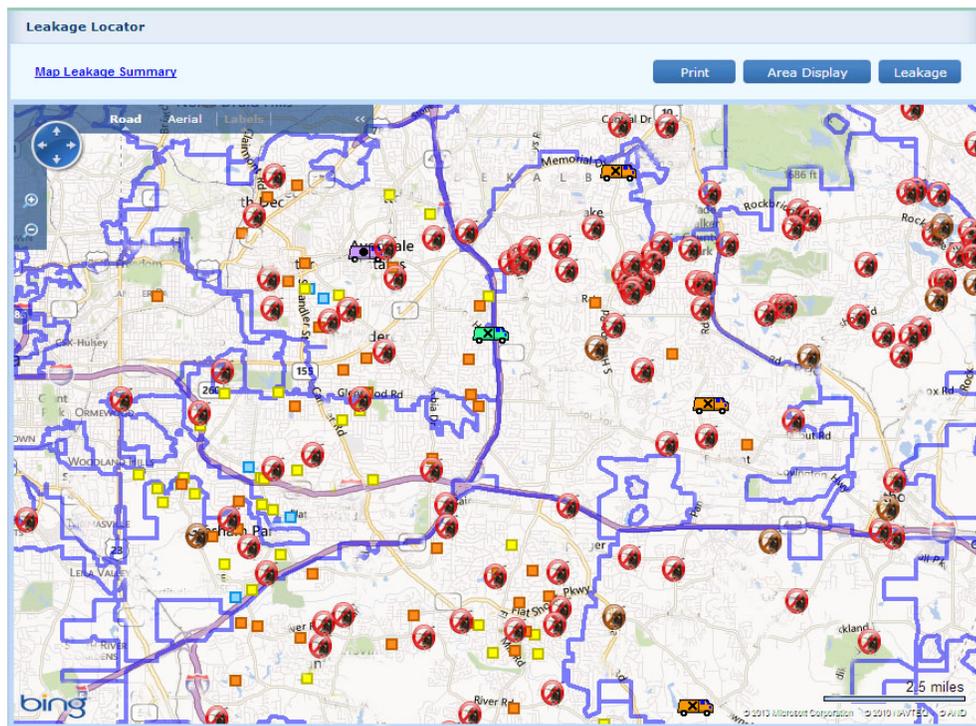
maintenance technician’s use, while the QAM Shadow is better suited for the installer.

- The QAM Marker and QAM Sniffer products work together to form a digital-compatible leakage detection system that can be used to detect very low-level leakage signals. The leakage detection method described in this section uses a non-interfering low level “marker” signal that is injected at the headend or hub directly between two adjacent QAM signals. The handheld detection units are then programmed to detect the corresponding marker signal.

### Recommended Tools

There are two primary tools needed to for a comprehensive leakage management program:

**Automated Fleet Application:** In order to support continuous leakage detection and obtain good plant coverage on a regular basis, a fleet-based platform is recommended that typically uses a mix of maintenance and installation vehicles. In most situations about 30% to 40% of vehicles *should* be outfitted with a mobile detection capability to provide a high percentage of plant coverage every three months. An example of the leaks found using the mobile application is shown in Figure 1, allowing system personnel to manage and prioritize leakage repair.



**Figure 1: Genacis Web Application – Leakage Locator Map**

**Handheld Leakage Detectors:** The second category of equipment needed for leakage management is handheld leakage detection devices that can provide a combination of directionality and leakage level information. This category can be further broken down into two subcategories: maintenance and installation. The maintenance technician generally needs a leakage detection device that provides

directionality information that will allow him/her to track down leaks in the outside plant. For this reason, a device such as the QAM Sniffer is recommended as it has a built-in directional dipole antenna. The installation technician is generally working inside a home or building and thus *may* not require the same level of directivity to find leakage due to the limited working area. The recommended device for this work group is the QAM Shadow which has a built in near-field antenna. This will help the technician zero in on a leak once he or she is in close proximity to the leak source.

The two different device types are shown in Figures 2 and 3. The QAM Sniffer is on the left has retractable di-pole antenna elements and the QAM Shadow on the right contains a near-field antenna.



**Figure 2: QAM Sniffer**

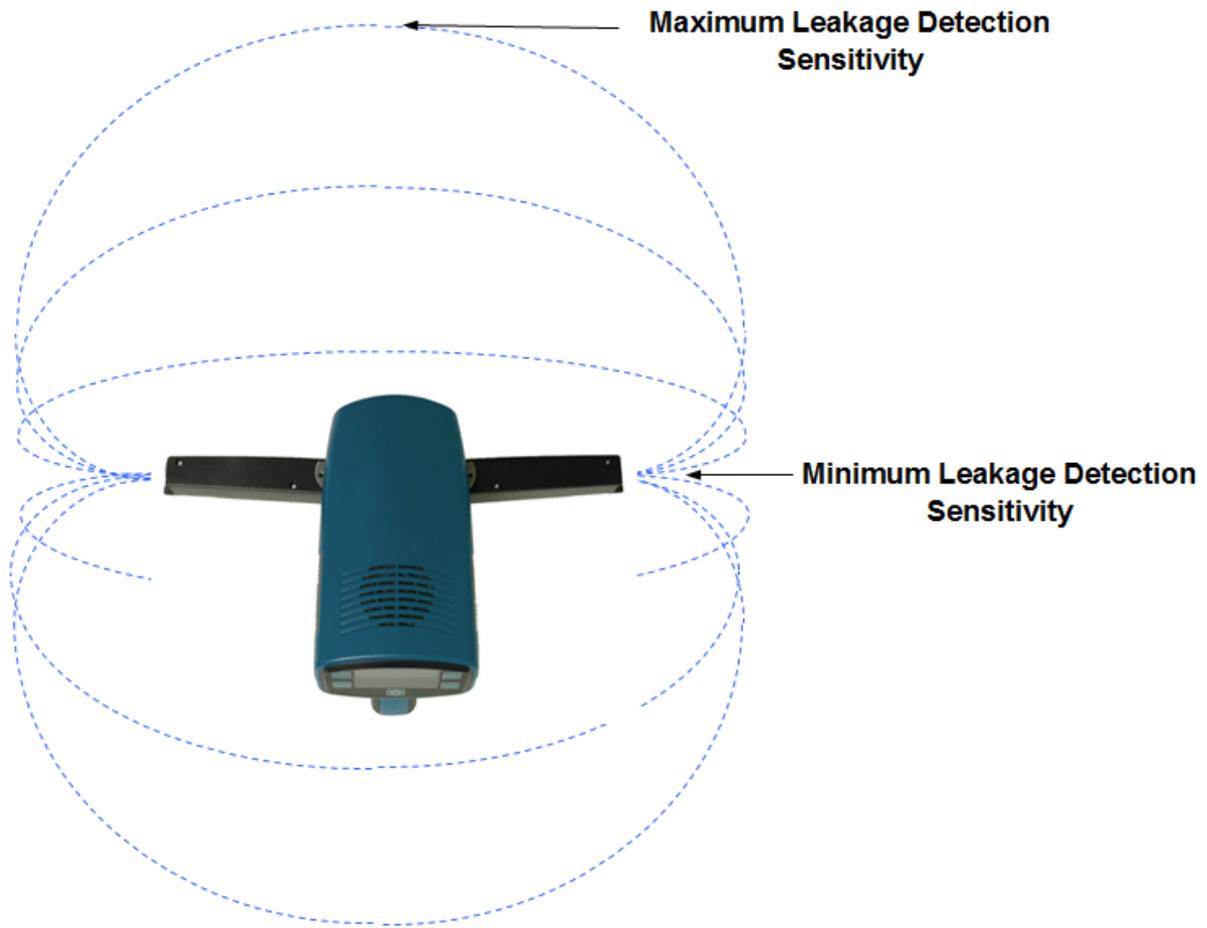


**Figure 3: QAM Shadow**

### **How to Find a Leak Using the QAM Sniffer**

In this section of the document, the technique of finding a leak using ComSonics' leakage detection equipment is discussed. The first step is to understand the antenna radiation pattern of the QAM Sniffer dipole antenna. This is important because the radiation pattern is the fundamental mechanism that provides the device's directionality.

The area of the pattern that provides the maximum antenna gain also provides the maximum signal reception. As shown in Figure 4, this area revolves around the front, back, top and bottom of the unit. The "Null" or minimum gain portion of the antenna pattern is from the right and left sides of the unit; the end of the antenna elements.



**Figure 4: QAM Sniffer antenna pattern**

The technician can use the maximum gain and null points of the antenna pattern to provide directional information to track down a leak. This is done by using these recommended guidelines:

After a leak has been detected or a general location provided, the technician unfolds the antennas on the QAM Sniffer and extend the elements to the correct length to match the frequency of interest. For 612 MHz range, the antenna elements *should* remain retracted. For the 138 MHz range, the antenna elements *should* be pulled out to full length.

The technician points the QAM Sniffer in the general direction of the existing cable plant. A good starting point is usually a visible amplifier or tap point.

The technician must then find the maximum or minimum signal level of the detected leak by orienting the QAM Sniffer correctly. The technique involves two steps: The technician can slowly turn around standing in place and note where the reading is highest or lowest. The technician can also rotate the QAM Sniffer to orient the antenna elements from a horizontal position to a vertical position. As the QAM Sniffer is slowly maneuvered from both perspectives, the orientation producing the highest signal level generally points to the location of the leakage source. As a general rule, the technician *should* follow the directional information from the QAM Sniffer that points towards some part of the cable plant.

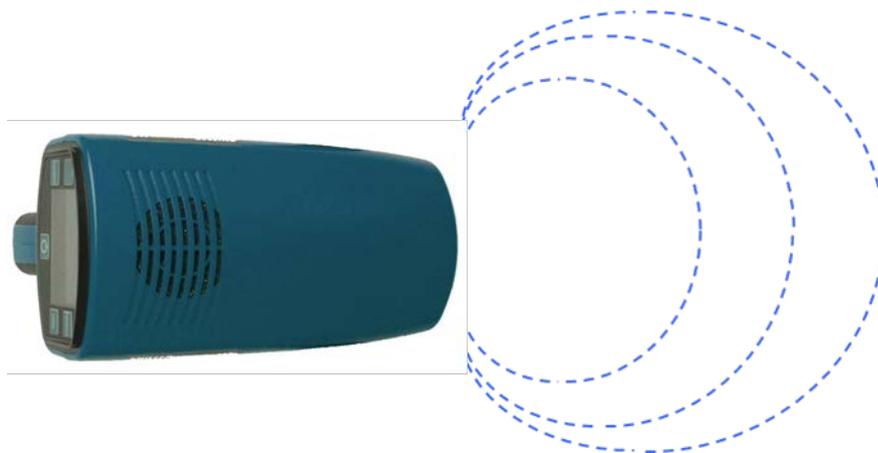
Two directional methods can be used to locate a leak: (1) use the maximum leakage level or (2) use the minimum leakage level (null point). If the technician prefers to use the maximum leakage level to find the leak, he or she will then follow the direction the QAM Sniffer is pointing which maintains the highest signal level possible. If the technician chooses to use the null point (lowest level) to find the leak, the antenna elements will point in the direction of the leak. Note that using the null point actually provides more accurate directional information because the antenna pattern at the null point is much narrower than the maximum gain point. Both the maximum and null point information can be used in combination to provide a double confirmation that the direction is correct. The technician will then start walking in the direction of the cable plant using the information provided by the QAM Sniffer.

As the technician approaches the cable plant, the detected level of the leak *should* increase. This *should* be continuously monitored/checked (every 20 to 30 feet or so) while closing-in on the probable leakage source location. Sometimes the detected leak can come from a reflection from a building or house, so the direction of the leak *may* suddenly change once a direct line-of-sight to the leak is established. Once the technician reaches the cable plant, it is recommended to walk a short distance up and down the cable plant to validate the leakage location. This will also determine if multiple leaks are present and can help rule out possible reflections.

If the level does not increase as the technician initially walks towards the leak, this is an indication that the leak was likely a reflection. The technician *should* stop and redo the direction readings to get a new bearing.

This process continues until the technician closes in on the leak. There *may* be several leaks in the general proximately which can make the process a bit more challenging. Once the technician gets to within several feet of the leak, the antennas can be closed which will convert the QAM Sniffer to be used as a near field detector. This pattern is shown in Figure 5.

Using the near field configuration, the technician can locate the source of the leak to within a few inches. At this point, the source of the leak *should* be either visible if it is caused by external damage or the technician will have narrowed down the possible culprits to the most common problems such as loose connectors on a tap plate.



**Figure 5: QAM Sniffer near-field antenna pattern**



**Figure 6: QAM Shadow near-field antenna pattern**

To find leaks using the QAM Shadow, the technique is fairly straight forward. The antenna operates in a near-field mode only and is activated by flipping open the lid on the device. The antenna is located inside the lid. Using both the audible tone and the visible display readings, the technician will move in a direction that produces the largest signal level reading. There is not a definitive null point on this instrument's antenna, so only the maximum signal level can be used to localize the leakage source. As the technician nears the leakage source, the QAM Shadow can be used to pinpoint the leak source to within a few inches. Once the general location of the leak is found, the technician *should* be able to reasonably determine the cause of the leakage. If the leakage source is not visibly obvious such as a damaged cable, then tightening and replacing suspect components is the usual course of action to fix the leak.

Finding leaks is not always a straight-forward science, and often requires an element of “art” as well. Leakage signals can be reflected, absorbed, and combined to give the technician misleading information causing him or her to look in the wrong direction. This is where the technician’s experience and understanding of how leakage interacts with other objects come into play. Radiation patterns from a leakage source are not uniform in nature, which can also require the technician to move around the area to find where the leak is radiating at its maximum level. All these factors combined make leakage hunting a bit more complex to master. There are many instances where a leak was thought to be coming from a certain location, but upon investigation a much larger leak at a distant location was found.

If a technician is equipped with the right equipment, a basic understanding of radiation patterns, and training on how to use the equipment, he or she will be outfitted with the core fundamentals required to track down leaks. Only experience and trial and error will round off the technician’s ability to more efficiently to track and find cable leakage.

### A.3 Effigis Geo Solutions

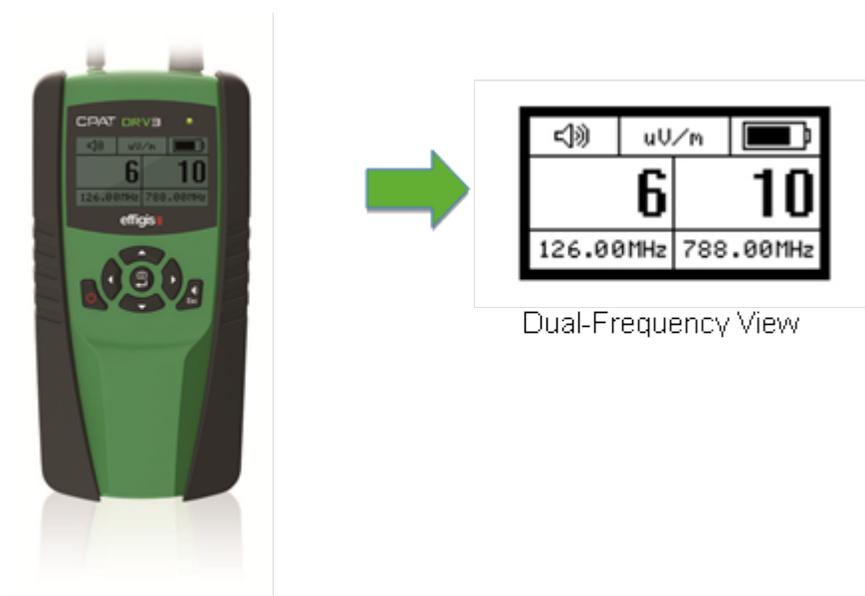
#### Technological Description

##### CPAT Flex Digital Leakage Monitoring System

The CPAT FLEX is designed as a fully automatic mobile system that monitors the network while the technicians are performing their daily work routine. The CPAT FLEX digital leakage monitoring system is composed of a headend-based signal generator (DSG1), portable vehicle-based receiver (DRV3), autonomous event recorder (ARD4) and Web-based application service.

##### Digital Signal Generator (DSG1)

The DSG1 is a dual-band signal generator that inserts an ultra-low level digital signal between adjacent QAMs signals. The dual-band signal generator utilizes two frequency agile digital carriers. The first band operates from 118 MHz to 140 MHz to satisfy FCC’s cable leakage regulatory requirements in or near the VHF aeronautical spectrum. The second band operates from 572 MHz to 960 MHz, to cover cable leakage In the LTE cellular band. Each low-level digital signal is inserted at -30 dBc from the QAM RF level measured in a 6 MHz bandwidth. The DSG1 can also generate up to 3 code combinations or digital tags to discriminate leaks in overbuild networks.

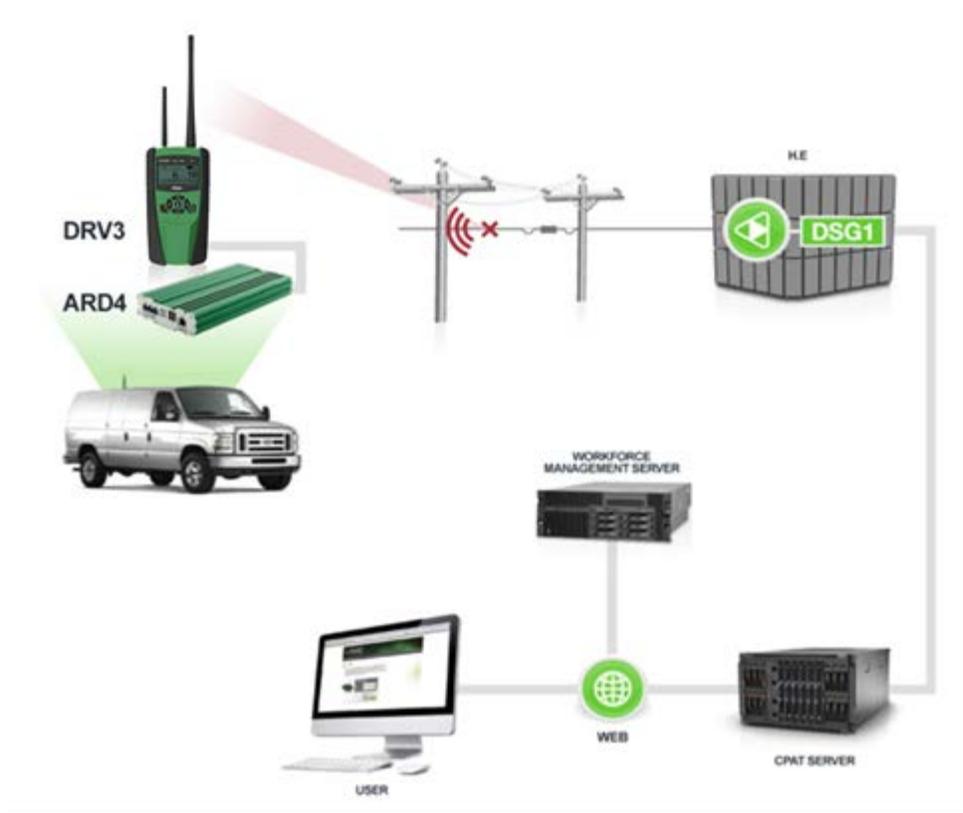


**Figure 1: DRV3 Dual-band screen display**

##### Portable Leakage Meter (DRV3)

The portable DRV3 frequency-agile meter detects and measures leakage events in all-digital networks. The DRV3 meter is designed as a find-and-fix tool and a monitoring receiver when used as part of the CPAT FLEX system. The DRV3 is connected to an autonomous event recorder (ARD4) module or can be used as a standalone find-and-fix meter for digital leak repairs.

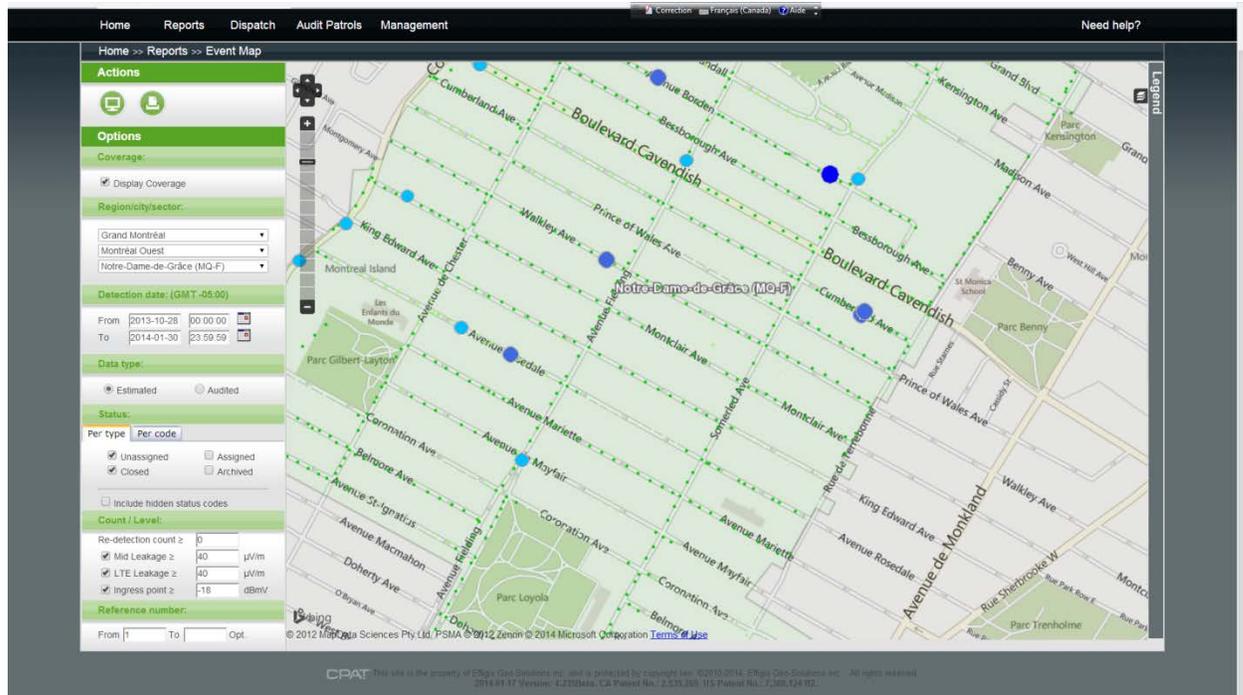
With the DRV3 real-time dual-band receiver, operators can monitor both frequency bands (mid/LTE) RF levels simultaneously on the meter screen display.



**Figure 2: CPAT Flex schematic diagram**

**Autonomous Recording Device (ARD4)**

The Autonomous Recording Device module (ARD4) begins monitoring the plant as soon as the technician's vehicle starts up. As the truck is driven, the ARD4 performs all of its monitoring functions without any intervention from the technicians.



**Figure 3: CPAT Flex schematic diagram**

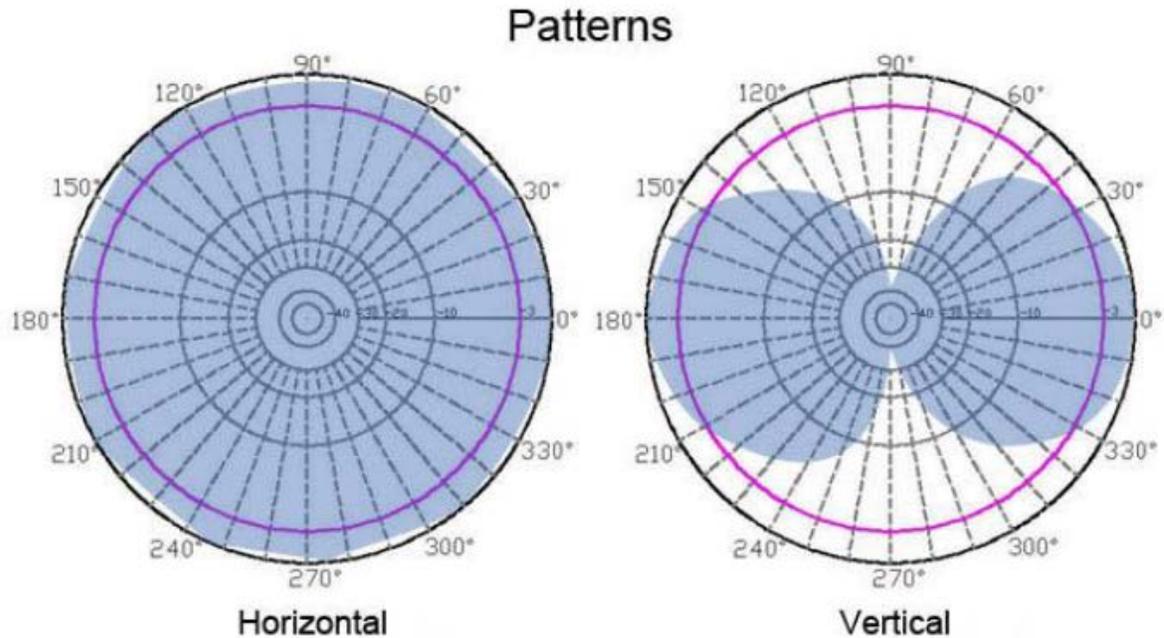
**CPAT Web-based Application Service**

The CPAT Web-based service locates and display monitored leaks on a digital mapping system for the operator’s geographical service area. Driveout path mileage coverage is automatically tracked on a daily basis, to display quarterly driveout progression. Real-time processing of monitoring data inserts each unique leak event in the database, for multiple detections at same physical location coordinates.

The CPAT application provides report generator functionality with filtering and sorting capability. The application prioritizes leaks according to management criteria and allows the creation and dispatch of work orders using a repair ticketing function.

**General Operation**

The DRV3 meter when used as a monitoring probe part of the CPAT Flex system operates in a docking station, which provides power and vehicle roof antenna connectivity. When the DRV3 is undocked, the vehicle antennas (mid/LTE band) and power are automatically disconnected from the meter, which now operates as a find-and-fix tool. In this operational mode, the DRV3 utilizes two omnidirectional rubber duck antennas. The omnidirectional antenna receives equally well in all directions as shown in Figure 4.



**Figure 4: DRV3 monopole antenna radiation pattern**

For troubleshooting purposes, one can use the horizontal field radiation pattern of the antenna for a ‘coarse’ leak detection approach by holding the DRV3 meter in a vertical position. The ‘coarse’ approach will provide maximum leakage readout on the meter and will provide a general direction of source leak location.

The vertical field radiation pattern or ‘null point’ where the gain of the antenna is at minimum, provides lowest RF level readout. This can be utilized for a ‘fine’ leak detection approach by pointing the tip of the antenna in direction of the suspected leak source. Since the vertical field radiation pattern is more directional, it is typically used to provide a precise direction of leakage source location. Depending on the source and location of the leak, either or both detection methods can be used.

Once a leak has been assigned for repair, the field technician will drive to the leak location as displayed on the work order or event map display. As the technician drives toward the leak location, the DRV3 *should* start displaying the detected leak level when approaching the site.

1. The technician will undock the DRV3 from its docking station and point the DRV3 in the general direction of the cable plant. The technician *should* look and point the meter at the portion of the plant where higher RF levels are expected (amplifier, RF coupler or distribution multi-tap).
2. The technician must then find the peak signal level of the detected leak by pointing the DRV3 antenna in different directions, until he or she finds the location where the signal is the strongest. The technician will walk in the direction where the peak was detected.
3. The technician *should* notice if the leak level is continuously increasing while walking in the direction of detected leak. If the RF level varies erratically, the meter could be detecting a reflection of the main leak bouncing off of a physical obstruction

- nearby (building, house, tower, etc.). The technician *should* make sure to be positioned clear of any significant obstruction when possible and achieve best line-of-sight when pointing the meter in direction of cable plant. It is a good practice to walk back and forth in line with the cable strand plane to finalize the leak location.
4. Once the technician has closed in on the approximate leak area, he or she can use the null point method or connect a near field probe (NFP) on the DRV3 to pinpoint the exact location of leakage source. The probe *should* be moved slowly and within close distance (1-2 inches). The technician will move on same plane as cable direction until he or she finds the peak reading of the leak.
  5. Once peak reading location is achieved, a visual inspection performed by the technician *should* identify the root cause of the leak (bad connector, damaged drop, broken cable, etc.).
  6. Once the technician has completed the initial leak repair, he or she *should* verify that the DRV3 does not record any leakage from this location, and ensure that root cause of leakage was properly identified and repaired.

#### **A.4 JDSU Solutions**

##### **Detecting QAM Signal Leakage with JDSU DSAM QAM Egress Option**

Cellular service providers are licensed to use frequencies in the UHF band. Cable service providers also carry signals in this frequency range on their networks. The cellular provider services, called LTE have been deployed nationally and are primarily used by smart-phones for data transmission. In some cases, cable service providers have received complaints from cellular providers of interference to LTE services caused by signals leaking from the cable network.

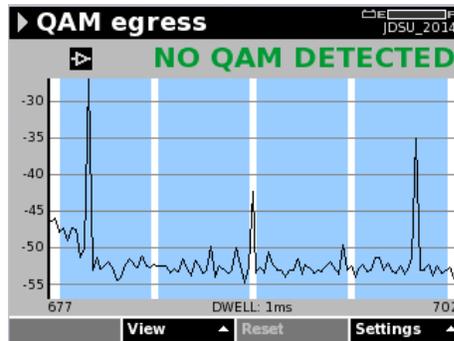
Cable service providers have established methods for monitoring leakage and for detection and measurement by field personnel. These methods are focused on the aeronautical band in order to meet the most stringent leakage test requirements put forth in FCC regulations. Cable industry tests have shown that leaks can be frequency specific, and that there is little or no correlation of field strengths across frequency. It is logical that monitoring for leakage in the UHF band will help to mitigate LTE service interference issues. Also, where there are leaks in the UHF band, there is the potential for interference to cable provided services.

Cable industry leakage test and monitoring equipment manufacturers are now providing systems that operate in the UHF band to enable detection and troubleshooting in this range. Most of this equipment is designed specifically for leakage testing, and only for that purpose.

The JDSU DSAM Digital Service Analysis Meter is used by cable field personnel to perform preventive maintenance, to verify signal quality and to troubleshoot network problems. The DSAM offers a “QAM Egress Option” that enables a technician to detect and locate QAM signal leakage from the cable network. Key features of this test mode are optimized preset spectrum settings, automated detection of QAM signals present in the over-the-air environment, and clear visual and audible confirmation of the presence of QAM egress.

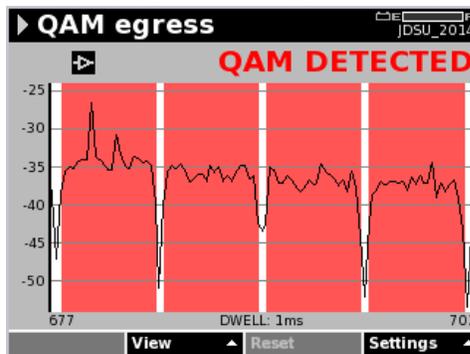
A technician with this DSAM test feature typically uses it to respond to a known leak, which *may* have been discovered using the leakage monitoring system, or to determine if a leak exists at a particular location. In either case the technician connects the log periodic antenna to “port 1” on the DSAM, and

enters the test mode. The QAM Egress test mode is accessed by pressing the “Measure” key, and then scrolling to “QAM Egress” and pressing enter. When the mode starts, with no QAM signal detected the display will scan and show the spectrum with blue vertical “bars” to indicate QAM channel bands (See Figure 1).



**Figure 1: QAM Egress Mode with no QAM signals detected**

With the meter scanning the test frequency range, the technician slowly “waves” the antenna, pointed in the direction of possible leak locations. When a QAM signal or signals are detected the channel band bars turn red as shown in Figure 2.



**Figure 2: QAM Egress Mode with QAM signals detected**

As the antenna is swept in the direction of the leak, the detected signals will peak when the antenna is pointed directly at the leak. The technician then moves closer and continues this process until the leak location is fairly obvious. In some cases it *may* be helpful to use the near-field probe antenna to further identify the exact source of the leak. In this case the technician connects the near-field probe antenna and, with the meter in the egress detect mode, “waves” the probe over the cable or network component to find the point at which the signal peaks on the egress detect scan.

Another use case is for the technician to test the location of a repair or service to ensure that no inadvertent leak has been created. With the DSAM in the egress detect mode, the technician can pass the near-field probe over and around the network component that has been serviced to ensure that no QAM signals are leaking.



**Figure 3: DSAM Digital Service Analysis Meter**



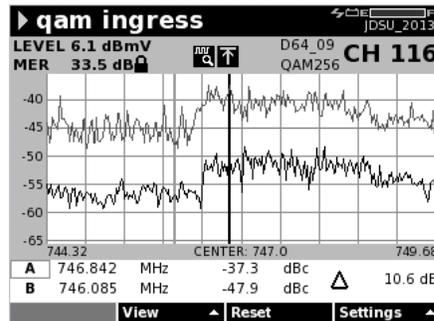
**Figure 4: Log periodic antenna**



**Figure 5: Near-field probe antenna**

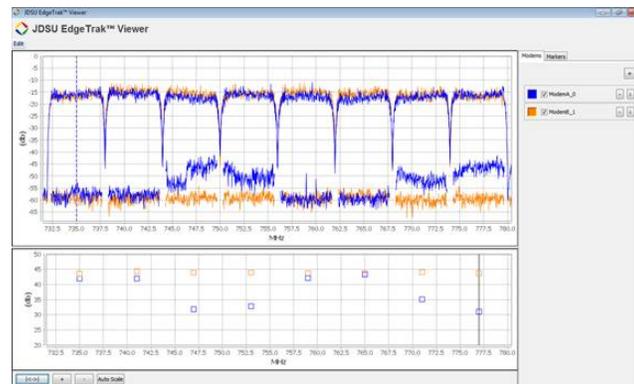
The DSAM QAM Egress Option is designed to enable any technician with a DSAM and the proper antennas to locate and troubleshoot QAM signal egress. It is not intended to be used for leakage monitoring or for calculating CLI, but as a handy tool to help avoid the occasion of a cable signal interfering with licensed off-air services such as LTE. Any instance of signal leakage is also an opportunity for signal ingress that can interfere with cable provided services. The DSAM can also be used to locate and troubleshoot this ingress, especially using the QAM Ingress option that allows seeing the

channel spectrum with the QAM “haystack” removed as shown in Figure 6. The combination of these two features gives the technician a powerful toolset for managing signal leakage/ingress in the UHF band.



**Figure 6: LTE carrier interfering with cable video QAM in DSAM QAM Ingress Mode**

In addition to the DSAM QAM Ingress option, a new enhancement to CPE full band capture technology is available via licensing (from JDSU) that enables viewing ingress under the QAM signal. When polled via simple network management protocol (SNMP) the CPE will return ingress under QAM data which can be plotted in a familiar spectrum display along with MER for all downstream Data Over Cable Service Interface Specifications (DOCSIS) and digital video carriers. As more CPE devices are deployed with Broadcom FBC technology, it is expected that polling neighboring devices will enable narrowing down root cause locations prior to dispatching technicians for service/repair. The example in Figure 7 shows a comparison of two modems, with a clear indication (blue trace) of interference in the spectrum under the QAM haystack and the related lower MER reading on the affected channels.



**Figure 7: Example of enhanced data available including MER and spectrum under the QAM signal enabling LTE ingress analysis**

## A.5 Trilithic Solutions

### Dual-Frequency Digital Leakage System Overview

Once a cable operator adopts a 100% digital channel lineup, the system of products described in this section provides the ability to perform leakage detection and measurement in both the VHF and the UHF bands at the same time. While this equipment will work with analog or digital lineups, the devices described here are optimized for all-digital plants. The system consists of a CT-4 digital channel tagger installed in the headend or hub site, which injects special test signals that the Seeker D picks up in the field as RF signal leakage. A third component is the GPS-based mobile communications adapter (MCA

III). The MCA III supports the ability to log leakage and rideout data, which then uploads said data to the Leakage Analysis Workshop (LAW) software.

The CT-4 transmitter is used to inject low level, non-intrusive signals into the downstream spectrum in both the VHF and UHF frequency ranges. The dual CW carriers are injected at 138 MHz between CEA (2013) channels 16 and 17 and at 612 MHz between CEA channels 88 and 89. The injection level is 30 dB down from the total average power of the adjacent QAM signals.



**Figure 1: CT-4 Transmitter**

The dual-frequency leakage detector can be programmed to toggle between the two injected carriers for monitoring leakage in both bands during a single rideout. The Seeker D provides leakage detection while driving the plant, and also can be removed from the vehicle mobile mount to walk out leaks. A variety of antennas are available for use on the detector while in portable mode.

The technician drives around the plant as part of his or her daily work routine, and the equipment automatically collects leakage data and connects via Ethernet or Wi-Fi for uploading purposes. The latter can be programmed to take place multiple times per day. The MCA III also provides a means to remotely upgrade firmware in both itself and the Seeker D without any action on the part of the technician.



**Figure 2: Seeker D**

### **Monitoring Mode**

As mentioned previously, when the seeker is mounted in the vehicle, it can be programmed to toggle between the VHF and UHF bands, monitoring both frequencies in a single rideout. A collinear array antenna with 6 dBi gain is used for 612 MHz. At 138 MHz, a standard whip antenna is used. Both

antennas connect to a diplexer, which in turn feeds into the vehicle mobile mount where the detector is docked while in monitoring mode.

In the vehicle, as the meter quickly toggles between frequencies, the detector’s display will show the leakage values and provide an audible tone for the primary frequency, and provide an audible tone with no leak level displayed for the secondary frequency. A quick look at the display in the presence of a leak will indicate whether the detected leak is at 138 MHz, 612 MHz, or both.

The field strength of the secondary frequency can be seen by pushing a button on the detector, and it will temporarily show the alternate frequency’s level. While in monitoring mode, the MCA III will log leakage values for both frequencies once per second, along with GPS data. Once uploaded to the LAW platform, the data is then processed to determine the exact leak location, providing both GPS latitude and longitude, and a reverse geocoded address of the leak’s location on a map.

### Find and Fix Mode

The process to find leaks from a LAW-generated work order or previous ride out is nearly the same. From a work order, the starting point to look for the leak is the GPS coordinates of the leaks, which are displayed as a dot on the map on the work order. The work order also provides the projected leak level in  $\mu\text{V/m}$ , which helps determine the order in which the technician *may* decide to troubleshoot and repair the leaks. A reverse geocoded address provides a quick reference to the street on or near where the leak is located. If the technician is looking for a newly detected leak, the detector’s meter will peak in value as the vehicle is driven by the likely leak location. This location where the meter indicates a peak *should* be the starting point to find the leak in question.

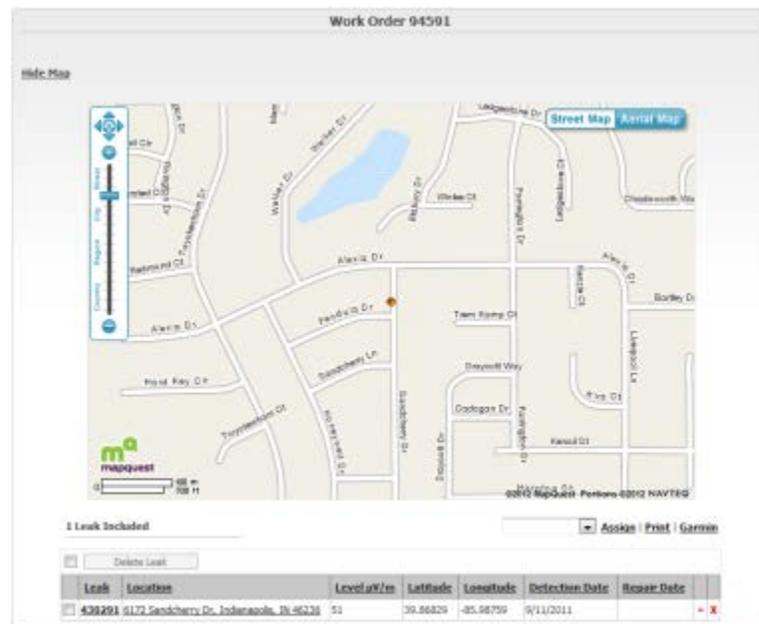


Figure 3: Example work order map

Before walking out a leak, the technician needs to know at which frequency the leaks were detected: 138 MHz, 612 MHz, or both. This information will help determine not only the type of failure to look for, but also which antennas are most appropriate for use with the detector to find the leak. If the frequency leaking is 138 MHz then the antenna options are a half wave dipole, a low-frequency rubber duck antenna, and a near-field probe. If the leak is occurring at 612 MHz, then the antenna options are a 9 dBi

gain Yagi antenna, a 3 dBi gain high-frequency rubber duck, and a near-field probe. The same near field probe is used for both cases since it is not frequency dependent.

### Locating a UHF leak

If the cable network is leaking at 612 MHz, the Seeker D is removed from the vehicle mobile mount and connected to the Yagi antenna. The technician *should* step a few feet away from the vehicle to reduce possible reflections from the vehicle.



**Figure 4: Seeker D attached to Yagi antenna**

Because of its high gain and directivity, the Yagi works well for pinpointing rear easement leaks. Noting where the cable plant is, the technician simply aims the Yagi antenna towards the plant, slowly sweeping the antenna back and forth in the direction of the plant. As the antenna is swept in a fanning motion, the elements *should* be rotated vertically and horizontally, in order match the polarity of the leak. When doing so, the intent is to peak the leakage signal strength on the meter. Walk in the direction of the maximum signal until the general location of the leak has been found. This method will often get the technician within a few feet, if not closer, to the leak.

Once near the leak, remove the detector from the Yagi antenna mount and connect the near-field probe. Since the near field probe is small, it affords the ability to get into tight places as it is swept in and around all the amps, connectors, fittings, etc., that can be the source of the leak. Using the near-field probe in this fashion will pinpoint the leak right down to the failed component.



**Figure 5: Seeker D with near-field probe**

An option to using the Yagi is the high-frequency rubber duck, which is actually a collinear antenna that when mounted to a hand held device has approximately 3 dBi gain. While holding the detector with the antenna vertically oriented, the technician *should* walk in the direction of the most likely place of a leak and determine if the leakage value increases. If the value increases, the technician *should* keep walking toward the same location. If the value decreases then the technician *should* change direction until the value starts to increase again in order to pinpoint the general location of the leak. At that point, the rubber duck can be replaced with the near-field probe to pinpoint the plant impairment.

Another and potentially better way to use a rubber duck antenna is as follows: Orient the rubber duck antenna horizontally. Although having the rubber duck antenna oriented vertically can be done as just described, a more efficient way is to orient it horizontally. Because of the nature of the rubber duck, when held horizontally the lobe pattern somewhat resembles that of a horizontal half-wave dipole antenna. It is possible in this method to gain directionality out of what otherwise would be an omnidirectional antenna. While holding the detector and antenna horizontally and parallel to the plant, the technician *should* sweep along and rotate in the horizontal plane looking for the leakage value to peak. Then the technician can walk in the direction perpendicular to the antenna until he or she gets close to, and isolates the general location of the leak. As before the rubber duck can be replaced with the near-field probe to find the exact failed component.

### **Locating a VHF leak**

If the cable network is leaking at 138 MHz, the Seeker D is removed from the vehicle mobile mount and connected to the directional half wave dipole antenna mounted on a telescoping support. The technician *should* step a few feet away from the vehicle to reduce possible reflections from the vehicle. The dipole support *should* be extended to position the antenna 3 meters above the ground (caution: watch for overhead power lines and other hazards). With the antenna elements horizontally oriented and perpendicular to the cable plant, the antenna *should* be slowly rotated. As with measurements described previously, the goal is to detect the peak value of the leak as the antenna is rotated. Once the peak leakage field strength is found, the technician *should* walk in a direction perpendicular to the antenna elements. If the indicated leakage field strength increases then the technician is getting closer to the leak and therefore

walking in the proper direction. If the leakage level is getting smaller, the technician *should* change direction and walk until the indicated field strength increases, and the general location of the leak is determined. Once at the leak location, the dipole *should* be disconnected and replaced with the near-field probe. The near field probe can be used to precisely locate the source of the leak.

Leaks can also be located using the low-frequency rubber duck antenna. An effective way to use a rubber duck antenna is to orient it horizontally and perpendicular to the cable plant. This method provides some directionality out of what otherwise would be an omnidirectional antenna if used in a vertical orientation. The procedure to find the approximate location of the leak is similar to using the dipole, as just discussed. When the technician is close to the likely leakage source, the low-frequency rubber duck can be replaced with the near-field probe, and the latter used to precisely identify the faulty component.

### Signal Leakage Detection in the Customer Premises

The TR-4 System includes a transmitter and a receiver with a matched antenna to receive signals in both the VHF aeronautical and 700 MHz bands. To meet the requirement for measuring signal leakage in the 1  $\mu\text{V}/\text{m}$  range, the TR-4 System uses a high output transmitter (TX-4) to temporarily replace the cable service within the subscriber premises. The TX-4 *may* be connected to the subscriber drop at the tap or at the subscriber’s ground block. When connecting to the ground block, care must be taken to avoid inadvertently injecting the test carriers back into the HFC network. The higher levels transmitted by the TX-4 will increase the field strength of the signals radiating from the subscriber cabling, allowing the TR-4 receiver to measure signal leakage levels as low as the equivalent of 1  $\mu\text{V}/\text{m}$  based on nominal system levels within the subscriber premises.

The TX-4 is used to inject two carriers into the subscriber cabling, one at 138 MHz and another at 757.5 MHz. The technician *may* set the output level to +60 dBmV for home certification, but also has the option to reduce the output level to +40 dBmV *should* the subscriber cabling prove to be too leaky for pinpointing the location of a leak at the higher transmit level.

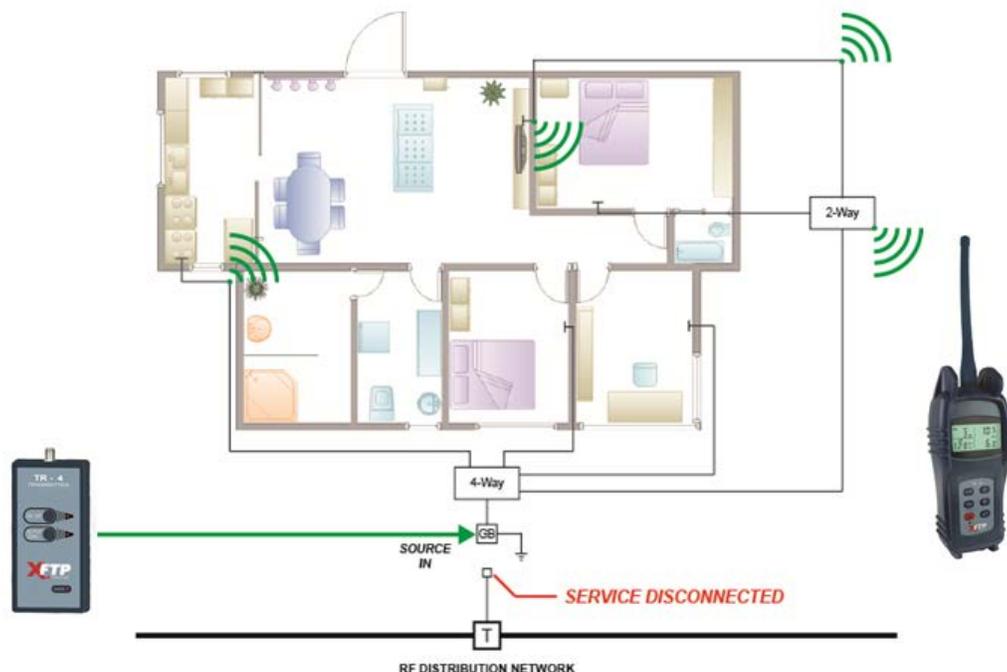


Figure 6: Leakage detection in customer premises

The TR-4 receiver provides both a visual readout of the measured levels in  $\mu\text{V}/\text{m}$  and a tone proportional to signal strength. To prevent false triggering, the TR-4 System utilizes Trilithic's channel tagging technique. To provide constancy with signal leakage levels typically found within the subscriber premise the levels displayed by the TR-4 have been mathematically corrected to represent the level of a leak at nominal system levels within the subscriber premise. This correlation between measured and displayed signal leakage levels provides the technician with a familiar unit of measure ( $\mu\text{V}/\text{m}$ ), which will assist in evaluating the severity of a leak based upon established industry practices.

It is a good practice to carry the TR-4 receiver to the tap location when connecting the TX-4 transmitter to support testing of the drop cable between the tap and the ground block.

### **Locating a residential leak**

Powering up the TR-4 receiver will display a configuration screen that the technician can use to enter the nominal level of system services inside the subscriber premises. The nominal system level will be used to establish a ratio between the test carrier transmit level and the system carrier levels used in the computation of the  $\mu\text{V}/\text{m}$  value in the TR-4 receiver. With the ratio between test and system carriers set and stored, the TR-4 will begin monitoring the 138 MHz and 757.5 MHz frequencies for emissions from the subscriber cabling. If a leak *should* be encountered, the TR-4 will lock onto the appropriate frequency displaying both a numeric readout of the leakage level and a tone proportional to the measured level of the leak.

Once a leak has been detected it is important that the technician continues to follow the path of the coaxial cable if visible or move from room to room within the subscriber premises to find the highest measured value of the leak. Observing the location of cable outlets within the subscriber premises will provide a clue about where the coaxial cable has been installed and will assist the technician in pinpointing the location of the leak. Once the identified cable leak has been repaired the TR-4 receiver will resume monitoring both the VHF aeronautical and 700 MHz bands for additional leaks. After the subscriber premise is free of signal leakage, the installer can retrieve the TR-4 transmitter and reconnect the tap or ground block to the HFC network. It *should* be noted that even with the elevated levels injected by the TX-4 into the subscriber cabling, a properly installed and undamaged coaxial cable within the subscriber premise will not produce any measureable leakage on the TR-4 receiver.

## Appendix B: What is Field Strength?

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), orient the antenna to get a maximum reading and see what value the leakage detector reports. The measured field strength is stated in microvolts per meter,<sup>21</sup> and hopefully is below the maximum limit defined by the FCC.

The field strength in  $\mu\text{V/m}$  can be converted to a dBmV value at the dipole antenna’s terminals using the formula

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

where  $E_{\mu V/m}$  is the field strength in microvolts per meter, and  $f$  is frequency in MHz. But that still doesn’t explain what field strength is. Things get even more confusing when measuring leakage at more than one frequency. Assuming the same field strength - say,  $20 \mu\text{V/m}$  – 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  $20 \mu\text{V/m}$  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  $20 \mu\text{V/m}$  at 782 MHz will produce -58.29 dBmV at the terminals of a resonant half-wave dipole for that frequency.

To understand what is happening, consider the following example, based upon the assumptions in Table 1.

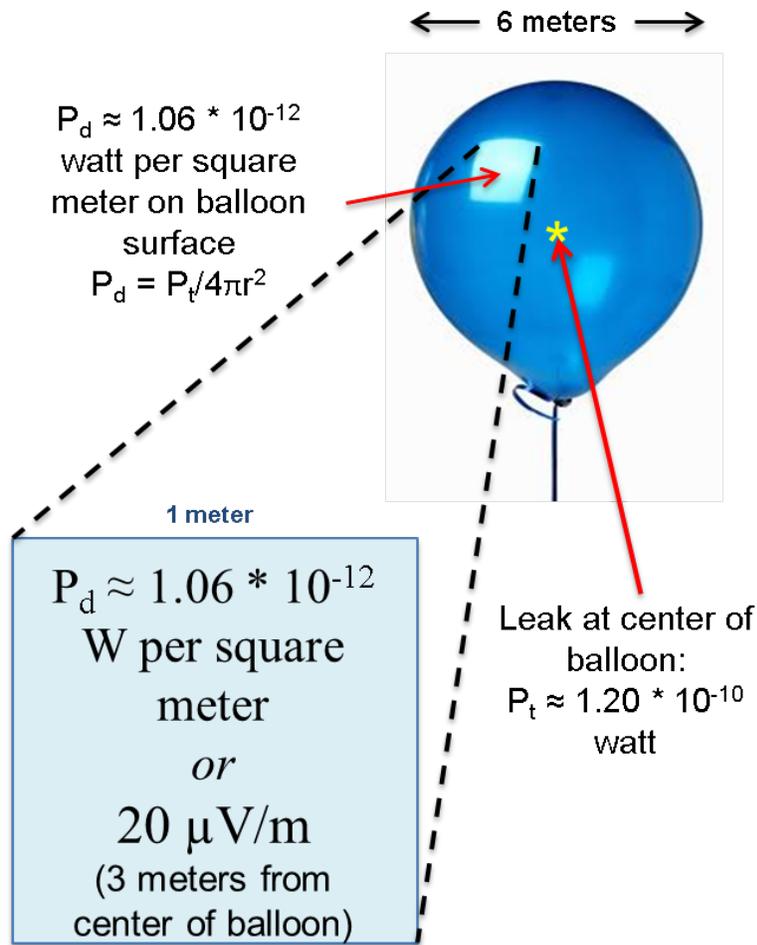
**Table 1: Assumptions for example**

<ul style="list-style-type: none"> <li>• Measurement frequencies are 121.2625 MHz and 782 MHz</li> <li>• Antennas for the two frequencies are lossless resonant half-wave dipoles</li> <li>• Field strength at the point of measurement is <math>20 \mu\text{V/m}</math> for both frequencies</li> <li>• Measurement distance from the leak is 3 meters, which is in the far-field for this exercise<sup>22</sup></li> <li>• Each antenna is terminated by a load equal to its radiation resistance (approximately 73 ohms for a half-wave dipole)</li> <li>• Each dipole is oriented for maximum received signal level</li> <li>• Each antenna does not re-radiate any of the intercepted signal</li> <li>• The polarization of the RF coming from the leak is linear and is the same as the orientation of the dipoles when the field strength measurements are made</li> </ul>
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<sup>21</sup> Outside of the North American cable industry, field strength measurements are more commonly stated in decibel microvolt per meter, or dB $\mu\text{V/m}$ .

<sup>22</sup> The far-field is 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, and  $\lambda$  is wavelength.

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.



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

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

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  $\mu$ V/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.

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 0.0000000000106103295 watt per square meter).

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

$$E = \sqrt{PZ}$$

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

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

= 0.000020 volt per meter, or 20  $\mu\text{V/m}$ .

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  $\mu\text{V/m}$ . 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  $\sim 73$  ohms impedance at the antenna terminals. What's of interest is the power  $P$  delivered by the antenna to that impedance, where  $P = I^2 R_T$ . Here  $R_T$  is the sum of the antenna's radiation resistance ( $\sim 73$  ohms) and loss resistance, the latter assumed to be zero for this example.

Kraus (1988) 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...

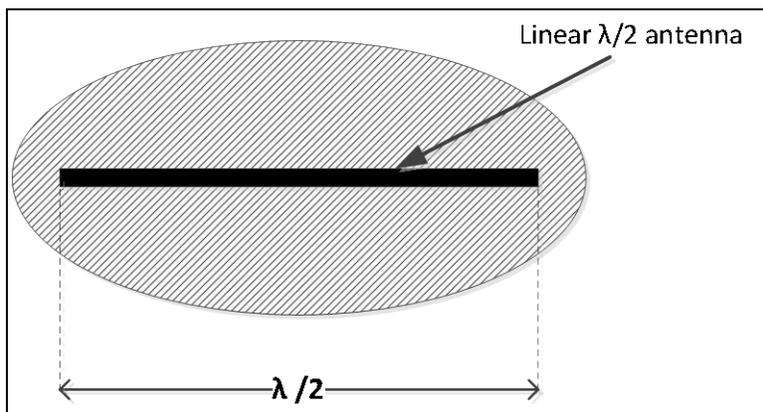
The same is true of a dipole antenna – that is, it can be regarded as an aperture with a specific area that extracts power from a passing wave and delivers it to the load connected to the antenna terminals. Defining aperture isn't quite as simple as one might assume, though. According to Kraus, three 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

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

where  $\lambda$  is wavelength in meters ( $299.792458/f_{\text{MHz}}$ ) 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 1.



**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 *Antennas*, by J. Krauss, New York, NY: McGraw-Hill**

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  $0.797668339532 \text{ m}^2$  for the 121.2625 MHz dipole, and

0.0191805865422 m<sup>2</sup> 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

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

or 16.19 dB, which is equal to the antenna factor<sup>23</sup> difference between the two dipoles.

In other words, when measuring a 20  $\mu$ V/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 ( $\sim 8.46 * 10^{-13}$  watt) than the higher frequency antenna does ( $\sim 2.04 * 10^{-14}$  watt). Here, too, the decibel difference is 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  $\mu$ V/m field strengths at the two frequencies.

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<sup>23</sup> The antenna factors for the VHF and UHF dipoles in this example are 8.12 dB/m and 24.31 dB/m respectively. For more information about antenna factor, see Hranac (2012, July).

### Appendix C: How to Calculate LTE UE Field Strength

The maximum LTE UE transmit power is +23 dBm or 199.53 (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 is being used in this example). The transmit frequency range for a Verizon LTE handset 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:

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

$$23 \text{ dBm} - 0 \text{ dB} + (-1 \text{ dBi}) - 30.31 \text{ dB} + 2.14 \text{ dBi} = -6.17 \text{ dBm at the dipole's terminals.}$$

Converting the received power in dBm to dBmV is done by adding 48.75 to the dBm value: -6.17 dBm + 48.75 = +42.58 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  $\mu\text{V/m}$ :

$$\mu\text{V/m} = 21 * (782 \text{ MHz}) * 10^{(42.58/20)} = 2,210,172 \mu\text{V/m or } \sim 2.2 \text{ V/m}$$

From this, the maximum 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.

**Appendix D: USEFUL SIGNAL LEAKAGE FORMULAS**

The following formulas are used to calculate various signal leakage-related parameters and to convert between various signal leakage-related units. When dealing with leakage measurements and distance(s) from a leakage source, it is assumed that all field strength measurements are in the far-field.

**Calculate free space path loss**

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

where

$Loss_{dB}$  is free space path loss in decibels

$f$  is frequency in megahertz

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

**Convert microvolt per meter ( $\mu\text{V}/\text{m}$ ) to decibel millivolt (dBmV)**

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

where

$dBmV$  is RF signal level in decibel millivolt 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 decibel millivolt (dBmV) to microvolt per meter ( $\mu\text{V}/\text{m}$ )**

$$E_{\mu V/m} = 21 * f * 10^{\frac{dBmV}{20}}$$

where

$E_{\mu V/m}$  is field strength in microvolt per meter

$f$  is frequency in megahertz

$dBmV$  is RF signal level in decibel millivolt at the terminals of a resonant half-wave dipole antenna

**Convert decibel millivolt (dBmV) to microvolt (μV)**

$$\mu V = 1000 * 10^{\frac{dBmV}{20}}$$

where

$\mu V$  is RF signal level in microvolt

$dBmV$  is RF signal level in decibel millivolt

**Convert microvolt (μV) to decibel millivolt (dBmV)**

$$dBmV = 20 \log \left( \frac{\mu V}{1000} \right)$$

where

$dBmV$  is RF signal level in decibel millivolt

$\mu V$  is RF signal level in microvolt

**Convert microvolt (μV) to microvolt per meter (μV/m)**

$$E_{\mu V/m} = \mu V * 0.021 * f$$

where

$E_{\mu V/m}$  is field strength in microvolt per meter

$\mu V$  is RF signal level in microvolt

$f$  is frequency in megahertz

**Convert microvolt per meter (μV/m) to microvolt (μV)**

$$\mu V = \frac{E_{\mu V/m}}{0.021 * f}$$

where

$\mu V$  is RF signal level in microvolt

$E_{\mu V/m}$  is field strength in microvolt per meter

$f$  is frequency in megahertz

**Convert decibel millivolt (dBmV) to decibel microvolt (dBμV)**

$$dB\mu V = dBmV + 60$$

where

$dB\mu V$  is RF signal level in decibel microvolt

$dBmV$  is RF signal level in decibel millivolt

**Convert decibel microvolt (dBμV) to decibel millivolt (dBmV)**

$$dBmV = dB\mu V - 60$$

where

$dBmV$  is RF signal level in decibel millivolt  
 $dB\mu V$  is RF signal level in decibel microvolt

**Convert decibel millivolt (dBmV) to decibel milliwatt (dBm) – 75 ohm impedance**

$$dBm = dBmV - 48.75$$

where

$dBm$  is RF signal level in decibel milliwatt  
 $dBmV$  is RF signal level in decibel millivolt

**Convert decibel milliwatt (dBm) to decibel millivolt (dBmV) – 75 ohm impedance**

$$dBmV = dBm + 48.75$$

where

$dBmV$  is RF signal level in decibel millivolt  
 $dBm$  is RF signal level in decibel milliwatt

**Calculate received signal power at a resonant half-wave dipole antenna's terminals**

$$P_{receive} = \text{transmit power (dBm)} - \text{transmit feedline loss (dB)} + \text{transmit antenna gain (dBi)} - \text{free space path loss (dB)} + \text{receive antenna gain (dBi)}$$

where

$P_{receive}$  is the RF power in decibel milliwatt (dBm) at the terminals of a receive antenna  
 $\text{transmit power (dBm)}$  is the transmitter's output power in decibel milliwatt  
 $\text{transmit feedline loss (dB)}$  is the attenuation in decibels of the feedline between the transmitter and its antenna (if a filter is used between the transmitter and antenna, its loss in decibels *should* be added to the feedline loss)  
 $\text{transmit antenna gain (dBi)}$  is the transmitter's antenna gain in decibel isotropic  
 $\text{free space path loss (dB)}$  is the free space path loss in decibels between the transmit antenna and receive antenna  
 $\text{receive antenna gain (dBi)}$  is the receiver's antenna gain in decibel isotropic (2.148 dBi for a resonant half-wave dipole)

**Convert microvolt per meter ( $\mu\text{V}/\text{m}$ ) to decibel microvolt per meter ( $\text{dB}\mu\text{V}/\text{m}$ )**

$$dB\mu V/m = 20\log(E_{\mu V/m})$$

where

$dB\mu V/m$  is field strength in decibel microvolt per meter

$E_{\mu V/m}$  is field strength in microvolt per meter

**Convert decibel microvolt per meter ( $\text{dB}\mu\text{V}/\text{m}$ ) to microvolt per meter ( $\mu\text{V}/\text{m}$ )**

$$E_{\mu V/m} = 10^{\frac{dB\mu V/m}{20}}$$

where

$E_{\mu V/m}$  is field strength in microvolt per meter

$dB\mu V/m$  is field strength in decibel microvolt per meter

**Convert leakage field strength at 30 meters measurement distance to an equivalent field strength at 3 meters measurement distance**

$$E_{\mu V/m} \text{ at 3 meters} = E_{\mu V/m} \text{ at 30 meters} * \left(\frac{30}{3}\right)$$

where

$E_{\mu V/m} \text{ at 3 meters}$  is field strength in microvolt per meter at a 3 meter measurement distance

$E_{\mu V/m} \text{ at 30 meters}$  is field strength in microvolt per meter at a 30 meter measurement distance

**Convert leakage field strength at 3 meters measurement distance to an equivalent field strength at 30 meters measurement distance**

$$E_{\mu V/m} \text{ at 30 meters} = E_{\mu V/m} \text{ at 3 meters} * \left(\frac{3}{30}\right)$$

where

$E_{\mu V/m} \text{ at 30 meters}$  is field strength in microvolt per meter at a 30 meter measurement distance

$E_{\mu V/m} \text{ at 3 meters}$  is field strength in microvolt per meter at a 3 meter measurement distance

**Calculate leakage field strength difference in decibels at new measurement distance versus reference measurement distance**

$$C_{dB} = 20 \log \left( \frac{d_{new}}{d_{ref}} \right)$$

where

$C_{dB}$  is the correction factor in decibels

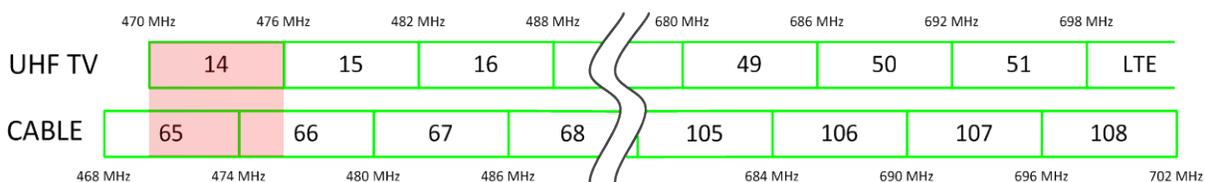
$d_{new}$  is the new measurement distance

$d_{ref}$  is the reference measurement distance (e.g., 3 meters)

## Appendix E: OVER-THE-AIR UHF SPECTRUM USAGE

### North American UHF Television Allocations

The UHF television broadcast spectrum once occupied 470 MHz to 890 MHz, comprising channels 14-83. The 698 MHz to 890 MHz portion of the original UHF television broadcast spectrum has over the years been reallocated to other services such as trunked two-way radio, public safety, cellular, and LTE services. The remaining UHF TV channels 14-51 occupy 470 MHz to 698 MHz. Of importance to North American cable operators is the 2 MHz offset alignment of UHF TV channels relative to CEA standard cable channels in the same frequency range. That is, each over-the-air UHF TV channel overlaps parts of *two* CEA standard channels. The following figure illustrates the overlap.



**Figure 1: Overlap of UHF broadcast TV channels with CEA standard cable channels**

### Know What is in the Over-the-Air Spectrum

Cable operators are encouraged to use a spectrum analyzer and suitable antenna to occasionally look at the over-the-air spectrum, and see what signals are present that *may* have the potential to cause ingress or direct pickup interference. Figure 2 shows an example of over-the-air signals in the 500 MHz to 806 MHz range. The left approximately two-thirds of the display includes a mix of mostly 8-VSB (eight-level vestigial sideband) digital TV signals and a few analog TV signals (low power TV, translator, etc.). The right approximately one-third of the display covers the 698 MHz to 806 MHz LTE spectrum, in which LTE downlink signals and some public safety communications signals are visible. Note the presence of leaking QAM signals from a nearby cable network.

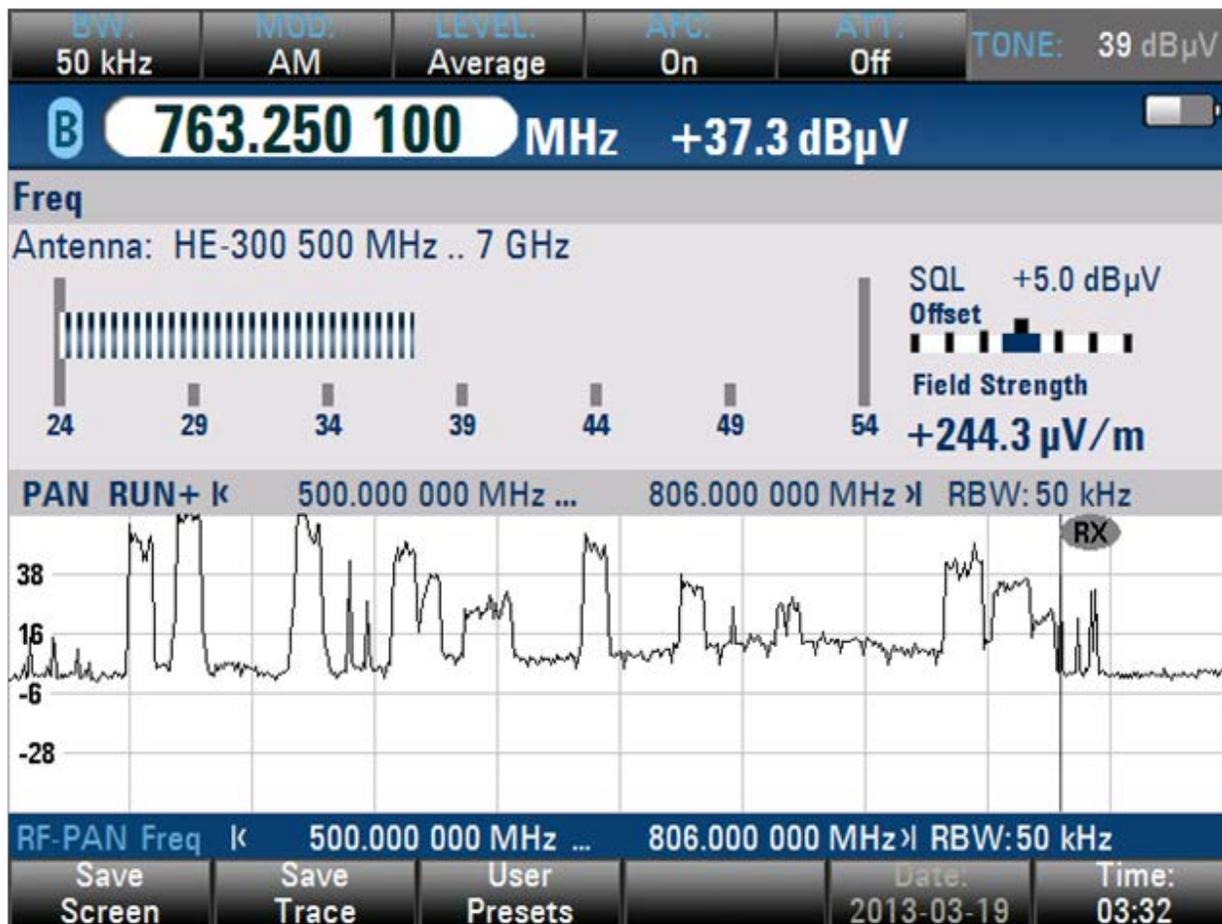


Figure 2: Over-the-air signals (including leaking QAM signals) in the 500 MHz to 806 MHz spectrum

**Public Safety**

Table 1 summarizes over-the-air U.S. public safety frequency allocations between 700 MHz and 1 GHz. Cable operators *should* be aware that signals within these frequency ranges are susceptible to interference from signal leakage, and *may* be a potential source of ingress or direct pickup interference.

**Table 1: Public safety and private land mobile (including cellular SMR) allocations**

Base station transmit (downlink)	Mobile station transmit (uplink)	Applicable FCC Rules
758 MHz to 775 MHz	788 MHz to 805 MHz	Part 90, Subpart R
851 MHz to 869 MHz	806 MHz to 824 MHz	Part 90, Subpart S
935 MHz to 940 MHz	896 MHz to 901 MHz	Part 90, Subpart S

Note: The 758 MHz to 769 MHz and 788 MHz to 799 MHz bands *shall* be licensed to the First Responder Network Authority.

### LTE Operating Bands<sup>24</sup>

Table 2 summarizes worldwide LTE band allocations. Bands 2, 4, 5, 7, 10, 12, 13, 14, 17, 23, 24, 25, 26, 27, 29, 35, 36, 37, 41, and 42 are currently used in North America or *may* be in the future. The highlighted bands overlap downstream frequencies below 1 GHz used by cable operators.

**Table 2: Worldwide LTE band allocations**

Band Number	Uplink (UE to tower)	Downlink (tower to UE)
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz
5	824 MHz – 849 MHz	869 MHz – 894MHz
6	Replaced by Band 19	
7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz
8	880 MHz – 915 MHz	925 MHz – 960 MHz
9	1749.9 MHz – 1784.9 MHz	1844.9 MHz – 1879.9 MHz
10	1710 MHz – 1770 MHz	2110 MHz – 2170 MHz
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz
12	699 MHz – 716 MHz	729 MHz – 746 MHz
13	777 MHz – 787 MHz	746 MHz – 756 MHz
14	788 MHz – 798 MHz	758 MHz – 768 MHz
15	Reserved	Reserved
16	Reserved	Reserved
17	704 MHz – 716 MHz	734 MHz – 746 MHz
18	815 MHz – 830 MHz	860 MHz – 875 MHz
19	830 MHz – 845 MHz	875 MHz – 890 MHz
20	832 MHz – 862 MHz	791 MHz – 821 MHz
21	1447.9 MHz – 1462.9 MHz	1495.9 MHz – 1510.9 MHz
22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz
23	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz
24	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz
25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz
26	814 MHz – 849 MHz	859 MHz – 894 MHz
27	807 MHz – 824 MHz	852 MHz – 869 MHz
28	703 MHz – 748 MHz	758 MHz – 803 MHz
29	N/A	717 MHz – 728 MHz
30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz
31	452.5 MHz – 457.5 MHz	462.5 MHz – 467.5 MHz
32	N/A	1452 MHz – 1496 MHz
33	1900 MHz – 1920 MHz	1900 MHz – 1920 MHz
34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz
35	1850 MHz – 1910 MHz	1850 MHz – 1910 MHz
36	1930 MHz – 1990 MHz	1930 MHz – 1990 MHz
37	1910 MHz – 1930 MHz	1910 MHz – 1930 MHz
38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz
39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz
40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz
41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz
42	3400 MHz – 3600 MHz	3400 MHz – 3600 MHz
43	3600 MHz – 3800 MHz	3600 MHz – 3800 MHz
44	703 MHz – 803 MHz	703 MHz – 803 MHz

<sup>24</sup> Formally known as E-UTRA (evolved UMTS terrestrial radio access) operating bands.