SCTE® | STANDARDS

Network Operations Subcommittee

SCTE STANDARD

SCTE 209 2024

Technical Report
UHF Leakage, Ingress, Direct Pickup

NOTICE

The Society of Cable Telecommunications Engineers (SCTE) Standards and Operational Practices (hereafter called “documents”) are intended to serve the public interest by providing specifications, test methods and procedures that promote uniformity of product, interoperability, interchangeability, best practices, and the long term reliability of broadband communications facilities. These documents shall not in any way preclude any member or non-member of SCTE from manufacturing or selling products not conforming to such documents, nor shall the existence of such standards preclude their voluntary use by those other than SCTE members.

SCTE assumes no obligations or liability whatsoever to any party who may adopt the documents. Such adopting party assumes all risks associated with adoption of these documents and accepts full responsibility for any damage and/or claims arising from the adoption of such documents.

NOTE: The user’s attention is called to the possibility that compliance with this document may require the use of an invention covered by patent rights. By publication of this document, no position is taken with respect to the validity of any such claim(s) or of any patent rights in connection therewith. If a patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, then details may be obtained from the standards developer. SCTE shall not be responsible for identifying patents for which a license may be required or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Patent holders who believe that they hold patents which are essential to the implementation of this document have been requested to provide information about those patents and any related licensing terms and conditions. Any such declarations made before or after publication of this document are available on the SCTE web site at https://scte.org.

All Rights Reserved
© 2024 Society of Cable Telecommunications Engineers, Inc.
140 Philips Road
Exton, PA 19341

Document Tags

☐ Specification	☐ Checklist	☐ Facility
☒ Test or Measurement	☐ Metric	☒ Access Network
☐ Architecture or Framework	☐ Cloud	☐ Customer Premises
☐ Procedure, Process or Method		

Document Release History

Release	Date
SCTE 209 2015	*2015*
SCTE 209 2024	*2/28/2024*

Note: Standards that are released multiple times in the same year use: a, b, c, etc. to indicate normative balloted updates and/or r1, r2, r3, etc. to indicate editorial changes to a released document after the year.

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

List of Tables

Title **Page Number**

1. Introduction

1.1. Executive Summary

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.[1] Although Section 76.605(c) 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 600 MHz and 700 MHz bands 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 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.

1.2. Benefits

The guidance and recommendations in this technical report will help cable operators maintain the integrity of their networks as well as compliance with applicable regulations. Moreover, following recommendations to minimize signal leakage in the UHF spectrum will significantly reduce the risk of harmful interference to over-the-air services in that spectrum. These efforts build toward supporting a ‘good actor’ image to the FCC and the local community at large

1.3. Intended Audience

This technical report is intended for cable system technical personnel such as installers, service and maintenance technicians, and others who have to monitor, measure, and repair RF signal leakage levels as part of their daily jobs or are interested in the treatment of such signals.

---

[1] The VHF spectrum encompasses 30 MHz to 300 MHz, and the UHF spectrum encompasses 300 MHz to 3000 MHz.

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

Cable operators are working on future HFC bandwidth expansions to include moving the upper edges of the upstream and downstream to higher frequencies. The DOCSIS 4.0 specification supports upstream frequencies as high as 684 MHz and downstream frequencies up to 1,794 MHz (or more). As a result, there will be a need for updated leakage detection tools and measurement procedures for continuous monitoring and repair support for signals in both the downstream and upstream paths. This will be particularly important when frequencies being monitored for leakage are in the upstream spectrum and overlap aeronautical bands.

2. Normative References

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

2.1. SCTE References

No normative references are applicable.

2.2. Standards from Other Organizations

No normative references are applicable.

2.3. Other Published Materials

No normative references are applicable.

3. Informative References

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

3.1. SCTE References

No informative references are applicable.

3.2. Standards from Other Organizations

No informative references are applicable.

3.3. Other Published Materials

[1] Arcom Labs. (n.d.). Detecting leakage of digital channels in an HFC network. Syracuse, NY. Author.

[2] Consumer Electronics Association. (2023). CEA-542-D/CTA-542-D, cable television channel identification plan. Arlington, VA. Author.

[3] De Nijs, J. (2010, October). Co-channel interference tests of LTE to cable euro-DOCSIS services. TNO Information and Communication Technology.

[4] Denisowski, P. (2011). Recognizing and resolving LTE/CATV interference issues. Presentations and Collected Technical Papers of the Society of Cable Telecommunications Engineers, USA.

[5] Denisowski, P. (2012). Evolving challenges in LTE / cable interference issues. Presentations and Collected Technical Papers of the Society of Cable Telecommunications Engineers, USA.

[6] European Telecommunications Standards Institute. (2011, January). LTE; evolved universal terrestrial radio access (E-UTRA); requirements for support of radio resource management (3GPP TS 36.133 version 10.1.0 Release 10). Nice, France. Author.

[7] European Telecommunications Standards Institute. (2011, *May*). The concise report of the CENELEC/ETSI joint working group on the digital dividend. Nice, France. Author.

[8] European Telecommunications Standards Institute. (2011, June). LTE; evolved universal terrestrial radio access (E-UTRA); user equipment (UE) radio transmission and reception (3GPP TS 36.101 version 10.3.0 release 10). Nice, France. Author.

[9] Excentis. (2011, December). Technical considerations on the protection of cable services. Addendum to CEPT Report 159.

[10] Hranac, R. (2009, January). Signal leakage in an all-digital network. Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/09-02-0120signal20leakage20in20an20all20digital20network.pdf

[11] Hranac, R. (2009, *May*). Signal leakage in an all-digital network. Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/09-05-0120signal20leakage20in20an20all20digital20network20the20continuing20story.pdf

[12] Hranac, R., Thomas, R. (2009). Characterizing signal leakage from an all-digital cable network. Presentations and Collected Technical Papers of the Society of Cable Telecommunications Engineers, USA.

[13] Hranac, R. (2011, October). Some thoughts on LTE interference. Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/11-10-0120some20thoughts20on20lte20interface.pdf

[14] Hranac, R. (2011, November). LTE interference (part 2). Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/11-11-0120some20thoughts20on20lte20interface20part20two.pdf

[15] Hranac, R., Tresness, G. (2012) Another look at signal leakage: the need to monitor at low and high frequencies. Presentations and Collected Technical Papers of the Society of Cable Telecommunications Engineers, USA.

[16] Hranac, R. (2012, March). Untangling some of the confusion. Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/12-03-0120understanding20some20of20the20confusion.pdf

[17] Hranac, R. (2012, *May*). A leak is a leak – or is it? Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/12-05-2020A20Leak20Is20A20LeakOr20Is20It201.pdf

[18] Hranac, R. (2012, July). The antenna factor. Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/12-07-0120the20antenna20factor.pdf

[19] Hranac, R. (2012, August). Even more on LTE interference. Communications Technology. Retrieved October 14, 2014, from https://wagtail-prod-storage.s3.amazonaws.com/documents/12-08-0120on20lte20interface.pdf

[20] Hranac, R., Segura, N. (2013). UHF signal leakage and ingress: understanding the challenges. Presentations and Collected Technical Papers of the Society of Cable Telecommunications Engineers, USA.

[21] International Electrotechnical Commission. (2006, February). Electromagnetic compatibility (EMC) – part 4-3: testing and measurement techniques – radiated, radio-frequency, electromagnetic field immunity test. Geneva, Switzerland. Author.

[22] International Electrotechnical Commission. (2012, July). Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: general requirements. Geneva, Switzerland. Author.

[23] Kramer, J., et. al. (2009, March). Leakage in an all-digital world: heavy hitters weigh in. Communications Technology.

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

[25] Multichannel Video And Cable Television Service, 47 C.F.R. §76 (2014).

[26] Motorola. (2007, December). Shielding effectiveness of in-home cable TV wiring and splitters. (Motorola Whitepaper). Horsham, PA. Author.

[27] White, D. (2012) Multi-band leakage monitoring for the future. Presentations and Collected Technical Papers of the Society of Cable Telecommunications Engineers, USA.

4. Compliance Notation

shall	This word or the adjective "***required***" means that the item is an absolute requirement of this document.
shall not	This phrase means that the item is an absolute prohibition of this document.
forbidden	This word means the value specified ***shall*** never be used.
should	This word or the adjective "*recommended*" 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 weighed before choosing a different course.
should not	This phrase means that there *may* 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.
may	This word or the adjective "*optional*" indicate a course of action permissible within the limits of the document.
deprecated	Use is permissible for legacy purposes only. Deprecated features *may* be removed from future versions of this document. Implementations *should* avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

5G	fifth generation wireless network technology
µs	microsecond
µV/m	microvolt per meter
A_{em}	maximum effective aperture
BER	bit error ratio
BLER	block error rate
BTS	base transceiver station
CEA/CTA	Consumer Electronics Association (now Consumer Technology Association)[2]
CENELEC	European Committee for Electrotechnical Standardization
CEPT	European Conference of Postal and Telecommunications Administrations (Conférence Européenne des Administrations des Postes et des Télécommunications)
CLI	cumulative leakage index
CNR	carrier-to-noise ratio
CPE	customer premises equipment
CQI	call quality index
CR	code rate

---

[2] The Consumer Electronics Association changed its name to the Consumer Technology Association several years ago. When that change happened, CEA standards were renamed CTA standards. For example, CEA-542-D (Cable Television Channel Identification Plan) became CTA-542-D (Cable Television Channel Identification Plan). Note: The latest version is CTA-542-D R-2023.

CTA	Consumer Technology Association (formerly Consumer Electronics Association)
CW	continuous wave
dB	decibel
dBi	decibel isotropic
dBm	decibel milliwatt
dB/m	decibel per meter
dBmV	decibel millivolt
dBµV/m	decibel microvolt per meter
DOCSIS	Data Over Cable Service Interface Specifications
e.g.	for example (exempli gratia)
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
Pd	power density
Pt	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 (Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek)
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

5.2. Definitions

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

No definitions are applicable.

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.[3] These included the technical standards that are incorporated in §76.605 of the FCC Rules. In particular, the analog signal leakage requirements in §76.605(c) were adopted at that time.[4] One leakage limit 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.[5]

---

[3] See *Amendment of Part 74, Subpart K, of the Commission's Rules and Regulations Relative to Community Antenna Television Systems*, Report and Order: And Inquiry into the Development of Communications Technology and Services to Formulate Regulatory Policy and Rulemaking and/or Legislative Proposals, 36 FCC 2d 143 (1972) (1972 Amendment). See also generally Wong, J. (1983). Cable Signal Leakage: Where is it all going? Retrieved from https://www.nctatechnicalpapers.com/Paper/1983/1983-cable-signal-leakage-where-is-it-all-going (Signal Leakage Technical Paper).

[4] In 2017, the FCC added signal leakage requirements for digital signals. See *Cable Television Technical and Operational Standards*, Report and Order, 32 FCC Rcd. 7554 (2017) (2017 Report and Order).

1972 Amendment at ¶ 161.[6] Signal Leakage Technical Paper at 24.

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, citing the lack of an actual interference report and the minimal interference probability. [6]

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 - §76.613.[7] §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[8], and were revised again and subsequently adopted in 2017.[9]

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(c): Maximum allowable signal leakage field strength-versus-frequency
>
> §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(c), 76.611, 76.612, 76.613, 76.614, 76.616, 76.617, 76.1803 and 76.1804) **[Note: §76.610 references 76.605(d). This is an error in the rule.]**
>
> §76.611: Cumulative leakage index calculation, drive-out and flyover measurements[10]

---

[6] Signal Leakage Technical Paper at 24.

[7] See *Amendment of Part 76 of the Commission's Rules to Add Frequency Channeling Requirements and Restrictions and to Require Monitoring for Signal Leakage from Cable Television Systems,* Report and Order, 65 FCC 2d 813, FCC 77-541 (1977).

[8] See *Amendment to Part 76 of the Commission's Rules to Add Frequency Channeling Requirements and Restrictions and to Require Monitoring for Signal Leakage from Cable Television Systems*, Second Report and Order, 99 FCC 2d 512, FCC 84-516 (1984). See also *Amendment to Part 76 of the Commission's Rules to Add Frequency Channeling Requirements and Restrictions and to Require Monitoring for Signal Leakage from Cable Television System*s, Memorandum Opinion and Order, FCC 85-333, 101 FCC 2d 117 (1985).

[9] 2017 Report and Order.

[10] 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.

§76.612: Frequency offset requirements

§76.613: Harmful interference clause

§76.614: Quarterly monitoring and leakage repair

§76.616: Cable network operation near certain aeronautical and marine 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(c) specifies maximum leakage field strength limits-versus-frequency and is provided here for reference.

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

Table 1 to Paragraph (c)

Frequencies	**Signal leakage limit** (microvolt per meter)	**Distance in meters (m)**
Analog signals less than and including 54 MHz, and over 216 MHz	15	30
Digital signals less than and including 54 MHz, and over 216 MHz	13.1	30
Analog signals over 54 MHz up to and including 216 MHz	20	3
Digital signals over 54 MHz up to and including 216 MHz	17.4	3

The majority of U.S. cable operators are familiar with the digital signal leakage limit in the 108 MHz to 137 MHz VHF aeronautical band: 17.4 microvolts per meter (µV/m) at a measurement distance of 3 meters (approximately 10 feet) from the cable network. This limit applies to the entire frequency range from >54 MHz to and including 216 MHz, as noted in the previous table.

The digital signal leakage limit applicable to the UHF spectrum is 13.1 µV/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:

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

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

Converting the 30 meters field strength limit of 13.1 µV/m to an equivalent field strength limit at 3 meters gives 13.1 µV/m. If a cable network just meets the leakage limits-versus-frequency (or has even lower levels of leakage) defined in §76.605(c), 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 Regional Director for the Commission's local field office, and ***shall not*** be resumed until the interference has been eliminated to the satisfaction of the Regional Director. When authorized by the Regional Director, 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 Regional Director 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(c) 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[11]

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 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.

---

[11] The material in this section is adapted from Hranac (2014), and is used here with the permission of the author.

In the United States, LTE (long term evolution) and 5G services now operate in several frequency bands, including the 614 MHz to 806 MHz band, which overlaps the frequency spectrum used by many cable operators to deliver services to their customers. As mobile service providers continue to deploy these services, 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 [15].

What, then, can cable operators do to guard against signal leakage affecting LTE, 5G 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, 5G 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 UHF 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 its signal leakage limits, as well as for harmful interference to LTE, 5G and other 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 the affected service provider 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 affected service provider.
- Notify customer service representatives to direct interference complaints and inquiries to the appropriate cable company technical personnel.
- Document everything (e.g., dates and times of all communication with the affected 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 over-the-air service-related complaints and cable operator 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. Now, cases of leakage-related interference to LTE and other equipment in the UHF spectrum point to the need to monitor outside of the traditional 108 MHz to 137 MHz VHF aeronautical band. Cable signal leakage that affects LTE and 5G service 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 or higher 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 and 5G signals in the 614 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.

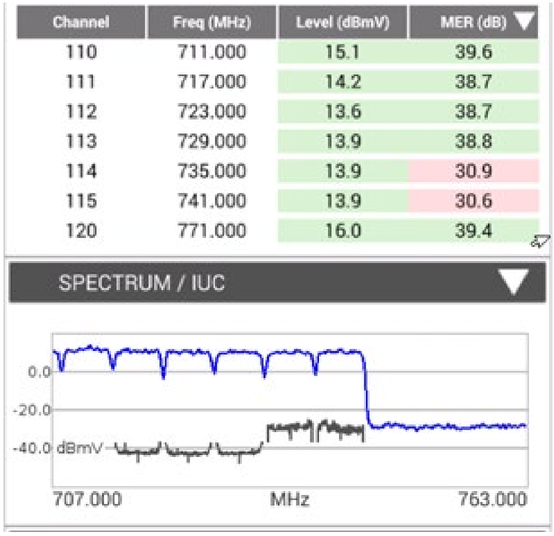
If system personnel have access to UHF leakage detection equipment, locations with UHF leakage might be where some of the ingress is entering the plant, but even that isn't assured.

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 single carrier quadrature amplitude modulation (SC-QAM) and/or OFDM signals occupying the same spectrum. It is generally not acceptable to temporarily turn off downstream signals to see if the suspect ingress is present, with the possible exception of doing that kind of service-disruptive work during a maintenance window.

One option when troubleshooting ingress is to use test equipment that displays the noise floor beneath an affected QAM signal. Some field test instruments have ingress detection displays that show the channel band with the haystack, as well as the spectrum within the channel in an overlayed display (see Figure 1, note the MER shown just above the spectrum display for the channels impacted by ingress). When ingress can be anticipated to occur at specific frequencies within active channel bands, some instruments can automatically detect this and notify the user.



Channel	Freq (MHz)	Level (dBmV)	MER (dB)
110	711.000	15.1	39.6
111	717.000	14.2	38.7
112	723.000	13.6	38.7
113	729.000	13.9	38.8
114	735.000	13.9	30.9
115	741.000	13.9	30.6
120	771.000	16.0	39.4

Figure 1- Example display of a field meter showing the noise floor beneath active SC-QAM signals (courtesy of Viavi Solutions).

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 CPE silicon for identifying downstream ingress in the VHF and UHF bands. This feature is generally known as full band capture (FBC). Technicians can look at a captured display (See Figure 1) for indications of the presence of downstream ingress.

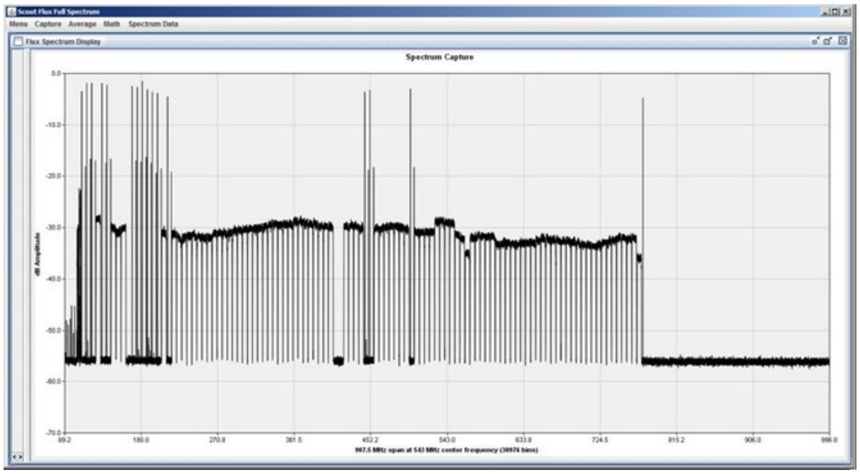


Figure 2 - Spectrum capture with FM ingress visible on far left edge of the display, from a FBC-capable cable modem

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, 5G, 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[12], 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

---

[12] 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.

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, blocking, or complete loss of picture and sound on digital video signals – sometimes on one 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) (±2 dB) [8], 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 µV/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. Leakage Detection and Measurement in Expanded Bandwidth Networks

U.S. cable operators' systems have been operating with upstream spectrum from 5 MHz to 42 MHz in most cases and with a downstream spectrum from 54 MHz to either 750 MHz, 860 MHz, and in some cases, 1002 MHz. Operators recognize the need for a strategically competitive plan for higher data tier speeds and enhanced programming offerings, and that to facilitate these offerings, additional outside plant bandwidth will become necessary. Some networks have been or are being upgraded to an upstream spectrum of 5 MHz to 204 MHz (high-split) and a downstream spectrum of 258 MHz to 1218 MHz. Incrementally, they will need to evolve the outside plant network to support higher frequency splits to augment upstream bandwidth, as well as higher downstream frequencies to offset those concessions and to provide incremental downstream capacity. The DOCSIS 4.0 specification contemplates upstream frequencies up to 684 MHz and downstream frequencies up to 1,794 MHz.

As active electronics capabilities extend beyond 1002 MHz, and up to 3 GHz, cable operators must take proactive steps to facilitate leakage and ingress detection before, during and after future upgrades.

10.1.1. Leakage measurements for 204 MHz or higher return

Cable operators are working on future HFC bandwidth expansions to include moving the upstream/downstream split to higher frequencies. High-split systems will require some thought on how we continue to monitor and repair signal leakage, because part of the upstream spectrum in a high-split network overlaps the 108 MHz to 137 MHz VHF aeronautical band. Regardless, if the aeronautical spectrum exists in the downstream, or soon to be upstream, cable operators must comply with existing FCC signal leakage rules.

While aeronautical band leakage monitoring and measurement in a high-split architecture sounds challenging, technology developments have largely overcome the challenges.

Figure 3 illustrates the overlap of aeronautical bands with frequencies used in various band plans and forward/reverse splits.

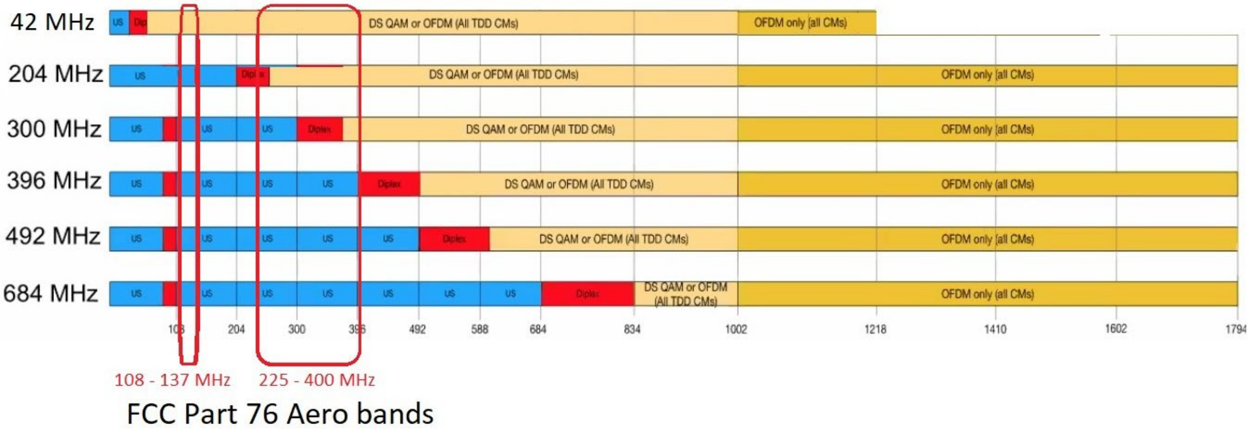


Figure 3 - Aeronautical band overlap with various cable network frequency plans.

Leakage detection solutions

A. 108 MHz to 137 MHz aeronautical band – The majority of suppliers' leakage equipment currently creates a proprietary leakage test signal that is inserted between downstream SC-QAM signals. The test signal is typically located at 138 MHz. Because the aeronautical band overlaps the upstream path in a high-split HFC design, CPE in the subscriber premises can be used as a test signal source for leakage monitoring.
B. 225 MHz to 400 MHz aeronautical band – This aeronautical band will partially fall into the downstream path of a 204 MHz/258 MHz high-split architecture allowing the use of traditional downstream detection technology cable operators are familiar with. However, with a 300 MHz and higher upstream split this aeronautical band will fall fully into a cable network's upstream and the solution could use CPE in the subscriber premises as a leakage test signal source.

A solution for leakage test signals in the 108 MHz to 137 MHz aeronautical band when that band overlaps the upstream follows:

- DOCSIS 3.1 and later cable modems can generate OFDMA upstream data profile (OUDP) testing bursts under the CMTS's control. The OUDP signals can be used for leakage detection and measurement.

10.1.2. Downstream leakage measurement options

Leakage test equipment can still be used for downstream leakage detection and measurement of CW carriers, existing SC-QAM or OFDM signals, or proprietary leakage test signals generated in the headend/hub or at the node in the case of DAA deployments. Some leakage detection equipment supports measurement of downstream leakage and upstream leakage, the latter using the previously discussed OUDP signals. Consult with equipment vendors for details.

11. “Homebrew” UHF Leakage Detection Solutions

As previously discussed, 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.

When this technical report was originally written, the then new digital-compatible leakage detection equipment was not yet widely deployed. At the time, a proposed alternative was the “homebrew” solutions discussed in this section. This information is retained for historical reference purposes.

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 [20][13]. 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.

11.1. Field Test 1

The following is excerpted from the aforementioned 2013 Cable-Tec Expo paper [20]:

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,[14] and an older consumer-grade UHF broadcast television antenna.[15] The spectrum analyzer was Sunrise Telecom’s (now VeEx) AT2500RQv,[16] and the preamplifier an Antronix 1 GHz drop amplifier.[17]

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

---

[13] 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.

[14] Kent Electronics 400-1000 MHz printed circuit board antenna. http://www.wa5vjb.com/products1.html

[15] Make/model and specifications unknown. Boom length 5’9”.

[16] http://www.veexinc.com/en-us/Products/AT2500RQvPlus

[17] 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

- 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 µV/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 µV/m.
- At afield strength of approximately 75 µV/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.[18] When the field strength was decreased by 6 dB to approximately 37 µV/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 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.

---

[18] 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.

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[19] 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.

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.

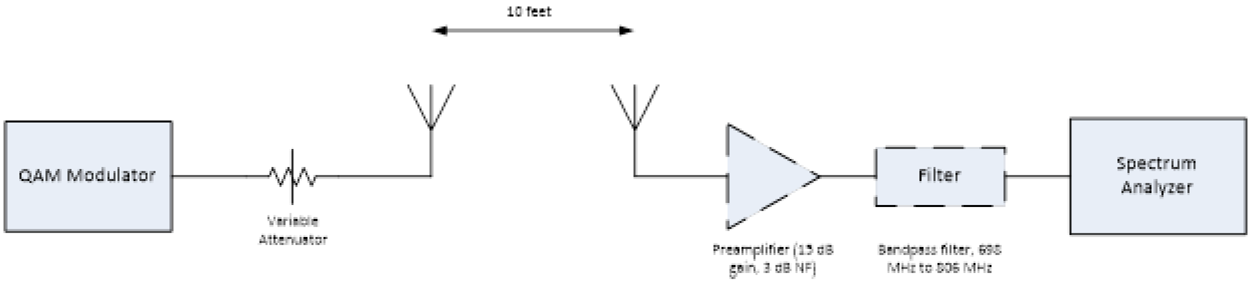


Figure 4 - Block diagram of equipment setup for Field Test 2

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

---

[19] JFW Industries, Inc., Model 75DA-003, S/N 215060 9720

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[20]	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)
A5	UHF broadcast TV antenna (est. 20 years old), boom length 5' 9"	Unknown	Unknown	Unknown

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 5 is a photo of antennas A1-A4 (left to right), and Figure 6 is a photo of antenna A5 on its support mast, with the calibrated leak's LPDA antenna visible in the background.

---

[20] 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.

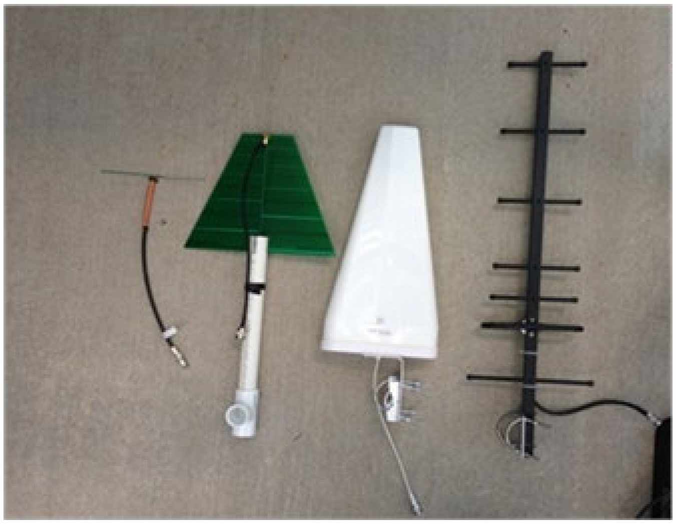


Figure 5 - Left to right, antennas A1-A4

Figure 6 - 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 µV/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 µV/m	-40.11 dBmV	1.78 dB	-41.89 dBmV
100 µV/m	-43.63 dBmV	1.78 dB	-45.41 dBmV
75 µV/m	-46.13 dBmV	1.78 dB	-47.91 dBmV
50 µV/m	-49.65 dBmV	1.78 dB	-51.43 dBmV
20 µV/m	-57.61 dBmV	1.78 dB	-59.39 dBmV
10 µV/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 µV/m.

The remaining tests were conducted at three field strength values: 150 µV/m, 75 µV/m, and 37.5 µV/m. Tables 3 through 9 summarize test results when measuring the CW carrier and QAM signal [21] 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 µV/m	-37.2 dBmV	-36 dBmV	QAM haystack about 12 dB above analyzer noise
75 µV/m	-42 to -43 dBmV	-41.2 dBmV	QAM haystack about 6 dB above the analyzer noise
37.5 µV/m	-48 dBmV	Could not measure	QAM haystack barely visible above analyzer noise

---

[21] The digital channel power of the QAM signal and the power of the CW carrier were identical.

Table 4 - Antenna A2 with preamp and filter

Field Strength	CW carrier level	QAM digital channel power	Comments
150 µV/m	-26 dBmV	-25.4 dBmV	N/A
75 µV/m	-32 to -33 dBmV	-31.4 dBmV	QAM haystack about 12 dB above the analyzer noise
37.5 µV/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 µV/m	-35 dBmV	-35 dBmV	QAM haystack about 14 dB above analyzer noise
75 µV/m	-40 dBmV	-40.4 dBmV	QAM haystack about 8 dB above analyzer noise
37.5 µV/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 µV/m	-24 dBmV	-23.7 dBmV	QAM haystack about 20 dB above analyzer noise
75 µV/m	-29.8 dBmV	-29.4 dBmV	QAM haystack about 14 dB above analyzer noise
37.5 µV/m	-35 dBmV	-34.7 dBmV	QAM haystack about 8 dB above analyzer noise

Table 7 - Antenna A4 connected directly to analyzer

Field Strength	CW carrier level	QAM digital channel power	Comments
150 µV/m	-33.7 dBmV	-33.7 dBmV	QAM haystack about 16 dB above analyzer noise
75 µV/m	-39.3 dBmV	-39 dBmV	QAM haystack about 10 dB above analyzer noise
37.5 µV/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

Field Strength	CW carrier level	QAM digital channel power	Comments
150 µV/m	-22.7 dBmV	-22.3 dBmV	QAM haystack about 21 dB above analyzer noise
75 µV/m	-28.5 dBmV	-28.1 dBmV	QAM haystack about 15 dB above analyzer noise
37.5 µV/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

Field Strength	CW carrier level	QAM digital channel power	Comments
150 µV/m	-34.5 dBmV	-33.8 dBmV	QAM haystack about 14 dB above analyzer noise
75 µV/m	-40.5 dBmV	-39.1 dBmV	QAM haystack about 9 dB above analyzer noise
37.5 µV/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 LDPA at any field strength up to and even above 150 µV/m. An Icom IC-92AD was able to receive the CW carrier with both antennas, but its signal strength meter provides only relative indications[22], and as such cannot be used to measure the field strength of the CW carrier.

---

[22] 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.

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.[23] 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 µV/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 µV/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.

---

[23] 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 7).
- Rohde & Schwarz CMW500 - Wideband Radio Communications Tester used to simulate the LTE downlink to UE (lower instrument in Figure 7).
- R&S CMW-Z10 Portable RF Shielding Box (denoted as 1 in Figure 8).
- Mini Circuits Splitter-Combiner ZAPDJ-2-S to mix QAM Channels with LTE signaling (denoted as 2 in Figure 8).
- LG V600 User Equipment Simulator (denoted as 3 in Figure 8).

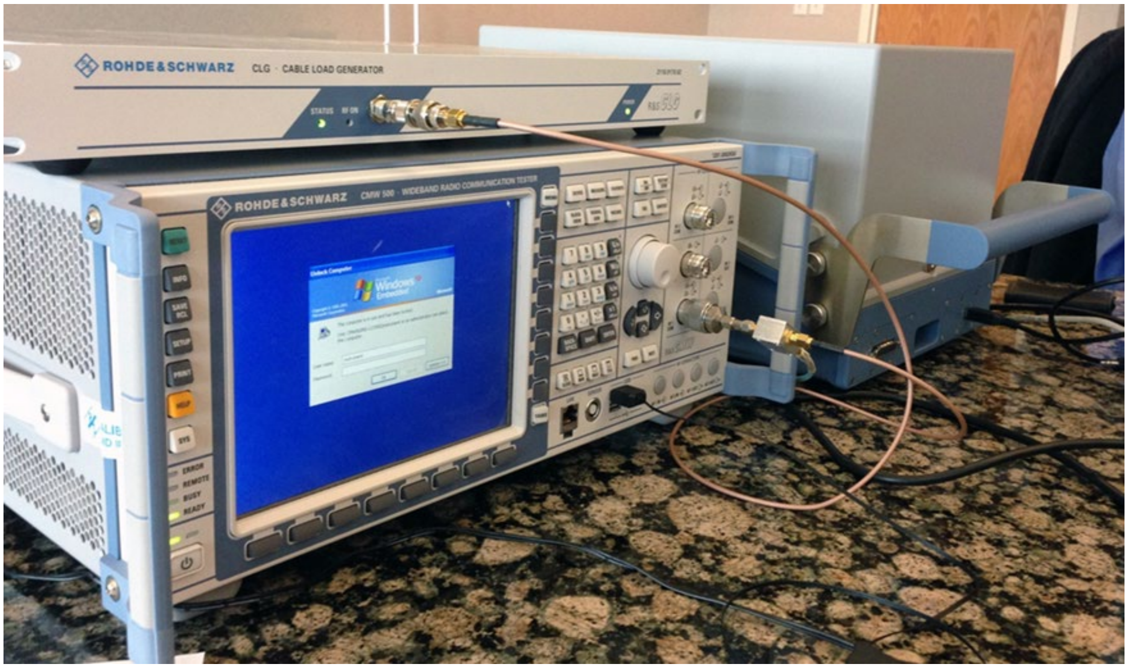


Figure 7 - Rohde & Schwarz cellular and cable signal generating equipment

Figure 8 - Controlled testing environment

A block diagram of the test setup is shown in Figure 9.

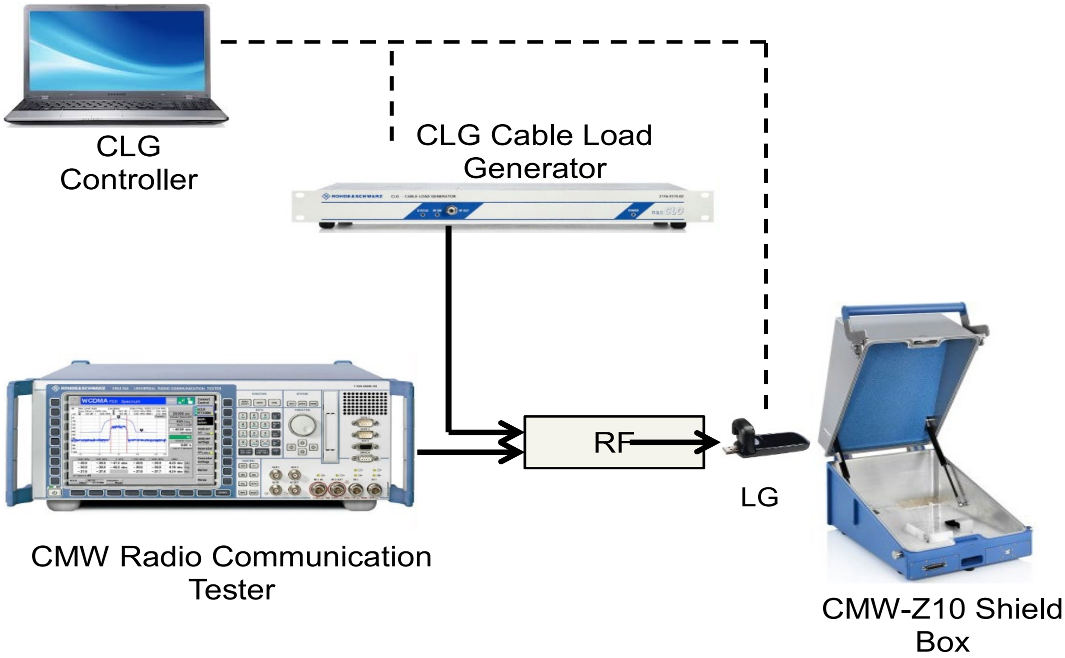


Figure 9 - Test setup for downlink test

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 date 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.

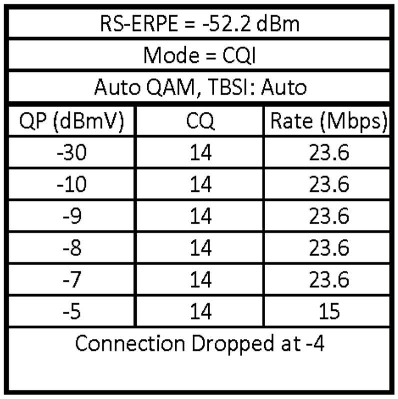
The QAM power was started at -30 dBmV (decibel millivolt) representing an equivalent 497 µV/m leak at 750 MHz and was combined with the downlink signal. The measured impact on the connection quality was as follows:

- 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 µV/m) where the data rate dropped to 15 Mbps. At -4 dBmV (9,914 µV/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

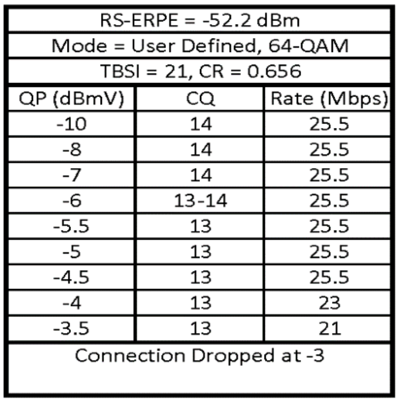


RS-ERPE = -52.2 dBm		
Mode = CQI		
Auto QAM, TBSI: Auto		
QP (dBmV)	CQ	Rate (Mbps)
-30	14	23.6
-10	14	23.6
-9	14	23.6
-8	14	23.6
-7	14	23.6
-5	14	15
Connection Dropped at -4		

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 µV/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 µV/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
Mode = User Defined, 64-QAM
TBSI = 26, CR = 0.9411

QP (dBmV)	CQ	Rate (Mbps)
-20	14	36.7
-15	14	36.7
-13	14	36.7
-10	14	33-35
-9.5	14	32.0
-9.0	14	30.0
-8.5	14	29.5
-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

RS-ERPE = -100 dBm
Mode = User Defined, 64-QAM
TBSI = 25, CR = 0.81

QP (dBmV)	CQ	Rate (Mbps)
-30.0	13	27-28
-29.5	13	25
-29.0	13	24
-28.5	13	24
-28.0	13	23
-27.5	13	23

Connection Dropped at -27
Connection was unstable at Start
TBSI too high for reliable results
Data Rate should have been 31.7

RS-ERPE = -100 dBm
Mode = User Defined, 64-QAM
TBSI = 24, CR = 0.787

QP (dBmV)	CQ	Rate (Mbps)
-100	14	30.6
-50	14	30.6
-45	13	30.6
-40	13	27.0
-39	13	25.0
-38	13	20.0

Connection Dropped at -37

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 µV/m. Note that the CQI and data rate did start to deteriorate slightly at -40 dBmV (157 µV/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 µV/m leak and completely dropped by 198 µV/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 µV/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 µV/m can degrade the downlink performance.

The FCC NPRM at the time proposes a leakage limit of 13.1 µV/m at 30 meters (equivalent to 131 µV/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 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 µV/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 µV/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 µV/m, the field strength 6 meters from the leak will be 75 µV/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 10. The following is a description of the primary elements used in the test setup.

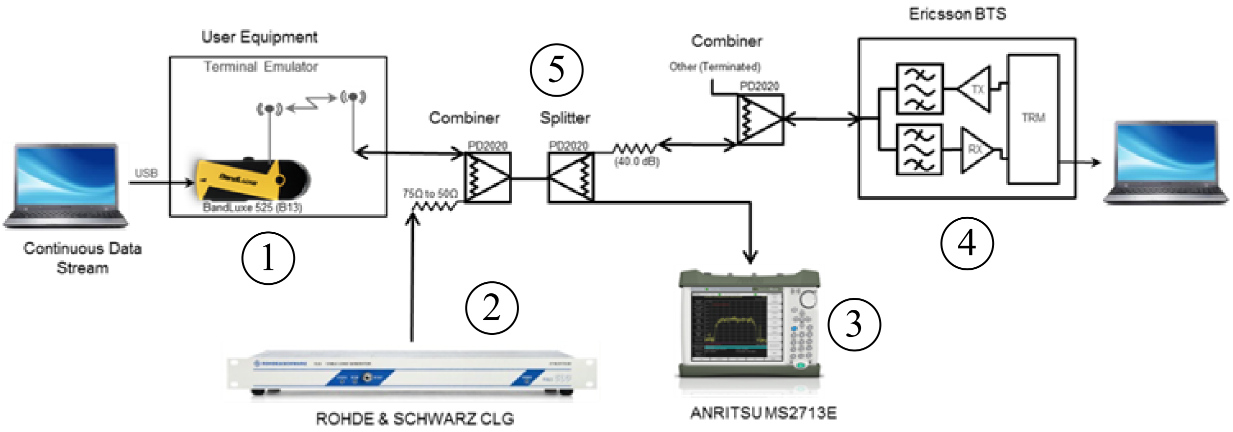


Figure 10 - Test setup for uplink test

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 measurable 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 µV/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	QAM Pwr	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	uV/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 11 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 µV/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.

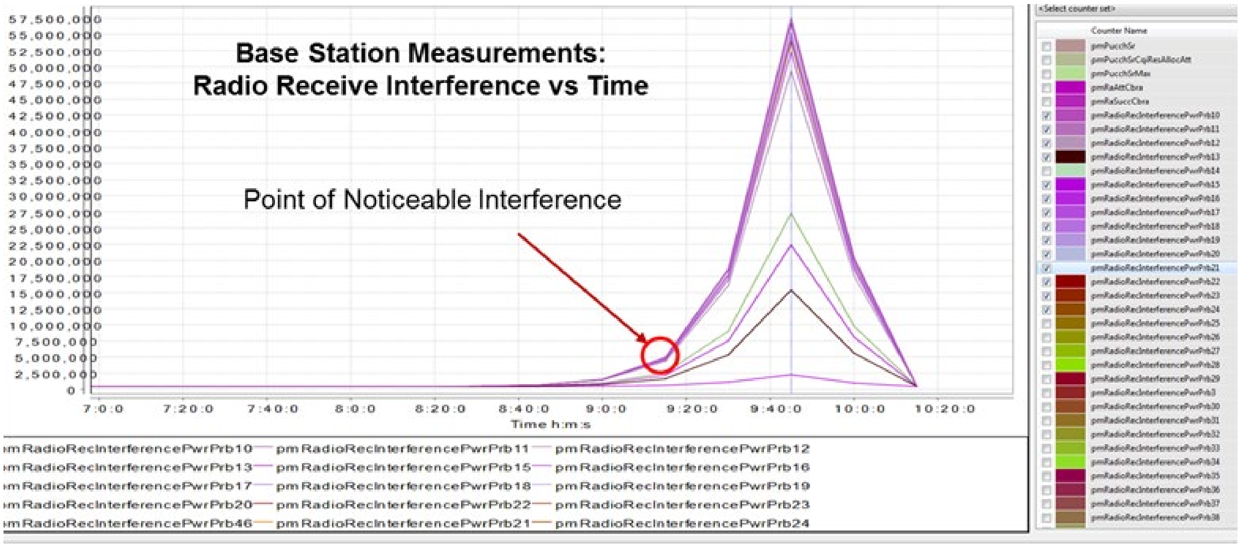


Figure 11 - RSSI output from BTS over time

The next step in the process was to convert the 5.1217 µV/m into useable information. The 5.1217 µV/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 µV/m?

Based upon free-space loss, the graph in Figure 12 plots the distance from the leak to the BTS antenna versus the equivalent leak level that represents the 5.1217 µV/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.

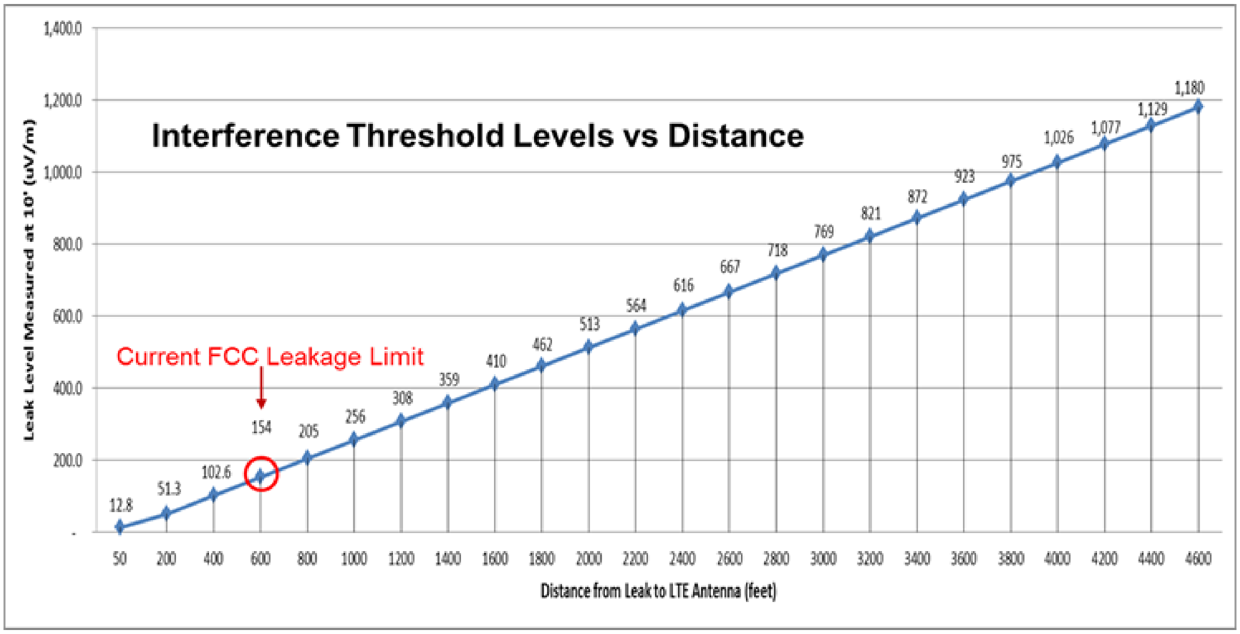


Figure 12 - Equivalent leakage levels versus distance from tower

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 12 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 µV/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 13.

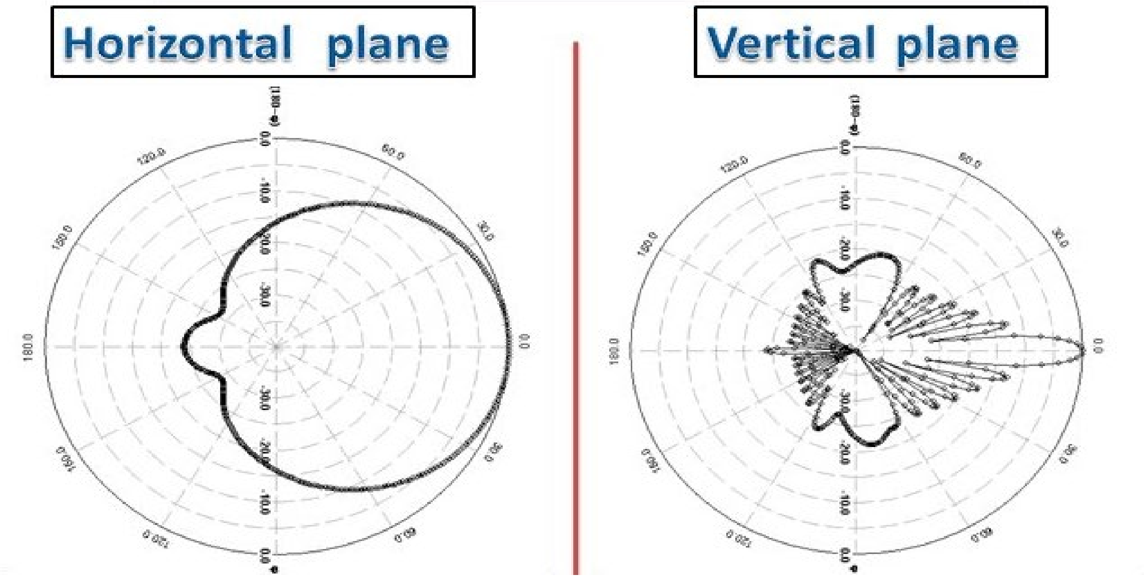


Figure 13 - Antenna tilt and radiation pattern

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 Ericson 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 14 shows the captured RSSI data from the BTS element management system during the field testing.

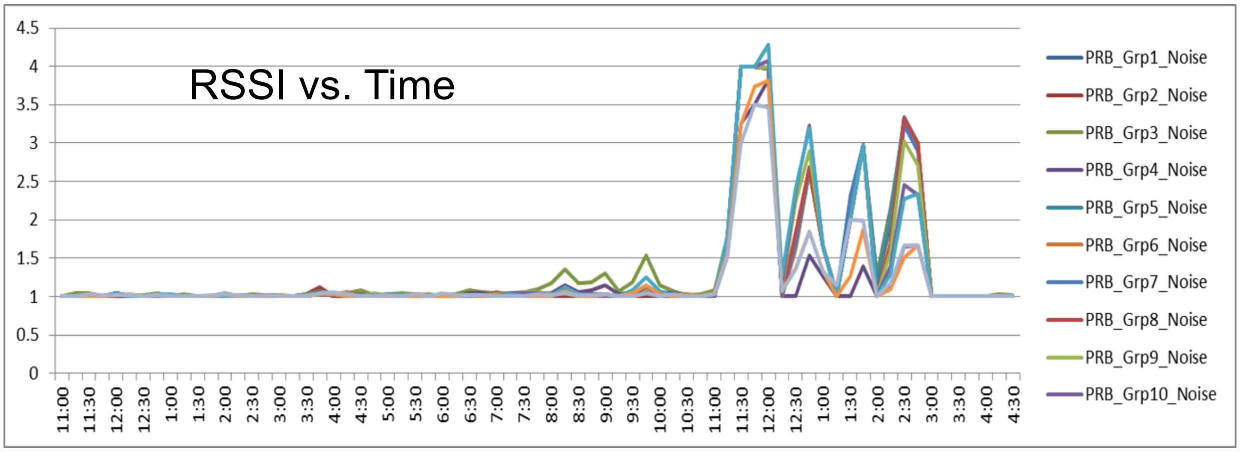


Figure 14 - RSSI data from Verizon field test

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 µV/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. Now, however, cases of leakage-related interference to LTE equipment in the UHF spectrum point 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. 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.

Appendix A. Current test equipment and procedures

The original version of this technical report (SCTE 209 2015) included product-specific information related to signal leakage detection and measurement equipment available at the time. That information is not included in this version. The reader is encouraged to contact equipment manufacturers directly for updated product information.

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,[24] and hopefully is below the maximum limit defined by the FCC.

The field strength in µV/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 µV/m – at two frequencies and the use of separate resonant half-wave dipoles for the measurements, the dBmV values at the two dipoles' terminals will be different. For example, a field strength of 20 µV/m at 121.2625 MHz will produce -42.1 dBmV at the terminals of a resonant half-wave dipole for that frequency. A field strength of 20 µV/m at 782 MHz will produce -58.29 dBmV at the terminals of a resonant half-wave dipole for that frequency.

To understand what is happening, consider the following example, based upon the assumptions in Table 14.

Table 14 - Assumptions for example

• Measurement frequencies are 121.2625 MHz and 782 MHz
• Antennas for the two frequencies are lossless resonant half-wave dipoles
• Field strength at the point of measurement is 20 µV/m for both frequencies

---

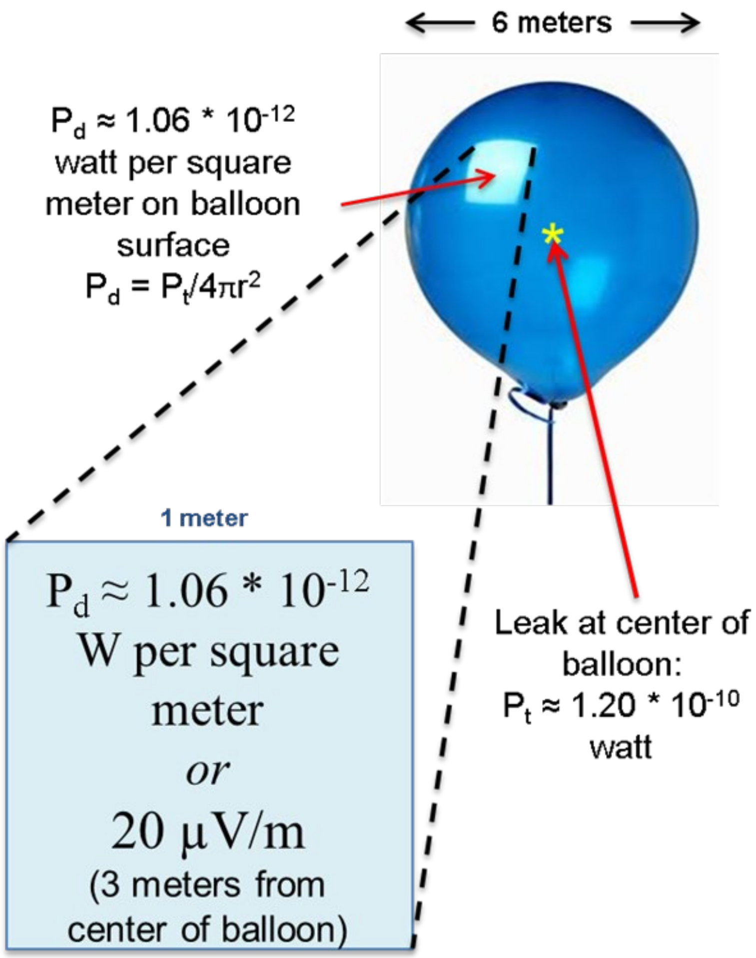
[24] Outside of the North American cable industry, field strength measurements are more commonly stated in decibel microvolt per meter, or dBµV/m.

• Measurement distance from the leak is 3 meters, which is in the far-field for this exercise[25]
• Each antenna is terminated by a load equal to its radiation resistance (approximately 73 ohms for a half-wave dipole)
• Each dipole is oriented for maximum received signal level
• Each antenna does not re-radiate any of the intercepted signal
• The polarization of the RF coming from the leak is linear and is the same as the orientation of the dipoles when the field strength measurements are made

Visualize a loose connector radiating RF into the space around it. Now imagine a 6-meter diameter balloon surrounding the loose connector, with the connector at the center of the balloon (Figure 15). 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.

---

[25] 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 λ is wavelength.



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

Figure 15 - 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 µV/m 3 meters away, P_t must equal 0.00000000012 watt or $1.2 * 10^{-10}$ watt. Because the RF source power P_t is uniformly illuminating the entire balloon (an analogy is a light bulb at the center of the balloon), the power density P_d on the surface of the balloon in watts per square meter is simply the source power P_t divided by the surface area of the balloon, or

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

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

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

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

$$E = \sqrt{PZ}$$

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

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

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

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

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

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

Kraus (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 λ is wavelength in meters ($299.792458/f_{MHz}$) and *G* is the antenna's numerical gain (1.64 for a half-wave dipole). A linear half-wave dipole's maximum effective aperture is an elliptically shaped aperture with an area equal to $0.13\lambda^2$, as shown in Figure 16.

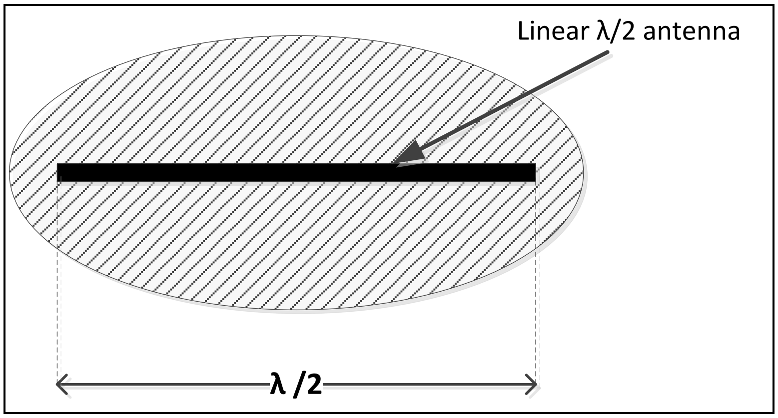


Figure 16 - A linear half-wave dipole's maximum effective aperture A_{em} is represented by an ellipse with an area of $0.13\lambda^2$. Adapted from *Antennas*, by J. Krauss, New York, NY: McGraw-Hill

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 m^2 for the 121.2625 MHz dipole, and 0.0191805865422 m^2 for the 782 MHz dipole. The A_{em} values denote what percentage of the power within the 1 meter x 1 meter square is intercepted by each dipole and delivered to the load at the antenna terminals. The difference between the two A_{em} values in decibels is

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

or 16.19 dB, which is equal to the antenna factor[26] difference between the two dipoles.

In other words, when measuring a 20 µV/m field strength at 121.2625 MHz and 782 MHz with resonant half-wave dipoles, the lower frequency antenna intercepts and delivers more power to its load (~8.46 * 10^{-13} watt) than the higher frequency antenna does (~2.04 * 10^{-14} watt). Here, too, the decibel difference is the same as the antenna factor difference. All of this jibes with the two different signal levels at the dipoles' terminals: -42.1 dBmV at 121.2625 MHz and -58.29 dBmV at 782 MHz, for identical 20 µV/m field strengths at the two frequencies.

---

[26] 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 in 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

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

where
f_{MHz} is the frequency in megahertz
d_{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

$\text{Loss}_{dB} = 20\log(782\text{ MHz}) + 20\log(0.001\text{ km}) + 32.45$
$\text{Loss}_{dB} = [20 * \log(782\text{ MHz})] + [20 * \log(0.001\text{ km})] + 32.45$
$\text{Loss}_{dB} = [20 * 2.89] + [20 * -3.00] + 32.45$
$\text{Loss}_{dB} = [57.86] + [-60.00] + 32.45$
$\text{Loss}_{dB} = 30.31\text{ dB}$

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 dBm – 0 dB + (-1 dBi) – 30.31 dB + 2.14 dBi = -6.17 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 µV/m:

$\mu\text{V/m} = 21 * (782\text{ MHz}) * 10^{(42.58/20)} = 2{,}210{,}172\ \mu\text{V/m}$ or ~2.2 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 (µV/m) to decibel millivolt (dBmV)

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

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 (µV/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
μV is RF signal level in microvolt
$dBmV$ is RF signal level in decibel millivolt

Convert microvolt (µV) to decibel millivolt (dBmV)

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

where
$dBmV$ is RF signal level in decibel millivolt
μV 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
μV 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
μV 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

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

where
$P_{receive}$ is the RF power in decibel milliwatt (dBm) at the terminals of a receive antenna
transmit power (dBm) is the transmitter's output power in decibel milliwatt
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)
transmit antenna gain (dBi) is the transmitter's antenna gain in decibel isotropic
free space path loss (dB) is the free space path loss in decibels between the transmit antenna and receive antenna
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 (µV/m) to decibel microvolt per meter (dBµV/m)

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

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 (dBµV/m) to microvolt per meter (µV/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

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

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

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

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

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

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 614 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, LTE and 5G services. The remaining UHF TV channels 14-36 occupy 470 MHz to 608 MHz. Of importance to North American cable operators is the 2 MHz offset alignment of UHF TV channels relative to Consumer Technology Association (CTA) standard cable channels in the same frequency range. That is, each over-the-air UHF TV channel overlaps parts of *two* CTA standard channels. The following figure illustrates the overlap.

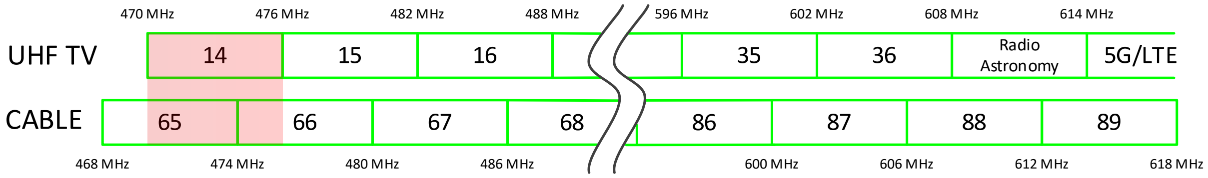
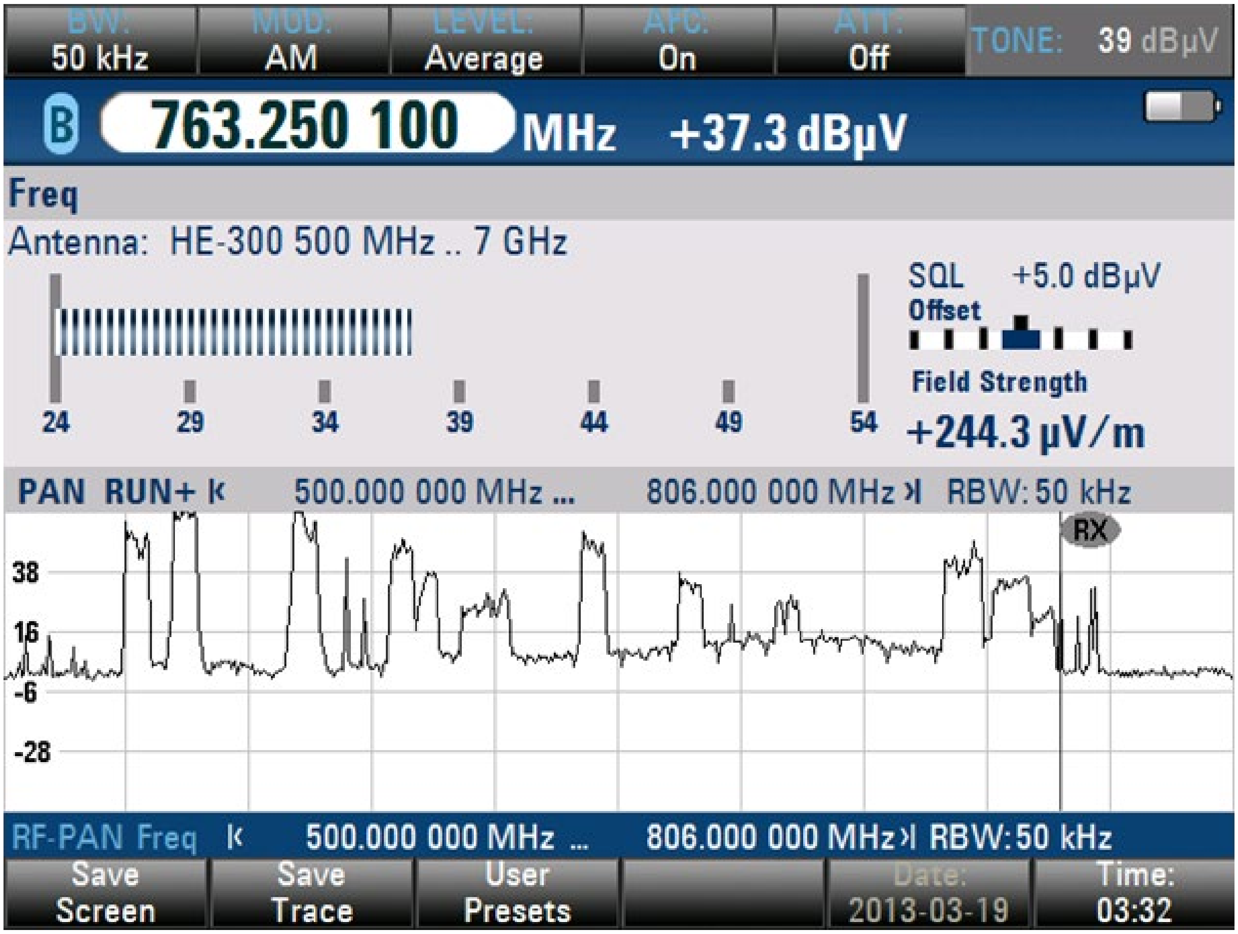


Figure 17 - Overlap of UHF broadcast TV channels with CTA standard cable channels

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 18 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.



BW: 50 kHz
MOD: AM
LEVEL: Average
AFC: On
ATT: Off
TONE: 39 dBµV

B 763.250 100 MHz +37.3 dBµV

Antenna: HE-300 500 MHz .. 7 GHz

SQL +5.0 dBµV

Field Strength +244.3 µV/m

PAN RUN+ 500.000 000 MHz ... 806.000 000 MHz RBW: 50 kHz

RF-PAN Freq 500.000 000 MHz ... 806.000 000 MHz RBW:50 kHz

Date: 2013-03-19

Time: 03:32

Figure 18- Over-the-air signals (including leaking QAM signals) in the 500 MHz to 806 MHz spectrum

Public Safety

Table 15 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 15 - 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 and 5G Operating Bands

Table 16 shows the worldwide LTE[27] and 5G NR operating bands as defined by the 3rd Generation Partnership Project (3GPP).[28, 29] Bands 2, n2, 4, 5, n5, 12, 13, 14, 17, 25, 26, 29, 30, 41, n41, 46, 48, 66, n66, 71, n71 and n77 are currently used in the United States or may be in the future. The highlighted bands overlap frequencies below 1794 MHz that may be used by cable operators.

---

[27] Formally known as E-UTRA (evolved UMTS terrestrial radio access) operating bands.

[28] TS 36.101: Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (17.7.0). 3GPP. 2022-09. Retrieved 2022-11-30.

[29] TS 38.101-1: NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone" (17.7.0). 3GPP. 2022-09. Retrieved 2022-11-30.

Table 16 - Worldwide LTE and 5G NR bands

LTE / 5G NR[30] Band Number	**Uplink (UE to base station)**	**Downlink (base station to UE)**
1 / n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz
2 / n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz
3 / n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz
5 / n5	824 MHz – 849 MHz	869 MHz – 894 MHz
6	830 MHz – 840 MHz	875 MHz – 885 MHz
7 / n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz
8 / n8	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 / n12	699 MHz – 716 MHz	729 MHz – 746 MHz
13 / n13	777 MHz – 787 MHz	746 MHz – 756 MHz
14 / n14	788 MHz – 798 MHz	758 MHz – 768 MHz
15	Reserved	Reserved
16	Reserved	Reserved
17	704 MHz – 716 MHz	734 MHz – 746 MHz
18 / n18	815 MHz – 830 MHz	860 MHz – 875 MHz
19	830 MHz – 845 MHz	875 MHz – 890 MHz
20 / n20	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 / n24	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz
25 / n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz
26 / n26	814 MHz – 849 MHz	859 MHz – 894 MHz
27	807 MHz – 824 MHz	852 MHz – 869 MHz
28 / n28	703 MHz – 748 MHz	758 MHz – 803 MHz
29 / n29	N/A	717 MHz – 728 MHz
30 / n30	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 / n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz

---

[30] 5G NR bands are defined with the prefix "n". When the NR band is overlapping with the LTE band, they share the same band number.

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 / n38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz
39 / n39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz
40 / n40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz
41 / n41	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
45	1447 MHz	–	1467 MHz	1447 MHz	–	1467 MHz
46 / n46	5150 MHz	–	5925 MHz	5150 MHz	–	5925 MHz
47 / n47	5855 MHz	–	5925 MHz	5855 MHz	–	5925 MHz
48 / n48	3550 MHz	–	3700 MHz	3550 MHz	–	3700 MHz
49	3550 MHz	–	3700 MHz	3550 MHz	–	3700 MHz
50 / n50	1432 MHz	–	1517 MHz	1432 MHz	–	1517 MHz
51 / n51	1427 MHz	–	1432 MHz	1427 MHz	–	1432 MHz
52	3300 MHz	–	3400 MHz	3300 MHz	–	3400 MHz
53 / n53	2483.5 MHz	–	2495 MHz	2483.5 MHz	–	2495 MHz
64	Reserved					
65 / n65	1920 MHz	–	2010 MHz	2110 MHz	–	2200 MHz
66 / n66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz
67 / n67	N/A			738 MHz	–	758 MHz
68	698 MHz	–	728 MHz	753 MHz	–	783 MHz
69	N/A			2570 MHz	–	2620 MHz
70 / n70	1695 MHz	–	1710 MHz	1995 MHz	–	2020 MHz
71 / n71	663 MHz	–	698 MHz	617 MHz	–	652 MHz
72	451 MHz	–	456 MHz	461 MHz	–	466 MHz
73	450 MHz	–	455 MHz	460 MHz	–	465 MHz
74 / n74	1427 MHz	–	1470 MHz	1475 MHz	–	1518 MHz
75 / n75	N/A			1432 MHz	–	1517 MHz
76 / n76	N/A			1427 MHz	–	1432 MHz
n77 / n77	3300 MHz	–	4200 MHz	3300 MHz	–	4200 MHz
n78	3300 MHz	–	3800 MHz	3300 MHz	–	3800 MHz
n79	4400 MHz	–	5000 MHz	4400 MHz	–	5000 MHz
n80	1710 MHz	–	1785 MHz	N/A		
n81	880 MHz	–	915 MHz	N/A		
n82	832 MHz	–	862 MHz	N/A		
n83	703 MHz	–	748 MHz	N/A		
n84	1920 MHz	–	1980 MHz	N/A		
85	698 MHz	–	716 MHz	728 MHz	–	746 MHz
n86	1710 MHz	–	1780 MHz	N/A		
87	410 MHz	–	415 MHz	420 MHz	–	425 MHz
88	412 MHz	–	417 MHz	422 MHz	–	427 MHz
n89	824 MHz	–	849 MHz	N/A		
n90	2496 MHz	–	2690 MHz	2496 MHz	–	2690 MHz
n91	832 MHz	–	862 MHz	1427 MHz	–	1432 MHz
n92	832 MHz	–	862 MHz	1432 MHz	–	1517 MHz
n93	880 MHz	–	915 MHz	1427 MHz	–	1432 MHz
n94	880 MHz	–	915 MHz	1432 MHz	–	1517 MHz
n95	2010 MHz	–	2025 MHz	N/A		
n96	5925 MHz	–	7125 MHz	5925 MHz	–	7125 MHz
n97	2300 MHz	–	2400 MHz	N/A		
n98	1880 MHz	–	1920 MHz	N/A		
n99	1626.5 MHz	–	1660.5 MHz	N/A		
n100	874.4 MHz	–	880 MHz	919.4 MHz	–	925 MHz
n101	1900 MHz	–	1910 MHz	1900 MHz	–	1910 MHz
n102	5925 MHz	–	6425 MHz	5925 MHz	–	6425 MHz
103	787 MHz	–	788 MHz	757MHz	–	758 MHz
n104	6425 MHz	–	7125 MHz	6425 MHz	–	7125 MHz