Evolving challenges in LTE / cable interference issues

Radiomonitoring & Radiolocation

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Introduction

The widespread deployment of LTE at 700 MHz has important implications for the cable industry with regards to signal ingress and egress. Awareness of this issue in both the cable and wireless community has grown tremendously since it was initially identified, and tools for detecting, locating, and resolving cable egress issues are now available.

Field investigations have shown that signal egress at lower (VHF airband) frequencies is not a reliable predictor of leakage at the higher frequencies used for LTE. The planned use of 700 MHz LTE for government and public safety applications will increase the importance and urgency of resolving egress. Moreover, ongoing technological developments in LTE such as the use of repeaters and femtocells will have significant impact in terms of both ingress and egress. Lastly, the development of the LTE-Advanced architecture should be followed closely, particularly in the case of cable equipment and infrastructure providers.

Unlike previous generations of cellular technologies, LTE (a fourth generation or "4G" technology) has the potential for creating both ingress and egress issues in most cable systems in the United States.

LTE-related interference is largely due to two factors:

- The frequencies used in the initial LTE deployments (in the 700 MHz range)
- The modulation schemes used in both the LTE uplink and downlink.

Field reports of significant LTE-related ingress/egress issues have been reported throughout the United States since early 2011, and the number and severity of these issues have increased as LTE becomes more widely deployed. Specific information about the causes, effects, and mitigation methods for LTE-related ingress/egress interference can be found in [Denisowski], [Hranac1] and [Hranac2].

Over the last year, awareness of LTE/cable-related interference issues has grown substantially in both the cable and the wireless/cellular industry. This paper discusses the results of continued field trials and studies in the area of LTE/cable interference and presents information regarding ongoing LTE developments that may have an impact on cable systems.

Field reports

Awareness of LTE-related ingress/egress issues is now widespread in both the cable and wireless industries.A significant number of articles, papers, presentations and webinars have been presented on this topic.
In addition, there is substantial empirical data from field reports and trials regarding the type, nature, and distribution of LTE-related ingress/egress issues.

The author's own field work with engineers in both the wireless and cable industry has largely been focused on methods for detecting, quantifying, and mitigating cable egress in the 700 MHz frequency bands used by wireless service providers. The results of some of these investigations are outlined in this section.

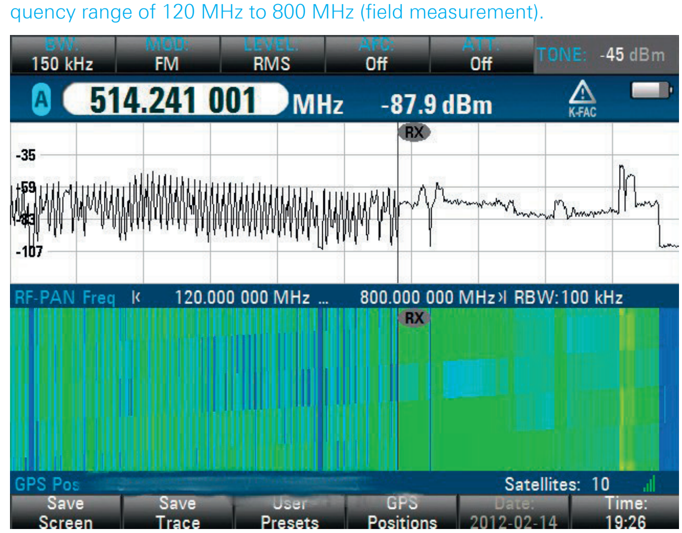
One of the more striking results of the author's field work is that 700 MHz egress is extremely widespread. Using the R&S®PR100 monitoring receiver and R&S®HE300 active directional antenna, the author was easily able to detect and locate 700 MHz leakage at distances of up to 100 meters, with the vast majority of leakage being detectable at distances of more than 30 meters.

The egress limits specified in FCC 47 C.F. R. §76.605(a)12 specify a maximum acceptable field strength of 15 µV/m at 30 meters for frequencies above 216 MHz. However, it is also important to note that the FCC also prohibits any level of egress which causes "harmful interference," and cellular network operators typically view any detectable level of egress as interference to their networks.

The other focus of the author's field work was an attempt to correlate leakage characteristics (frequencies, levels) with leakage modality (ring cracks, enclosure gaps, overhead vs. buried lines, etc.) or other physical factors.
In particular, it would be useful to know if leakage at one frequency (e.g. VHF aeronautical band frequencies) would be a reliable predictor of leakage at other frequencies (e.g. 700 MHz).

R&S®PR100 monitoring receiver.

R&S®PR100 screenshot of analog and digital leakage over the entire frequency range of 120 MHz to 800 MHz (field measurement).



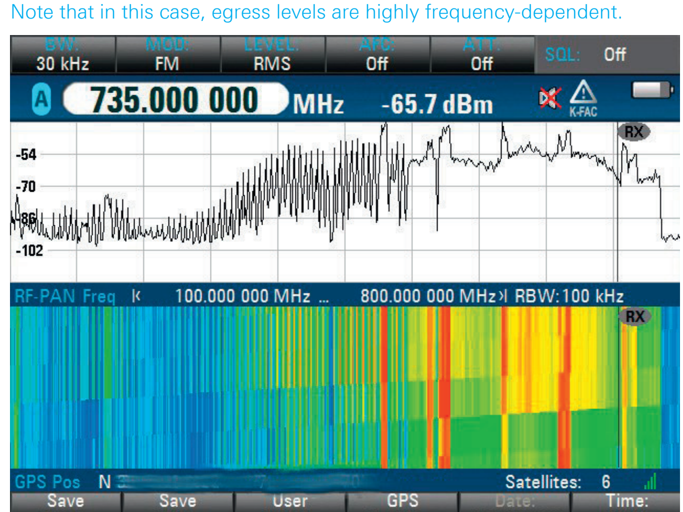
The author investigated well over a hundred individual field locations at which cable leakage was detected, recording the frequency/level of the leak(s) and the apparent leakage modality. Based on this sample set, it was impossible to draw any conclusions about leakage frequencies based solely on leakage modality – the same physical plant defect could cause leakage at widely different combinations of frequencies. It was also impossible to obtain a meaningful correlation between leakage at one frequency and leakage at other frequencies. In the author's investigations, leakage was either confined to low VHF (~30%), to 700 MHz (~50%), or was present over a very wide (100 MHz - 800 MHz) frequency range (~20%). An example of egress (analog and digital) over a wide frequency range is shown in the screenshot on the previous page.

Note that the leakage levels in this screenshot appear to be relatively constant across the entire frequency range. This is, however, an atypical result. Most often the leakage levels varied significantly by frequency as shown in the screenshot below.

Based on the author's own investigations and feedback from other engineers in both the cable and cellular industries, it would appear that no reliable correlation between egress frequency, level, or modality is possible.

The most important practical implication is that analog leakage in the VHF frequency range cannot be used to reliably detect or predict the presence of leakage at higher frequencies. This lack of correlation between leakage at different frequencies is the primary driver in the development of new test equipment and methodologies.

R&S®PR100 screenshot of analog and digital leakage over the frequency range of 100 MHz to 800 MHz (field measurement).
Note that in this case, egress levels are highly frequency-dependent.



Test equipment and methodologies

As discussed in [Denisowski], conventional leakage detection tools are incapable of detecting LTE egress in the 700 MHz range. This is due to several factors, including the inability of most of these tools to be tuned to frequencies significantly outside of the VHF aeronautical band (108 MHz to 137 MHz) and their inability to accurately measure the digital QAM signals commonly present at these frequencies.

Various approaches have been proposed for detecting and measuring digital egress at the 700 MHz frequency range. These can be grouped into three major categories:
- Insertion of a narrowband carrier
- Correlation of QAM signals
- Spectral analysis

The simplest of these solutions involves the insertion of a narrowband signal into a digital system. Since most cable operators are unwilling to give up a channel solely for the purpose of signal leakage detection, this narrowband signal would be inserted between digital QAM signals. The leakage detector would then be tuned to the frequency of this inserted narrowband signal. Physical location of leakage is performed using methods similar to those used in analog leakage.

The strengths of this approach are that it is relatively inexpensive and is similar to the effective and well-understood methods used in detecting and measuring narrowband analog leakage at VHF. Furthermore, it allows the flexible placement of the inserted signal at different frequencies – an important feature due to the possibility of the frequency-dependent leakage characteristics described previously.

The greatest potential disadvantage of the carrier-insertion approach is that experience has shown that inserting a narrowband carrier between two digital signals has the potential to degrade the QAM signals [Hranac3]. It is also possible that the inserted carrier could itself become a source of egress interference. The author has personally witnessed several cases in which test carriers inserted into a cable system have themselves created interference to 700 MHz LTE systems.

Another proposed methodology involves correlating QAM signals originating at the headend with signals measured in the field. A strong correlation indicates that the measured signal is egress from the cable system and not a signal being generated from some other source.

The correlation method does not require a special test channel or carrier. It works with content-carrying signals at any frequency. This method also does not introduce any new signals into the cable system, so the possibility of signal degradation or additional test signal egress is non-existent.

Correlation of the transmitted and received signals requires special equipment at both the headend and in the field. Furthermore, some type of independent data link (cellular wireless) between the headend and the field tester is required to perform correlation. Location of leakage can be performed using traditional methodologies or a time difference of arrival (TDOA) approach.

The most flexible approach for detecting and measuring digital leakage is the use of monitoring receivers: general purpose instruments capable of detecting both digital and analog signals. Monitoring receivers have a very wide frequency range that enables continuous coverage of all cable system frequencies. They provide visualization (spectrum and waterfall displays) over any arbitrary frequency range and have integrated radiolocation (direction-finding) functionality in the form of tone-based or bearing-based methodologies.

An additional advantage of monitoring receivers is that they require no intervention or equipment at the headend. They can also be used to detect and measure LTE and other signals that may be causing ingress interference.

The flexibility and strength of monitoring receivers typically requires a trained operator with a good understanding of radio frequency signal characteristics in order to maximize their effectiveness. In many cases, a monitoring receiver would be deployed as a "Tier 2" instrument used by trained technicians or engineers.

Lastly, it should also be noted that these test methodologies are not mutually exclusive. In many cases various tools can be used to complement each other by leveraging their individual strengths and areas of application.

New developments in LTE

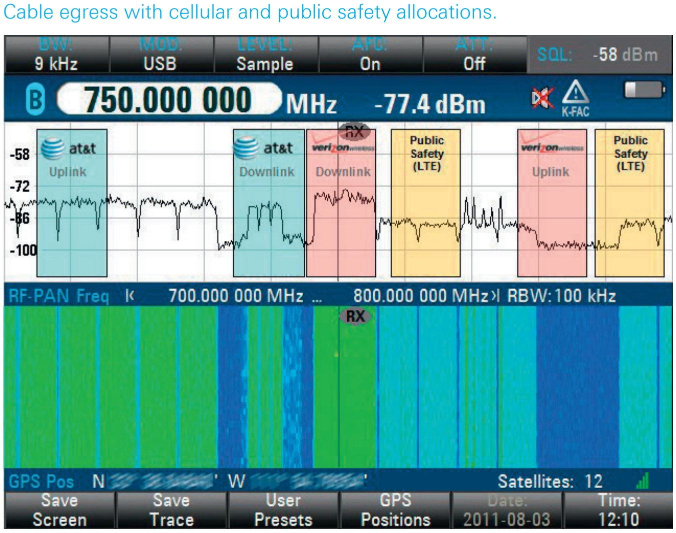
Public safety developments

One of the goals of LTE was to have a standardized radio access technology that would be used by all wireless service providers worldwide.
Although there are a variety of 3G radio access technologies such as WCDMA (AT&T/T-Mobile) and CDMA2000/EVDO (Sprint/Verizon), all wireless service providers in the United States have standardized on LTE for their 4G networks.

This standardization is not limited to cellular service providers. LTE has been proposed as a radio access technology in many other applications as well, including industrial and military applications. A common air interface enables equipment manufacturers to reduce cost and time-to-market and facilitates interoperability among a wide variety of devices.

At present, the most important non-cellular application of LTE (and the one with the greatest possible near-term ramifications for the cable industry) is in the area of public safety. The term "public safety" here refers to police, fire, ambulance, emergency, search and rescue, and other similar local/national government entities charged with preserving the safety of the general public.

Cable egress with cellular and public safety allocations.



Historically, public safety communications have been overwhelmingly voice (narrowband, FM), with an emphasis on rugged handheld and vehicle-mounted radios. A number of different standards have emerged for digital voice communications (APCO/P25, TETRA, etc.), but system interoperability remains elusive. Crises such as the September 11 terrorist attacks and natural disasters (Hurricane Katrina, et al), have pointed out the need for system interoperability among difference services and agencies [Palamara].

The other driving factor for the use of LTE in public safety is the potential to leverage LTE's high data-carrying capacity to support advanced applications. For example, first responders could have immediate, hand-held access to floor plans, live video, and other critical information. Command and control centers could simultaneously collect and monitor data from a wide variety of responders. A commercially deployed example of this is Motorola's realtime video intelligence (RTVI).

Although the use of LTE would allow interoperability with public data networks, these public safety LTE networks are intended to operate primarily on their own frequencies. Experience has shown that cellular data networks rapidly reach capacity during emergency (and non-emergency) situations. In addition to avoiding congestion-related issues, a separate public safety LTE network can provide better security and quality-of-service.

The FCC originally allocated 24 MHz of the 700 MHz band for public safety use, divided into a narrowband and broadband allocation [FCC700]. The narrowband (non-LTE) public safety allocation was organized into 960 pairs of 6.25 kHz channels (769 MHz to 775 MHz and 799 MHz to 805 MHz). Potential ingress/egress issues for these frequencies are similar to traditional narrowband analog and digital channels.

In 2011, the FCC specified that LTE was to be used as the radio-access technology for the broadband public safety allocation. The original broadband allocation was 763 MHz to 768 MHz and 793 MHz to 798 MHz. This was then followed in February 2012 by the allocation of the so-called D block spectrum (758 MHz to 763 MHz and 788 MHz to 793 MHz) to public safety, making a full 20 MHz of broadband spectrum (758 MHz to 768 MHz and 788 MHz to 798 MHz) available to public safety.

It is important to note that 700 MHz egress from cable systems overlaps with both the broadband (LTE) and narrowband public safety allocations. This means that egress in the 700 MHz band is no longer simply a cellular/cable issue – it now also has the potential for disrupting public safety communications and endangering first responders. The difference between interference to "commercial" and "public safety" networks should not be underestimated. It is not inconceivable that a public safety agency could force a cable service provider to turn off channels that are interfering with public safety LTE networks.

LTE repeaters (bidirectional amplifiers)

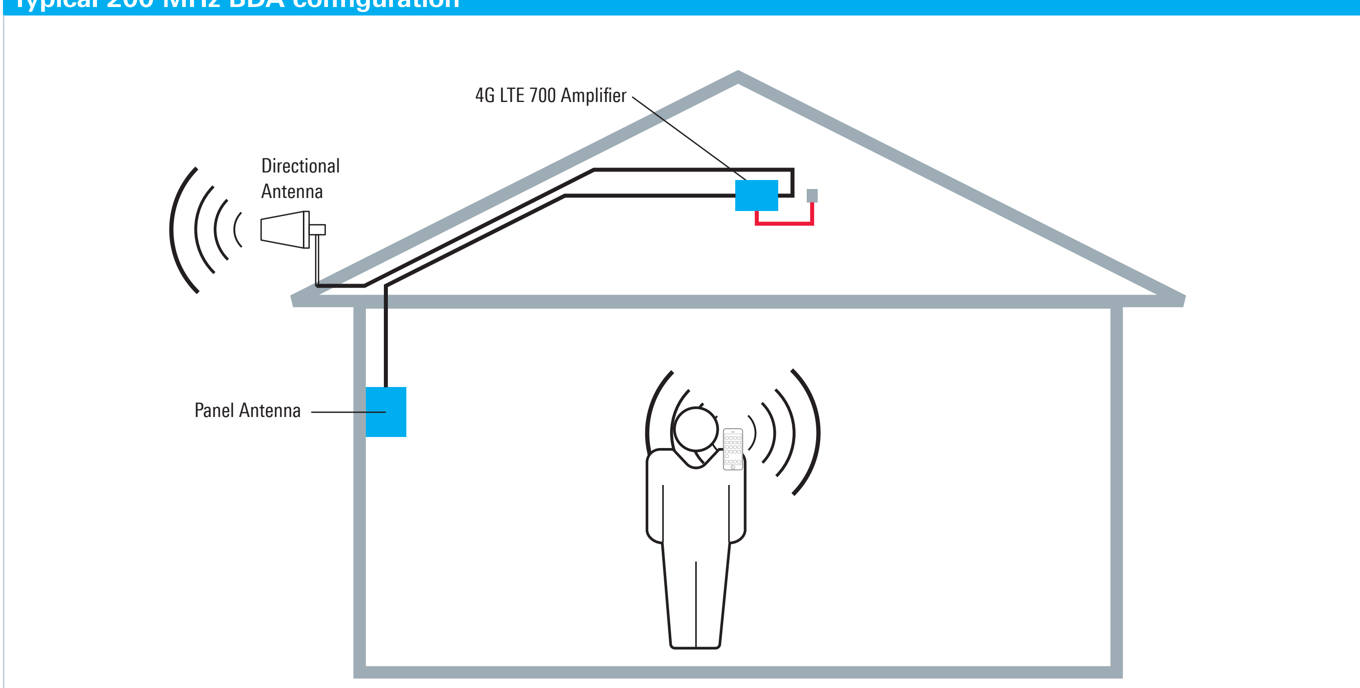
A common way to improve cellular coverage is through the use of a bidirectional amplifier (BDA) or "cell phone repeater/booster". Essentially, these are devices that receive the downlink signals on the "donor" antenna, amplify it, and retransmit it on the "coverage" antenna. The reverse process is performed on the uplink signal. When properly installed, BDAs provide a low-cost, user-installable method for improving cellular coverage.

BDAs are a frequent source of issues for wireless service providers. Insufficient separation of the donor and coverage antennas can cause the amplifier to oscillate, significantly raising the noise floor over the entire operating range. In the uplink direction, BDAs can also pick up and amplify small local noise sources and transmit these towards the base station. The fact that most BDAs are (legally) self-installed means that the wireless service provider has no knowledge of where BDAs are installed.

Bidirectional amplifiers for LTE are already commercially available (cost ~USD 400) from a variety of vendors. LTE BDAs are usually designed to operate over a specific carrier's frequency range and can often be identified by an external yagi or panel antenna pointing in the direction of the closest base station and/or by the presence of indoor dome-shaped or panel-shaped coverage antennas.

The greatest danger that LTE BDAs present to the cable infrastructure is the extremely high output power (~40 dBm) that they can generate over a wide portion of the 700 MHz frequency range if improperly installed/operated. This can cause significant ingress and CPE interference. Conversely, cable egress (QAM channels) at the LTE uplink frequencies can also force an otherwise properly functioning BDA into oscillation. It is recommended that any 700 MHz BDAs be disconnected or powered off before troubleshooting ingress or egress issues. It should also be noted that issues caused by BDAs are the responsibility of the BDA owner (usually the customer) and that FCC regulations require BDAs to be disconnected if they are found to be generating harmful interference to cellular (but not cable) systems.

Typical 200 MHz BDA configuration



LTE femtocells

In order to increase their coverage footprint and fill in so-called coverage holes, wireless service providers can deploy very small base stations at the customer premises (residential or commercial). These small base stations are most commonly referred to as “femtocells,” although the terms “picocell” and “microcell” are also used (there is no industry-standard definition of these terms). Unlike a cellular repeater, a femtocell does not simply amplify and retransmit the uplink and downlink signals: it is a fully functional base station that implements the complete wireless protocol stack and terminates the air interface connection between the user equipment (phone, data card, modem) and the network. Backhaul normally takes place over the customer’s standard Ethernet/IP connection.

Femtocells are purchased directly from the wireless service provider and are typically self-installed. The wireless service provider can provision and monitor the femtocell remotely, and many femtocells contain a GPS receiver to help the provider determine its precise geographical location. Most femtocells are designed to cover an average-sized residence (range ~ 40 feet) and limit the number of subscribers that can connect to the femtocell.

In the United States, AT&T, Verizon, and Sprint offer 3G femtocells. As of 2010, there were more femtocells (350,000) than cell towers (250,000) in the United States [Danno]. Since these femtocells operate on the same frequencies as the “macro” base stations, the potential for cable egress/ingress interference from 3G femtocells has been minimal.

However, the development and deployment of LTE femtocells operating in the 700 MHz band is likely to present additional challenges with regards to ingress and egress issues. The two main issues are proximity to the cable equipment and femtocell identification.

Fujitsu BroadOne LTE femtocell.

In order for a femtocell to operate, it must have some type of backhaul connection to the wireless service provider’s core network, and this backhaul is almost universally implemented in the form of an Ethernet/IP connection. Particularly in the case of a residential installation, the Ethernet/IP connection is provided by some type of cable (or xDSL/fiber) modem, meaning that a femtocell and cable modem may be in very close physical proximity to each other. Although both uplink and downlink power levels are substantially lower in femtocell applications (vs. macrocell applications), very close proximity of cable CPE and LTE femtocells can increase the likelihood of both ingress and egress interference [Cobham, Agentschap]. Placing the cable CPE and LTE femtocell as far apart as practically possible would be a good first troubleshooting step when investigating interference issues.

Identifying the presence of a femtocell is another potential issue. In the case of macrocells installed on towers or other tall structures, the possible presence of a nearby (strong) LTE signal source is relatively easy to identify. Even in the case of hidden or camouflaged base stations/antennas, there are many ways to determine if an LTE macrocell might be nearby, such as signage or cabling. On the other hand, there is usually no external visual indication that a femtocell is installed at a customer’s site or at an adjoining site, such as a multi-unit home/apartment building (MDU) or office complex. While LTE femtocells can be designed to recognize other LTE femtocells or macrocells and to adjust their operating parameters to reduce the probability of interference (so-called self-organizing networks), there is no way for cable CPE and LTE femtocells to recognize each other. Studies such as [ANGA] have shown the potential for interference from devices located in neighboring rooms. The lack of an LTE femtocell at the customer’s premises does not therefore mean that LTE femtocells can be ruled out as a possible interference source, especially in multi-unit structures.

With regards to LTE femtocell deployment in the United States: many equipment manufacturers have either developed or are in the process of developing LTE-capable femtocells. In addition, LTE femtocell trials are already underway in Europe and Asia and trials are expected to begin in the United States before the end of 2013 [Electronista]. Based on the trends seen in 3G femtocell rollouts, it should be expected that LTE femtocell deployment will become widespread in the United States within the next 24 to 36 months.

LTE jammers

Although strictly prohibited by the FCC, the possession and use of cellular frequency jammers is not uncommon in the United States. These jammers can often be purchased online from offshore suppliers for USD 20 to USD 100 and can be either portable (battery-powered, ~ 1 watt output power) or fixed (AC powered, ~ 15+ watts output power). Cellular jammers are almost always multiband devices, i.e. they are designed to jam multiple cellular bands simultaneously, and the presence of multiple antennas is one of the strongest visual indicators that a device is a cellular jammer.

Cellular band jammers were not previously an issue for the cable industry because of the lack of significant frequency overlap between cellular and cable systems. Unfortunately, the deployment of LTE at 700 MHz has also spawned the marketing of cellular jammers designed to operate at this frequency range. Although still somewhat expensive (~USD 100 for a portable model), it is expected that the prices of LTE-capable jammers will soon equal those of 2G/3G jammers.

Needless to say, 700 MHz LTE jammers have the potential to cause significant ingress interference across a wide frequency range. If ingress appears to be a broad increase in the noise floor over a range of 50+ MHz, checking the proper functioning of 700 MHz LTE devices in the same area is an important troubleshooting step. It should also be mentioned here that the wireless service providers take jamming very seriously and are usually able to identify and locate jammers relatively easily.

Portable LTE jammer
(725 MHZ to 779 MHz),
output 1.2 W.

LTE-Advanced

Despite the fact that LTE rollouts are still in the early stages, work has already begun on enhancements to the current LTE standard. Designed to be backwards compatible with LTE, LTE-Advanced will support data rates of up to 1 Gbps in the downlink. This increase in capacity is made possible primarily by multiple input, multiple output (MIMO) enhancements and bandwidths of up to 100 MHz. Since there are no wireless service providers in the United States who have large contiguous spectrum allocations, LTE-Advanced uses a technique called carrier aggregation in which several (possibly noncontiguous) LTE carriers are aggregated together to obtain higher data rates.

The implications of LTE-Advanced for the cable industry are as yet unclear. Because the same modulation is used in both LTE and LTE-Advanced, there should be no additional ramifications beyond those already found with LTE. The more important issue is the probability that LTE-Advanced will lead to a push for additional spectrum refarming, most likely in the 600 MHz band, which could in turn lead to further spectral overlap between LTE and cable systems.

Designers of both cable and LTE equipment and infrastructures would be well advised to consider the possibility of LTE (Advanced) being deployed at 600 MHz in the not-too-distant future.

Conclusion

Considerable progress has been made in increasing awareness of potential LTE/cable interference issues. Field work by engineers in the cable, wireless, and test equipment industry has shown that it is difficult to correlate cable leakage at different frequencies and that the leakage modality is not necessarily a good predictor of leakage level or frequency. Several new methods of detecting digital egress at 700 MHz have been proposed or developed, each with unique strengths and limitations. Developments in the LTE space, such as LTE femtocells, LTE jammers, and LTE-Advanced will create new challenges for both cable and cellular network operators. Finally, the deployment of 700 MHz LTE as a public safety technology will increase the importance of reducing ingress and egress issues through proactive maintenance and good engineering practice.

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- Built-in tone generator for measuring signal strength
- Waterfall display for detecting intermittent signals of all types
- Display easily viewable in direct sunlight

R&S®PR100 monitoring receiver and R&S®HE300 antenna.

List of abbreviations

- APCO: Association of Public-Safety Communications Officials
- P25: Project 25
- BTOP: Broadband Technology Opportunities Program
- BDA: bidirectional amplifier
- CDMA2000: code division multiple access (2000)
- CPE: customer premises equipment
- EVDO: evolution data optimized
- FCC: Federal Communications Commission
- QAM: quadrature amplitude modulation
- GPS: global positioning system
- IP: Internet protocol
- LTE: long term evolution
- MDU: multiple dwelling unit
- MIMO: multiple input, multiple output
- MoCA®: Multimedia over Coax Alliance
- R&S: Rohde & Schwarz trademark®
- RTVI: realtime video intelligence
- TDOA: time difference of arrival
- TETRA: terrestrial trunked radio
- WCDMA: wideband code division multiple access
- xDSL: digital subscriber line

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Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

Regional contact
- Europe, Africa, Middle East | +49 89 4129 12345
  customersupport@rohde-schwarz.com
- North America | 1 888 TEST RSA (1 888 837 87 72)
  customer.support@rsa.rohde-schwarz.com
- Latin America | +1 410 910 79 88
  customersupport.la@rohde-schwarz.com
- Asia/Pacific | +65 65 13 04 88
  customersupport.asia@rohde-schwarz.com
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  customersupport.china@rohde-schwarz.com

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