QUANTIFYING LEAKAGE THRESHOLDS FOR QAM/LTE INTERFERENCE

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ABSTRACT

The issue of interference between QAM signals carried over the cable network with wireless LTE signals in the 700 MHz band is well known and has been widely discussed. Egress of QAM signals from the coaxial network can negatively impact LTE performance, and ingress of LTE signals into the coaxial cable can negatively impact signal transmission within the cable network. Both of these phenomena are based on the fact that the coaxial network has "leakage holes" that allow the two signal sets to coexist. Technology is now available that provides visibility to the existence and location of these high frequency leaks within the cable network, but an important question remains: "What is an acceptable leak level within the LTE band"?

The goal of this paper is to attempt to mathematically define thresholds for acceptable QAM leak levels within the LTE band for two main scenarios:

1. QAM leak signals interfering with LTE receivers.
2. LTE signals interfering with QAM signals within the cable network.

As part of the second scenario above, specific to the case of LTE interference in the home, we will extend our analysis to include a discussion of how leak level is related to shielding effectiveness and FCC requirements for field strength immunity.

In our analysis herein, it is important to mention that "worst case" scenarios will be used for all assumptions which will assure that the requirements for the minimum allowable QAM leak levels should guarantee the absence of interference.

This specific subject of defining allowable high frequency leakage levels has been tasked to the SCTE Network Operation Standards Working Group 1. This paper is offered as a possible starting point for discussion on this subject within the working group, and is intended to assist said group in their efforts. Any conclusions or assumptions made within this paper are intended to be vetted within the working group and are intended to stimulate further discussion.

This paper does not attempt to set guidelines for operators as to which leaks should be mitigated, it simply presents data in a different fashion such that operators can come up with their own conclusion as to what should be repaired based upon their specific and individual business and operational objectives.

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SCENARIO 1. QAM LEAK SIGNALS INTERFERING WITH LTE RECEIVERS

The typical scenarios of QAM signals leaking from the cable network and interfering with LTE receivers is shown in Fig.1.
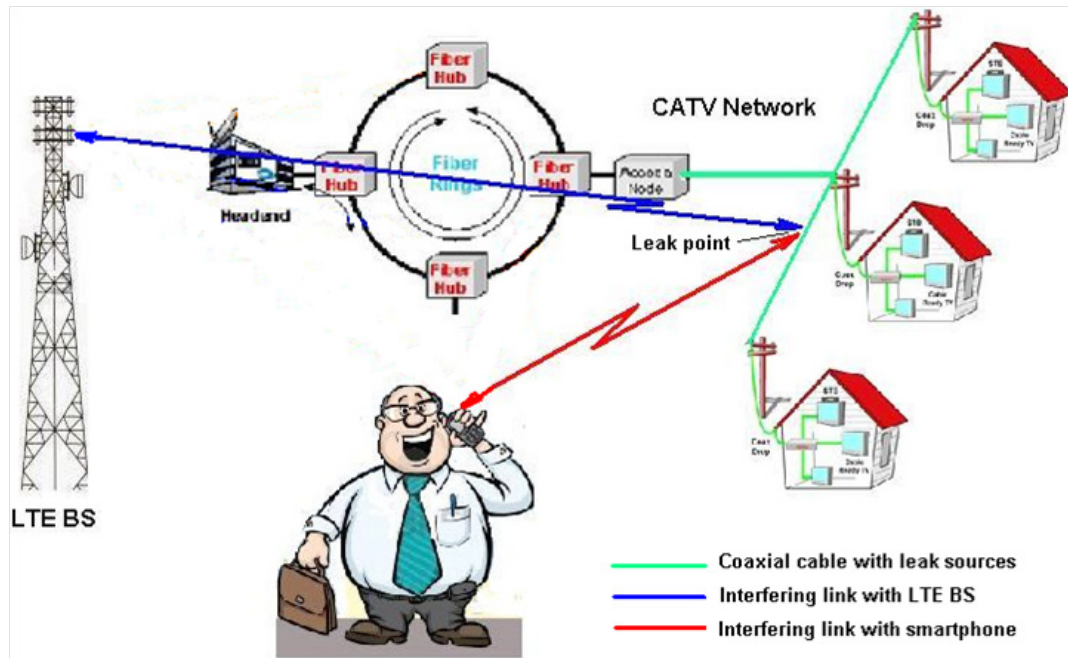
Fig. 1. Typical scenario of interfering QAM and LTE signals

The figure shows the two main mechanisms of QAM signals egress: interfering with LTE base stations (BS) and interfering with LTE user equipment (UE) – smart phones, iPads, etc. In reality there are more possible scenarios of QAM leaks interfering with other equipment such as LTE femtocells, LTE repeaters etc., but interference with base stations and user equipment has to date received the most attention and will be the focus of this study. In the future this analysis may be expanded to this additional equipment.

The field strength of the QAM leak signal at the point of the LTE receiver given free space propagation (worst case) is defined by equation:

$$E\ (\mu V/m) =\ E_{Leak}\ (\mu V/m)\ *\ 3(m)\ /D\ (m), \tag{1}$$

where:

E_{leak} – is the field strength of the QAM leak measured in µV/m at distance 3 meters
(10 feet) from leak source;

D – is the distance from leak source to LTE receiver in meters.

Assume that the bandwidth of the LTE receiver is 5 MHz and that the 6 MHz QAM leak signal fully overlaps the bandwidth of the LTE receiver. This is the worst case scenario of impact of the QAM leak signal interfering with the LTE receiver.[1] As such, the power of the QAM interfering leak signal at the input of the LTE receiver is defined by formula:

$$P_{Rx}(W) = 0.83 * (E^2 * G_{Rx} * \lambda^2)/(480 * \pi^2), \qquad (2)$$

where:

0.83 – is the coefficient (5/6) taking into consideration power losses due to bandwidths of the LTE receiver and the QAM leak signal;

G_{Rx} – is receiving antenna gain (numerical);

λ – is wave length (m) of interfering signal, for 750 MHz LTE λ = 0.4 m.

Taking into account equation (1), the formula (2) in logarithmic scale for 750 MHz LTE band (λ = 0.4 m) can be expressed as:

$$P_{Rx}(dBm) = E_{Leak}(dB\mu V/m) + G_{Rx}(dBi) - 20\log(D(m)) - 125.98 \qquad (3)$$

ANALYSIS AS PERTAINS TO LTE BASE STATION LOCATIONS

The graphs of the QAM interfering leak signal power at the input of LTE BS with a maximum receive BS antenna gain of 15 dBi (worst case) are shown on Fig.2. The red dotted line on Fig.2 shows the – 110 dBm threshold where egress begins to impact the LTE BS noise floor receiver with a 5 MHz bandwidth. This level may be used as a threshold for the minimum allowable QAM leak interfering signal.

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[1] The immunity of an LTE receiver to interfering signals depends not only on receiver bandwidth, but also on modulation, bit rate and additional factors such as MIMO. But for simplicity and because the spectrum of a QAM signal looks like Gaussian noise we'll compare impact from QAM leak with the relative increasing noise floor of the receiver. From this point of view, the impact from one 6MHz QAM channel on a receiver with bandwidth 5 MHz is approximately the same as the impact from spectrum of adjacent QAM channels on receiver with bandwidth 10, 15, and 20 MHz.

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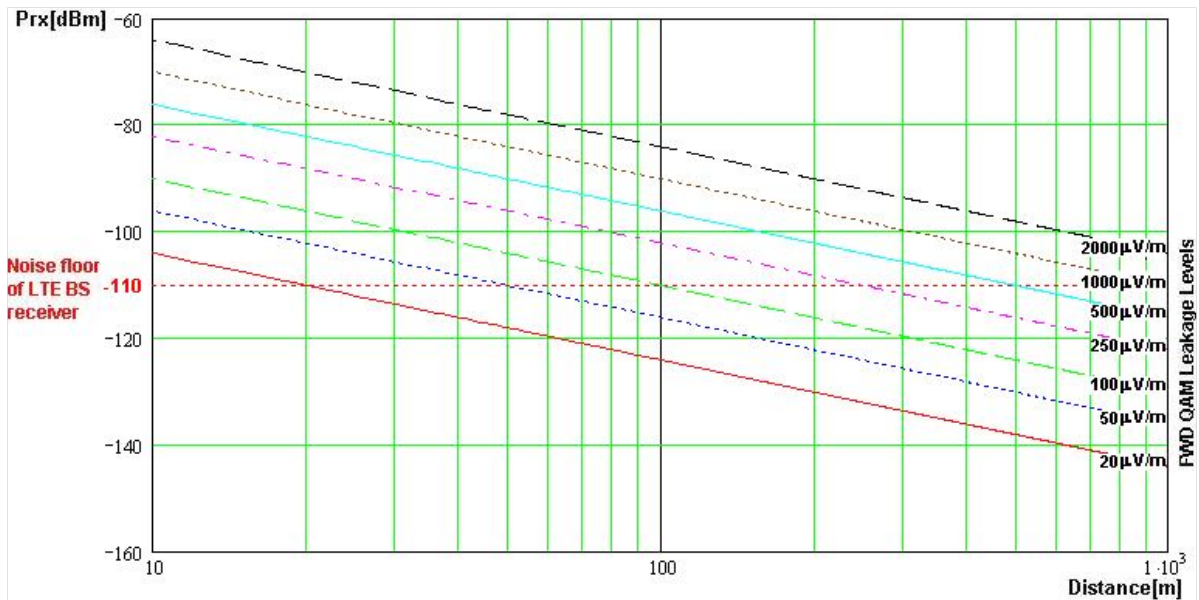
Fig. 2. Power of interfering QAM leakage signal at the input of LTE BS receiver vs. distance to the leak source and leak field strength @ 3meters

As can be seen in chart, a 50µV/m leak with direct visibility can affect the noise floor of the LTE BS from a distance of 50 meters. Continuing, a 100µV/m leak can affect the noise floor from 100 meters, 250µV/m from 275 meters, 500µV/m from 500 meters, 1000µV/m from 800 meters, etc. Were the locations of LTE BS known and coordinates placed within a database, it would be very easy to plug this data into any modern GPS based leakage location system, and generate repair rules based upon leak level and proximity to the LTE BS.

While a comprehensive database of LTE BS locations is not believed to exist, is it possible to acquire the information locally. Certainly technicians working in each market can visually determine the location of the rather conspicuous stand–alone towers, cells on roofs of building, or on other existing structures, etc. – and the address can be loaded into a database. As an alternative, certainly the LTE providers know the locations of their LTE BS's and would possibly share this data with the cable industry if it was shown to be in their benefit to do so.

Without such information, in order to ensure the absence of interference, a rather conservative approach would need to be taken as to the nearest proximity a LTE BS could be to the cable network. Given towers and cell sites are placed as high as possible, it would seem that it would be unusual for the cable plant on the ground or pole to be closer than 50 meters – as such perhaps a 50µV/m limit that corresponds to this distance would be sensible.

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ANALYSIS AS PERTAINS TO LTE USER EQUIPMENT

The typical smart phone receiving antenna gain is 0 dBi and the minimum noise floor of the UE receiver for a 5 MHz bandwidth is –100 dBm. This is the threshold at which QAM egress will begin to impact the user equipment noise floor. The graphs of QAM leak interfering power for these parameters are shown in Fig.3.
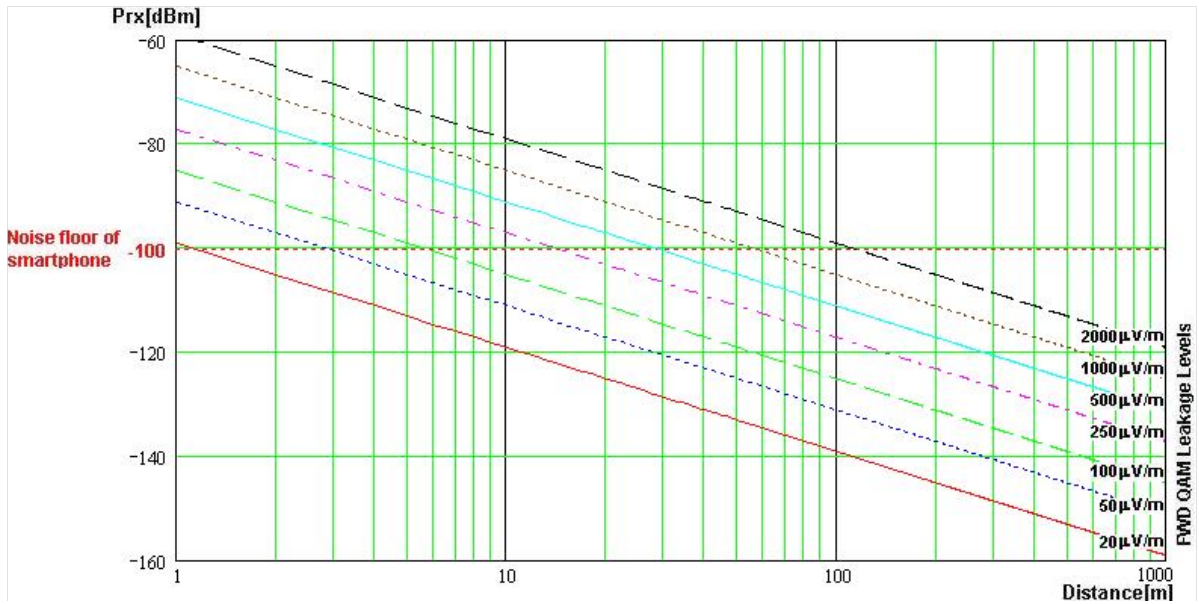
Fig. 3. Power of interfering QAM leakage signal at the input of LTE UE receiver vs. distance to leak source and leak field strength @ 3meters

As follows from the graphs above, a leak level of 50 µV/m will impact the UE receiver at a distance of 3 meters. This distance does represent real world situations of people walking in proximity to the cable network, both outside and within a subscriber home.

SCENARIO 2. LTE SIGNALS INTERFERING WITH QAM SIGNALS IN THE CABLE NETWORK

To define the influence of LTE signals on QAM signals within coaxial cable, we will use the CNR parameter. LTE signals looks like white noise, so using CNR is a reasonable and valid parameter for analysis of interference. To calculate degradation of CNR due to an LTE interfering signal, assume first that the noise present within the cable absent an interfering signal is low enough (CNR > 40 dB) such that it does not need to be taken into consideration. Also based on the worst case assumption, assume the free space model of propagation of the LTE signal from BS and UE to the leak source and that the LTE transmitter works with a 5 MHz bandwidth and all the energy of the LTE signal is placed within the 6 MHz band of one QAM channel within the coaxial network.

The field strength (E) is calculated by the well–known formula:

$$E \ (\mu V/m) = \sqrt{S * Z_0}, \tag{4}$$

where

$Z_0 = 120 \ \pi$ – is impedance of free space;

$S \ (w/m^2) = P_{Tx} * G_{Tx}/4 \ \pi * D^2$ – is the transmitter power flux density at distance D (m) from transmitter of power P_{Tx} (W) with the transmitting antenna gain G_{Tx} (numerical).

The final formula for field strength is as follows:

$$E \ (\mu V/m) = (\sqrt{(30 * P_{Tx} * G_{Tx})}/D) * 10^6 \tag{5}$$

or in the logarithmic scale

$$E \ (dB\mu V/m) = 104.77(dB) + P_{Tx} \ (dBm) + G_{Tx}(dBi) - 20 \log (D(m)) . \tag{6}$$

Converting dBm into dBmV and taking in account that leak field strength E leak is measured at distance D= 3 meters, then from above formula (6) the Tx antenna gain of leak source is defined as:

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$$G_{Leak} \text{ (dBi)} = E_{Leak} \text{ (dBμV/m)} - U_{qam} \text{ (dBmV)} - 46.48 \text{ (dB)}, \qquad (7)$$

where

U_{qam} – QAM signal level in coaxial cable in dBmV.

If one assumes that the leak source Tx antenna is also working as a receiving antenna with the same gain G_{Leak}, then the power of the LTE Ingress signal within coaxial cable is defined as follows:

$$P_{Rx} \text{ (dBm)} = 20 \log(\lambda) - 20\log(4 * \pi * D) + P_{Tx} \text{ (dBm)} + G_{Tx} \text{(dBi)}$$
$$+ G_{Leak}\text{(dBi)} - OPL\text{(dB)}, \qquad (8)$$

where

λ – is wave length of signal in meters ($\lambda = 0.4$ for 750 MHz LTE band);

D – is the distance from LTE transmitter to leak source;

P_{Tx} – is power of LTE transmitter;

G_{Tx} – LTE transmitter antenna gain;

OPL – is obstructed path loss, OPL= 0dB for coaxial trunk and drop lines located on
poles (worst case) and OPL = 15–30 dB for home environment (home
network).

Using formula (7) for G_{Leak} and converting dBm into dBmV for $\lambda = 0.4$ the LTE ingress signal level in cable in dBmV is defined as:

$$U_{ingress} \text{ (dBmV)} = P_{Tx}\text{(dBm)} + G_{Tx}\text{(dBi)} + E_{Leak}\text{(dBmV)} - U_{qam}\text{(dBmV)}$$
$$- 20 \log(D(m)) - OPL\text{(dB)} - 27.67\text{(dB)}. \qquad (9)$$

The CNR for the QAM signal impacted by interfering LTE signal is equal to:

$$CNR \text{ (dB)} = U_{qam} \text{ (dBmV)} - U_{ingress} \text{ (dBmV)}.$$

or using formula (9)

$$CNR = 2 U_{qam} - P_{Tx} - G_{Tx} - E_{Leak} + 20 \log D + OPL + 27.67 \qquad (10)$$

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Formula (10) shows a very interesting relationship between degradation of CNR from QAM signal level U_{qam} for the same leak level E_{Leak} – the degradation of CNR has a square dependency relative to the QAM signal level. As will be shown below, this relationship significantly increases the requirement for allowable leak level anywhere in the network where low level signals exist, either before an amplifier, within the drop, or especially within the subscriber home portion of the network.

The typical parameters of the LTE base station (BS) are as follows: P_{Tx} = 43 dBm and G_{Tx}= 15 dBi. The QAM signal level in coaxial cable is dependent upon the portion of the cable network and typically varies as follows[2]:

- trunk line: +5 to +40 dBmV ;
- drop line: +5 to +15 dBmV;
- home network: –10 to 0 dBmV .

The worst case parameter of OPL for both trunk and drop lines can be defined as 0 dB, which means that the leak source and LTE transmitter are located within a zone of direct RF visibility (free space). For home network the typical value of OPL is in range from 15dB to 30 dB depending from wall material, wall thickness, furniture, etc.

QAM CNR BEING AFFECTED BY LTE BASE STATIONS

Taking in account the above parameters and using formula (10) in Figs. 4–10, the family of graphs of QAM signal CNR degradation is shown for different scenarios of interference from LTE signals, with varying QAM signal level and OPL. The red dotted line on the graphs shows the CNR threshold of 33 dB for a QAM–256 signal.

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[2] Certainly levels are also architecture dependent. These numbers are provided as estimates and also reference QAM levels (not analog equivalent), and take into account slope differences between 700MHz and 860MHz.
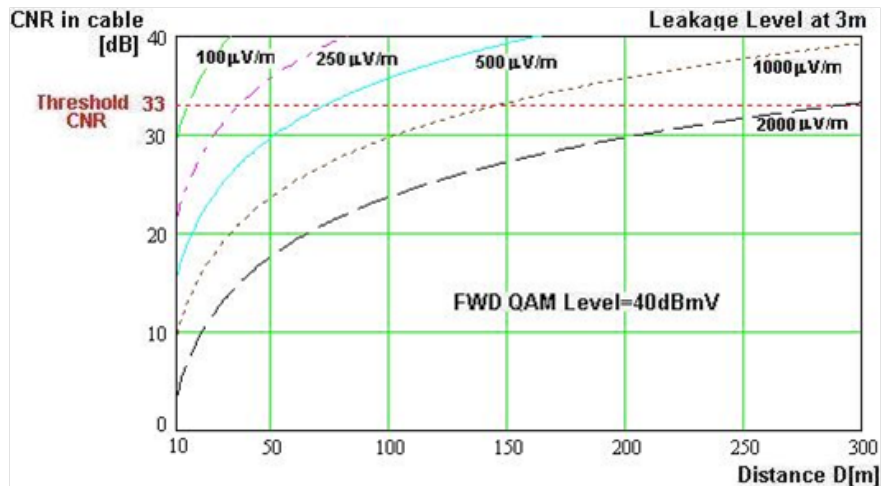
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Fig. 4. CNR curves vs. distance from LTE BS tower with +40dBmV QAM
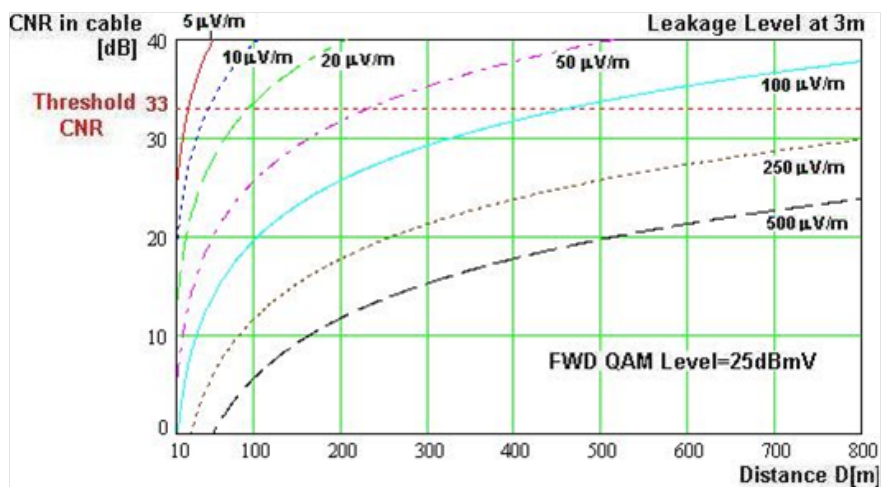level (level found in trunk) and 0dB OPL

Fig. 5. CNR curves vs. distance from LTE BS tower with +25dBmV QAM
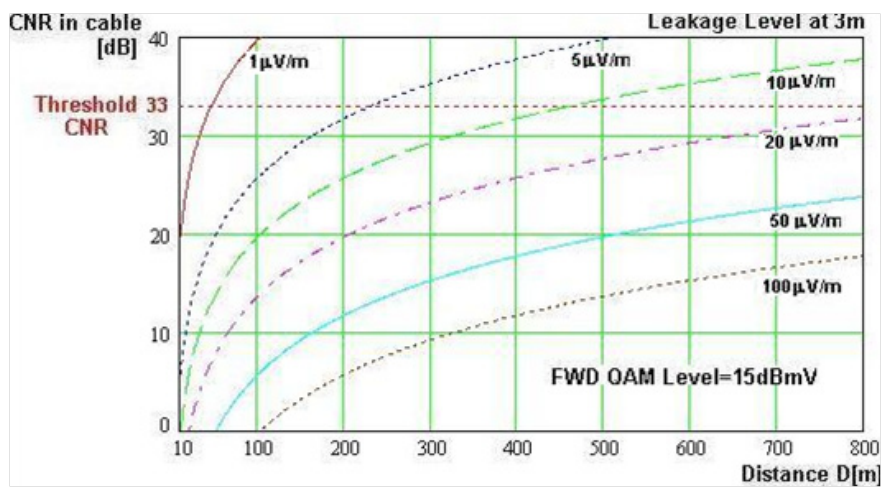level (level found in trunk) and 0dB OPL

Fig. 6. CNR curves vs. distance from LTE BS tower with +15dBmV QAM
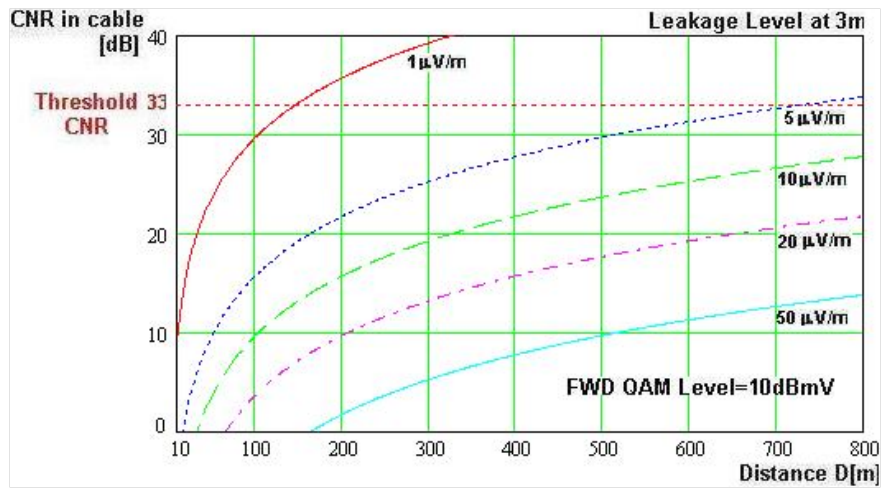level (level found in trunk and drop) and 0dB OPL

Fig. 7. CNR curves vs. distance from LTE BS tower with +10dBmV QAM level (level found in trunk and drop) and 0dB OPL
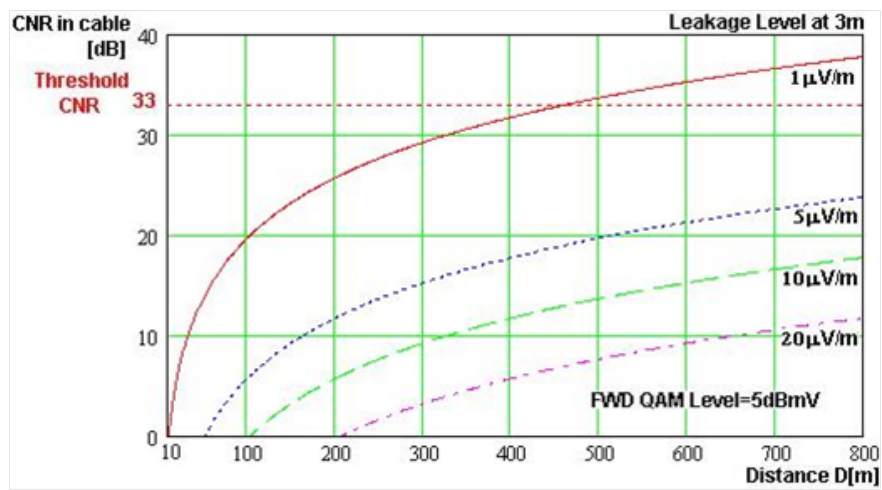

Fig. 8. CNR curves vs. distance from LTE BS tower with +5dBmV QAM level (level found in trunk and drop) and 0dB OPL
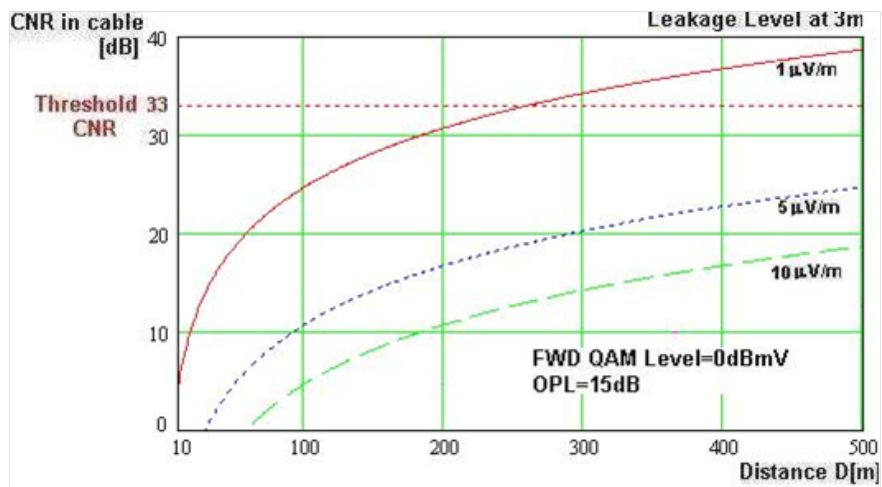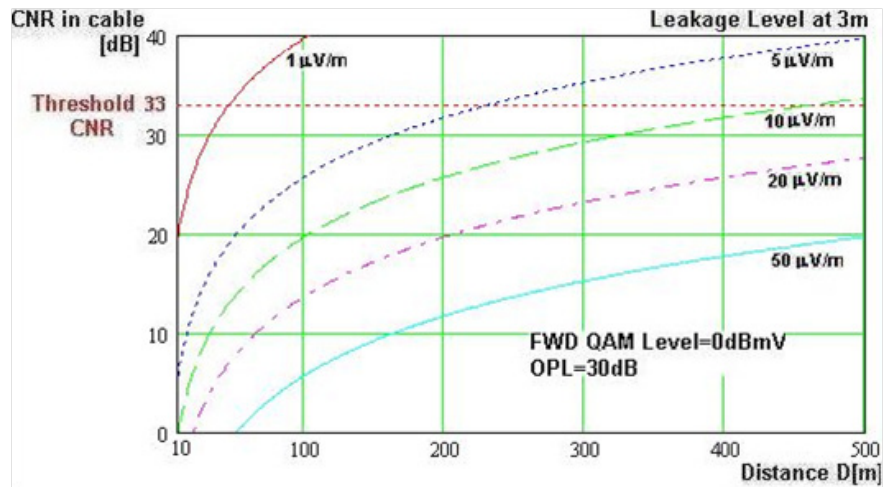

Fig. 9. CNR curves vs. distance from LTE BS tower with +0dBmV QAM level (level found in home) and 15 dB OPL

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Fig. 10. CNR curves vs. distance from LTE BS tower with +0dBmV QAM level (level found in home) and 30 dB OPL

Analysis of the various CNR graphs leads to an obvious observation that under certain low signal level condition, CNR can be quite significantly affected by LTE interference from the base station.

Looking at Fig 4. which shows a QAM signal level at the LTE band typical for the output of an amplifier – in this case even a 1,000 μV/m leak has no effect on CNR when an LTE base station is located at a distance of 150 meters[3]. Contrast this to Fig. 7 which has a QAM signal level corresponding to that which could be found at the input of the same amplifier. Here even a 1 μV/m leak with the LTE BS < 150 meters away could begin to degrade CNR assuming unobstructed transmission. The same figure also shows that a 5μV/m leak could cause a problem when the BS is located at a distance of 700 meters (assuming clear line of sight). This indicates that at low signal levels at locations prior to an amplifier, even very small amplitude leaks in the trunk line that are many hundreds of meters from a LTE BS can cause CNR for all downstream subscribers to be negatively affected.

When looking at Figure 2 which shows the effect QAM leakage has on an LTE receiver, and comparing it with Figures 4-8 which shows the opposite condition; it is clear that for a given leak in the proximity of an LTE base station, the negative effect on CNR will occur at a greater distance from the tower as compared to any negative effect on the LTE BS noise floor. And given the dependency on signal level, this relative distance will increase with decreasing signal level. Stated otherwise, every leak location is more likely to be negatively affected due to LTE ingress than the

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[3] This is not suggesting that a 1,000 μV/m does not have potential to affect an LTE BS (see Fig. 2)

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LTE BS is likely to be affected due to QAM egress. With regard to high frequency leakage, for a variety of reasons the majority of the attention to date has been focused on the egress aspects, with the ingress side receiving significantly less attention. While in no way trivializing the egress size, the ingress size rightly deserves increased attention as there clearly are significant benefits in the form of improved forward signal transmission quality that can be realized through high frequency leak mitigation.

In establishing any mitigation rules, consideration should be given to the possible cumulative effect of CNR degradation from many low level leaks and further investigation should be made as to how CNR degrades when leaks are combined with other RF impairments existing in coaxial cable such as micro-reflections and CPD.

Given the described QAM signal level and CNR relationship, it would be of benefit to merge databases containing leak locations and signal levels in order to better develop rules as to repair prioritization.

Fig. 10 shows the scenario of an LTE BS affecting CNR within the home. A QAM level of 0dBmV is used along with 30dB OPL which represents the signal traveling through the outer walls and roof. This shows that even a 5μV/m leak with the transmitter at 225 meters can begin to affect CNR.

QAM CNR BEING AFFECTED BY LTE USER EQUIPMENT

Switching now to the scenario of QAM CNR being affected by smart phones and other LTE UE, the power and gain parameters for these devices are: P_{Tx} = 23 dBm and G_{Tx}= 0 dBi. Taking in account these parameters and again using formula (10), in Figs. 11-21 the family of graphs of QAM signal CNR degradation is shown for different scenarios of interference due to LTE user equipment, for various QAM levels and OPL conditions.
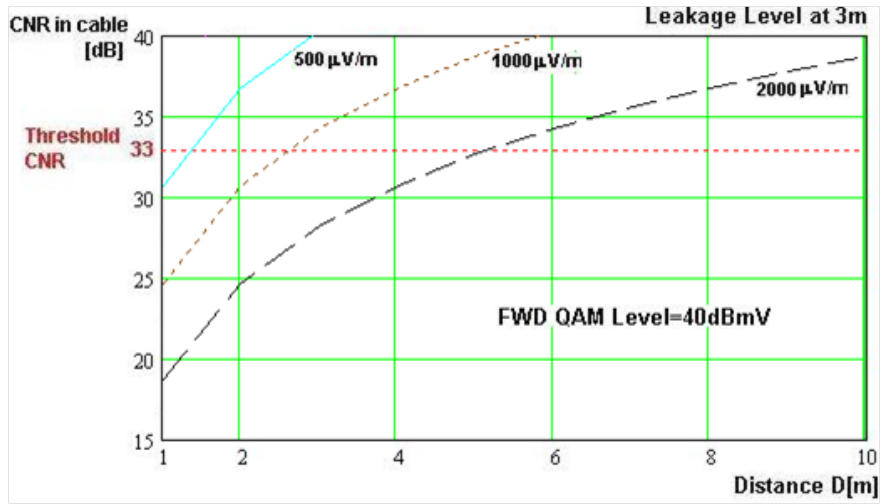
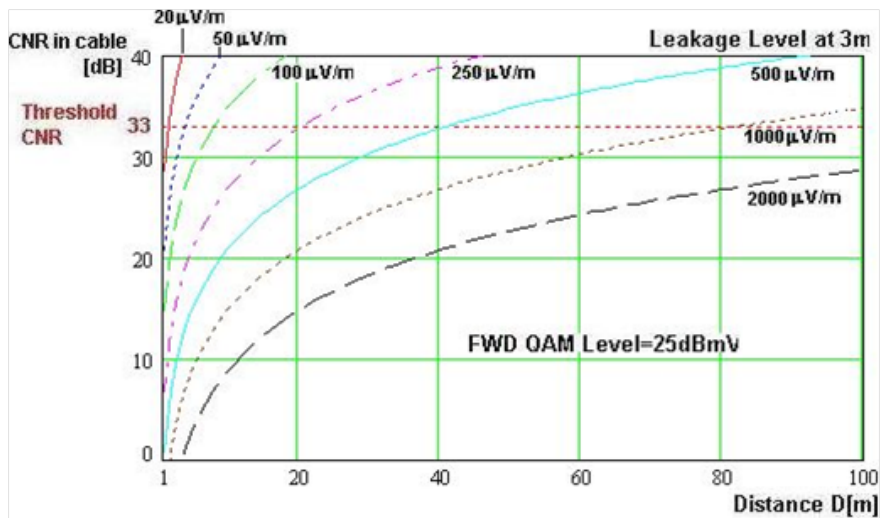**Fig. 11. CNR curves vs. distance from LTE UE with +40dBmV QAM level (level found in trunk) and 0 dB OPL**

Fig. 12. CNR curves vs. distance from LTE UE with +25dBmV QAM level (level found in trunk) and 0 dB OPL
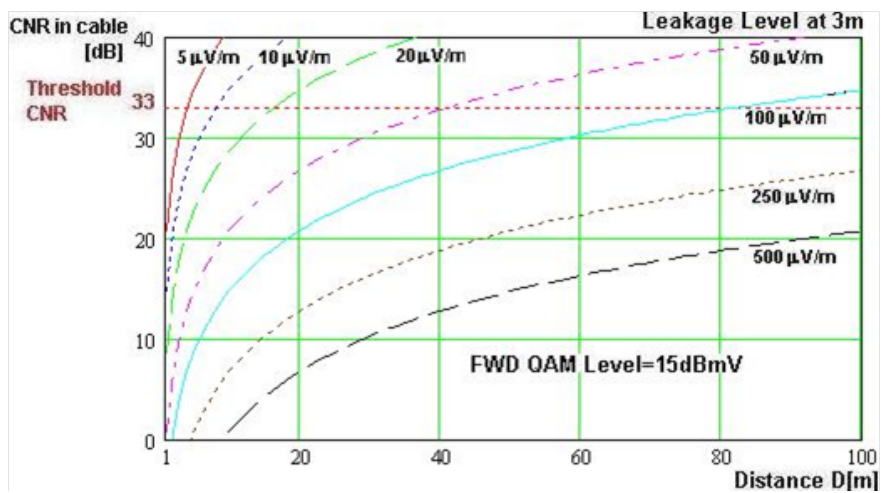

Fig. 13. CNR curves vs. distance from LTE UE with +15dBmV QAM level (level found in trunk and drop) and 0 dB OPL
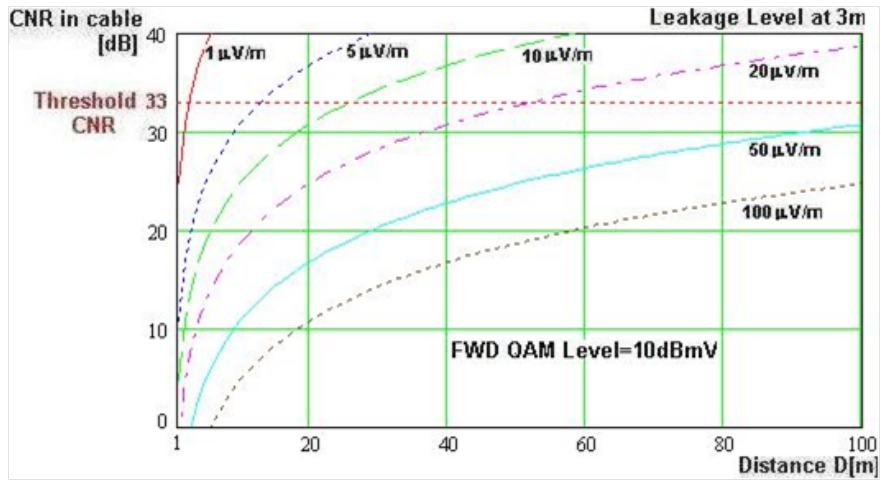
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Fig. 14. CNR curves vs. distance from LTE UE with +10dBmV QAM level (level found in trunk and drop) and 0 dB OPL
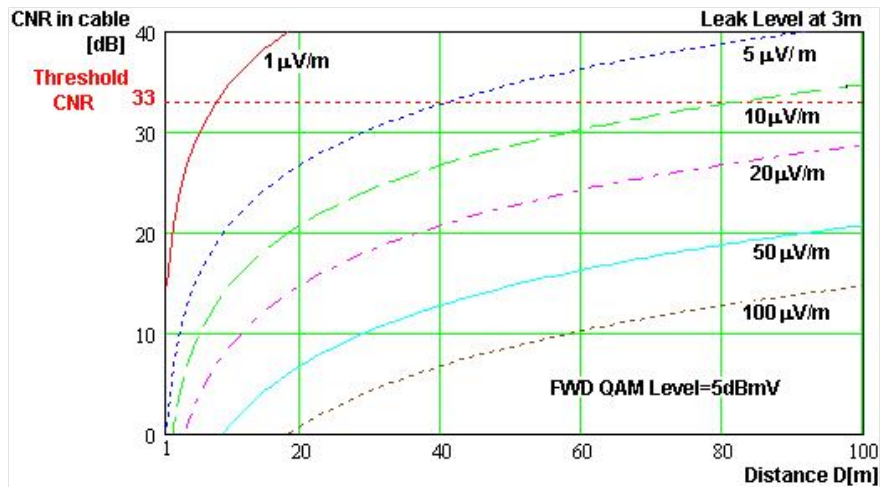

Fig. 15. CNR curves vs. distance from LTE UE with +5dBmV QAM level (level found in trunk and drop) and 0 dB OPL

Fig. 16. CNR curves vs. distance from LTE UE with +0dBmV QAM level (level found in home) and 0 dB OPL

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Fig. 17. CNR curves vs. distance from LTE UE with −5dBmV QAM level (level found in home) and 0 dB OPL
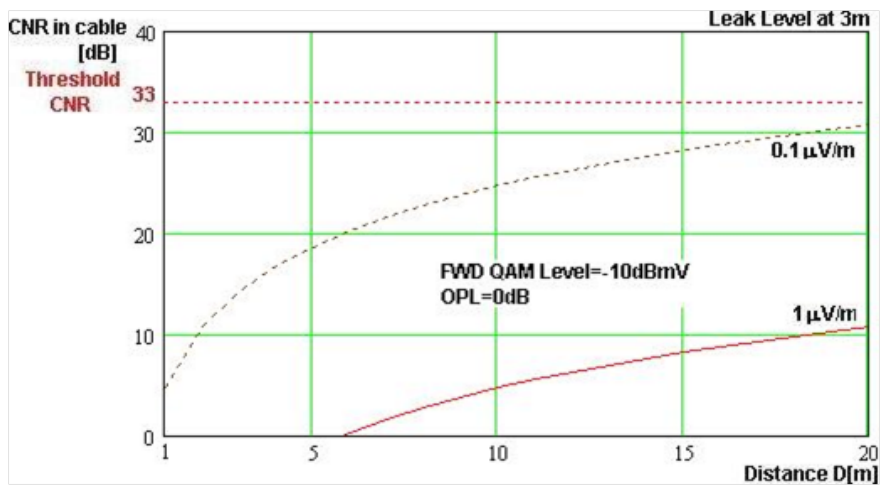
Fig. 18. CNR curves vs. distance from LTE UE with −10dBmV QAM level (level found in home) and 0 dB OPL
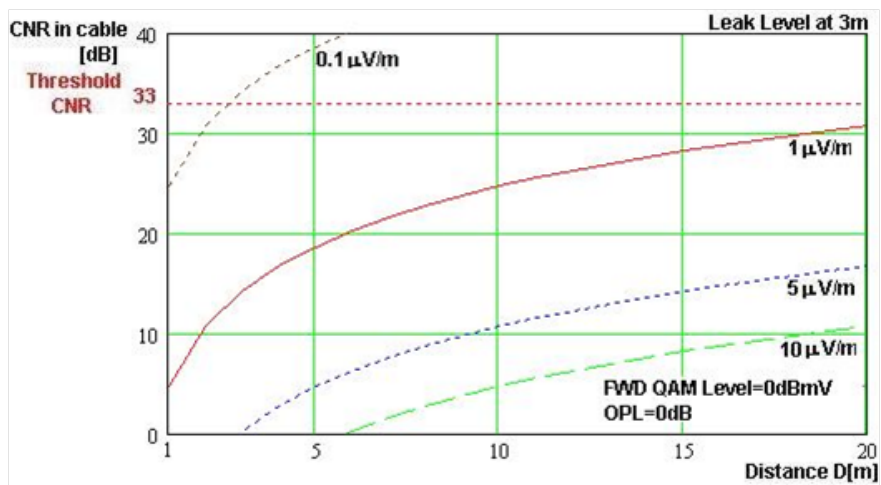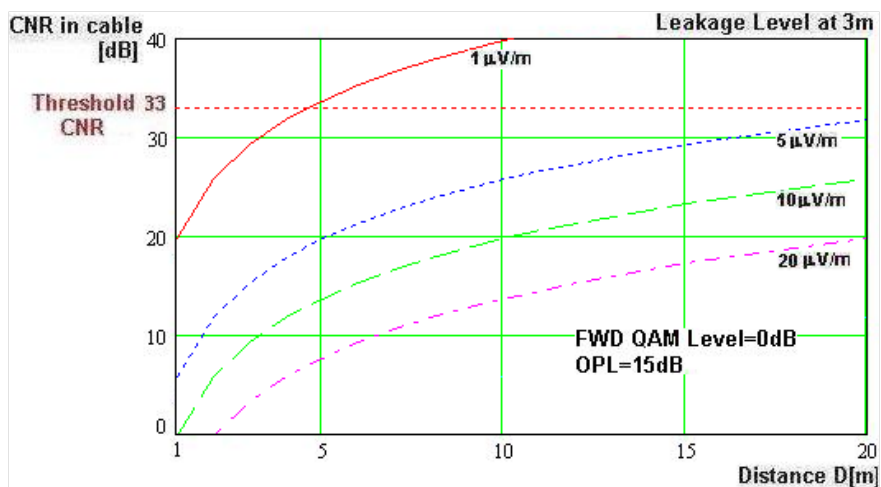

Fig. 19. CNR curves vs. distance from LTE UE with 0dBmV QAM level (level found in home) and 15 dB OPL
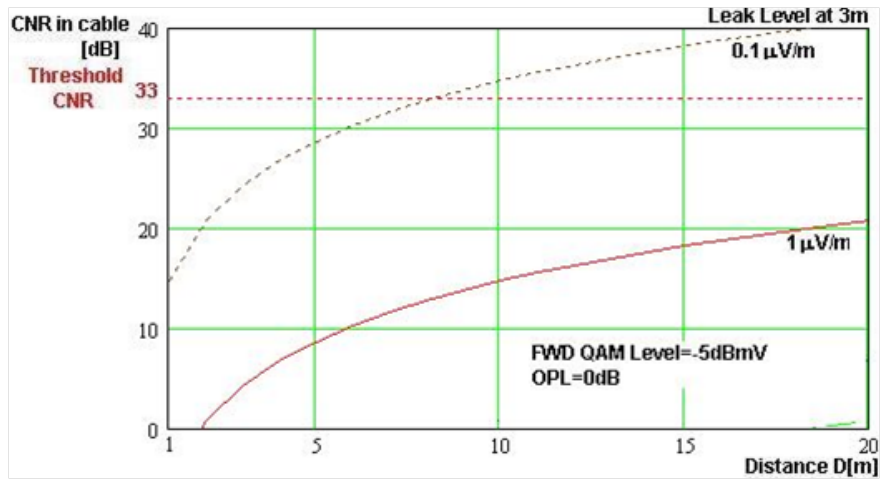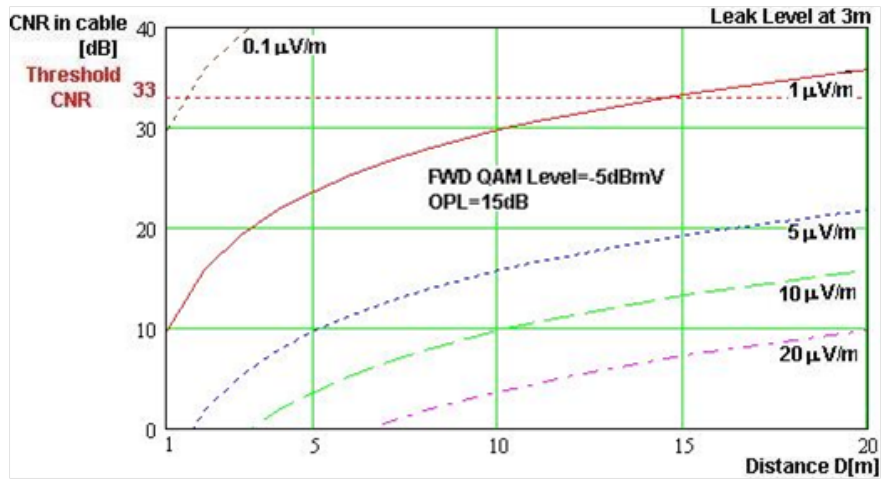
Fig. 20. CNR curves vs. distance from LTE UE with –5dBmV QAM level (level found in home) and 15 dB OPL
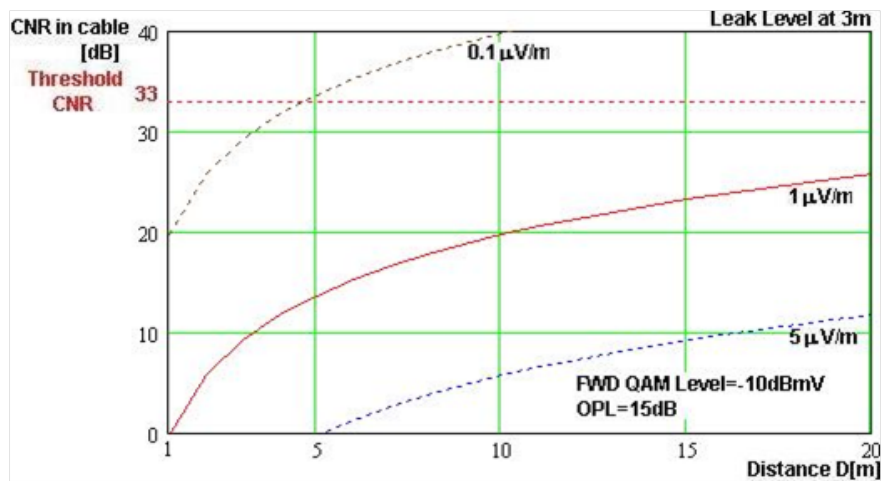
Fig. 21. CNR curves vs. distance from LTE UE with –10dBmV QAM level (level found in home) and 15 dB OPL

Analysis of the various CNR graphs of LTE interference from user equipment shows again that under conditions of low signal level CNR could be adversely affected. Figure 13 shows that at a location with a QAM level of 15dBmV and OPL of 0dB, if a person walks with a smart phone 10 meters from a 10µV/m leak, then CNR could begin to degrade. This is certainly a real world scenario.

INTERFERENCE FROM LTE USER EQUIPMENT WITHIN THE HOME

From a level perspective, the home portion of the network is clearly the most susceptible to CNR deterioration due to interference from LTE user equipment. Looking at the situation in the home, the math suggests that in order to ensure the threshold 33 CNR value is met, the requirement for allowable leak limits would need to be at a very stringent number of <1 µV/m. Figure 21 shows the lowest expected QAM level within the home of –10dBmV along with 15dB OPL – and the graph shows that even a 0.1µV/m leak could allow a LTE phone to begin to deteriorate CNR when located a distance of 5 meters from the leak, through a wall. Obviously a sub 1 µV/m leak can't be detected in the LTE band by any leak detector installed on a truck driving outside the home. So any measurement for this low level within the home only makes sense to implement for home certification processes or troubleshooting.

SHIELDING EFFECTIVENESS AND THE RELATIONSHIP TO LEAK LEVEL

One of the specific aspects of interfering LTE signal within the home portion of the cable network is that interfering signals may directly impact cable modems or set-top-boxes due to insufficient unit shielding effectiveness (SE). This type of interference is commonly referred as Direct Pickup or DPU interference (DPU). There have been multiple studies performed over the past few years on this subject, focusing to co-channel interference effects of LTE and other white space devices. Obviously if a cable modem or set-top-box is connected anywhere within the home network, then any requirements for SE and immunity to DPU should be extended to in-home cables, splitters and in general any component of the cable network within the home. Because the SE parameter is widely used for cables and splitters, it will be helpful to define the relation between SE and leak levels detected within the home, and compare these results with FCC requirements for DPU.

Current FCC immunity requirement for Cable Ready Devices specified in 47CFR15.118 defines the threshold for field strength of interfering signal as 0.1 V/m. But as is shown in the Motorola Whitepaper , *"Shielding Effectiveness of In-Home Cable TV Wiring and Splitters"*, and reproduced in Figure 22 below – the minimum separation of a Tx device (an LTE smart phone, for example) with Tx power of 100 mW (20 dBm) from the unit with FCC compliant threshold of 0.1 V/m should be 57 feet.[4]

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[4] Motorola Whitepaper, *"Shielding Effectiveness of In-Home Cable TV Wiring and Splitters"* – Figure 1, page 5
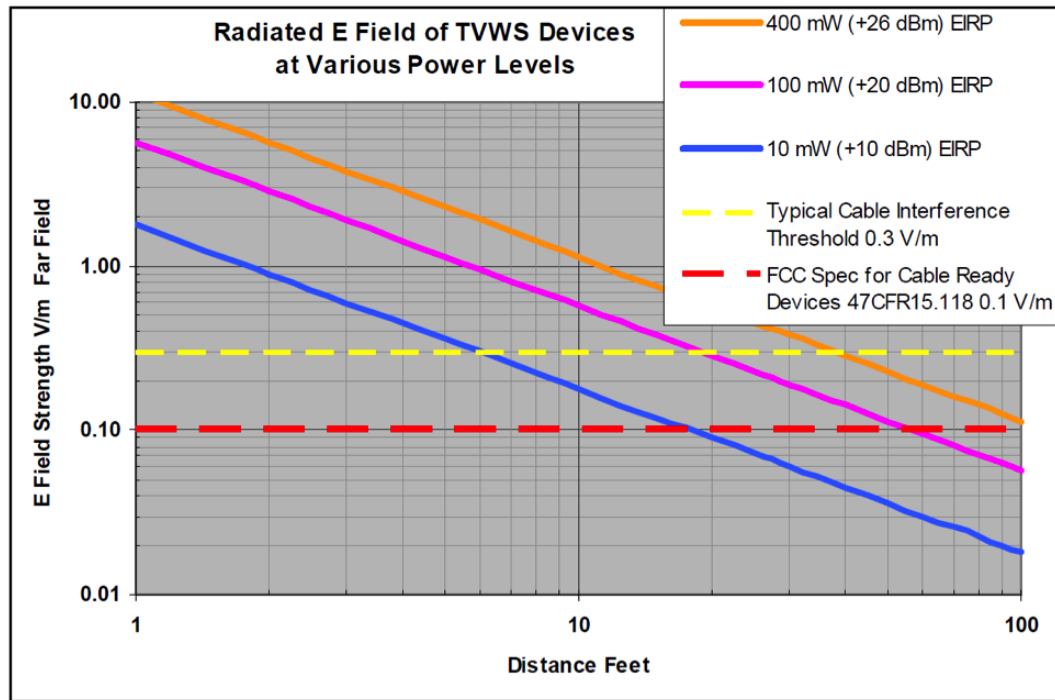
Fig. 22

Obviously this separation exceeds most room sizes, which is a reason that more stringent requirements of 0.3 to 1 V/m are currently being discussed in both the United States and Europe. In the same referenced Motorola Whitepaper, it calculates that for a 1 V/m threshold, the SE should be around – 100 dB/m[5]. This value of SE – 100 dB/m was calculated using a minimum QAM signal level in cable of –12 dBmV and SNR = 27 dB.

Additional data regarding testing of shielding effectiveness of coaxial cable as related to LTE interference is found in a report from the Netherlands Organization for Applied Scientific Research commissioned by NL Kable.[6]   In their study, one of the items investigated was ingress via the coaxial cable. They tested 5 different cables under various conditions, including one with shielding effectiveness >90dB up to 950 MHz, one with shielding effectiveness >75dB, and three additional cables with unknown shielding effectiveness. For all cables, there were scenarios where the maximum LTE field strength for lossless EuroDOCIS service was less than that of the equivalent field strength of an LTE user device transmitting @23dBm @3 meters. Conclusions from this paper were:

[5] Ibid., Appendix 1, page 17
[6] TNO Information and Communication Technology, author: Jan de Nijs, *Co-channel Interference Tests of LTE to Cable EuroDOCSIS Services*, 1 October 2010, pages 12–14

The tests show the following:

1. For the current cable modems and in-home networks, co-channel LTE transmission from a user terminal operating at the proposed maximum output level of 23 dBm strongly degrades the cable EuroDOCSIS service.
2. The ingress of the LTE signal takes place via both the cable modem and coaxial cables of an inferior quality connected to the TV connector of the 3 port wall outlet.
3. The use of Class A (Kabel Keur) or Class A+ shielded cables reduces the ingress of the LTE signal and the risk of degradation of the EuroDOCSIS service, however, it does not provide enough protection to eliminate the disturbance to the cable services.

In a second paper by Excentis, commissioned by UPC Broadband[7], tests were made on field strength immunity to many types of devices when exposed to LTE transmitters. Devices included integrated TV receivers, set top boxes, and cable modems. They concluded that the average field strength that caused disturbance was 114 dBµV/m (0.5V/m) – which corresponds to the LTE user equipment transmitting at a level of +23dBm, at a required separation distance of 5 meters to avoid interference. The worst case device required a separation distance of 24 meters.[8]

So looking at these three papers, it seems there is good correlation between the various sources as to the levels and distances that could cause co-channel interference to the home network from LTE user equipment transmitters.

In an additional report prepared by Joint working group of the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI) investigating Digital Dividend Issues, data is presented as to the shielding effectiveness of a large variety of cable and connector types.[9] The Executive Summary stated[10]: From the perspective of ingress to the cabling, it can be shown that the combination of worst-case connector and cable will reduce shielding effectiveness by 35dB against the best.

Plot 1 below shows test results displaying signals picked up by the cable, with the lower the signal representing improved shielding effectiveness.[11]

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[7] Excentis, *Addendum to CEPT Report 159: Technical Considerations On The Protection of Cable Services,* December 6, 2011.
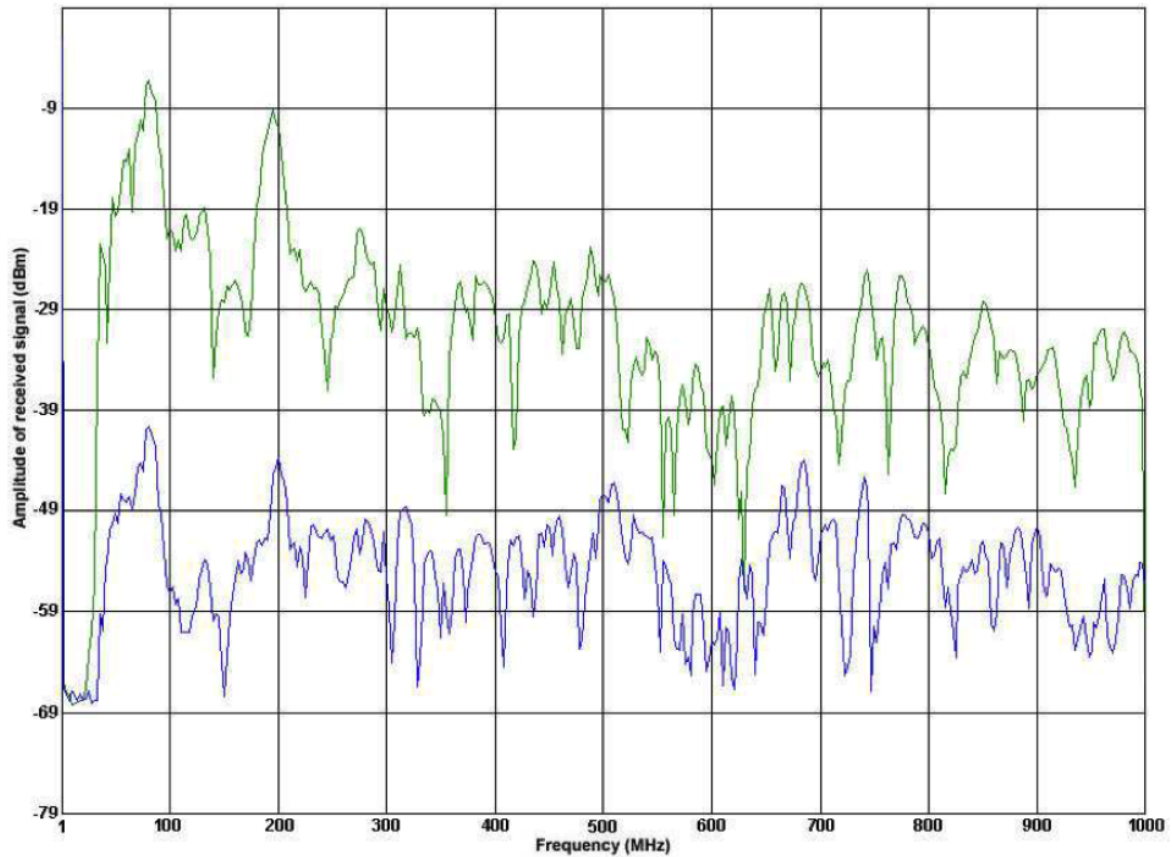[8] Ibid., page 23
[9] Annex B JWG DD Report v1.1(2011-05) Joint CENELEC-ETSI Working Group (JWG) on Digital Dividend Issues. Compilation of contributions to the JWG and outpus of sub groups of the JWG. Annex B: CPE and Cable Immunity
[10] Ibid., page 24
[11] Ibid., page 25

B.5.2.1   Comparison of cables with the most and least effective shielding

Plot 1: Colour-coded plot of coaxial cables with the most and least effective shielding.

Plot 4 below shows the complete results of all cables and connectors tested.[12] Note the wide variation of shielding effectiveness, and additionally note that each type of cable and connector combination has a corresponding frequency response. As such, in order to test for co-channel interference from an LTE transmitter – this would suggest that in order to ensure a valid result, any testing would need to be performed at the same frequency as the transmitter.   For example, in Plot 1 above, the best shielding effectiveness for both cables occurs around 600MHz, where at high frequency the relative worst high frequency shielding effectiveness is around 700–750MHz.

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[12] Ibid., page 32

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B.5.5.3.1   Overlay of results
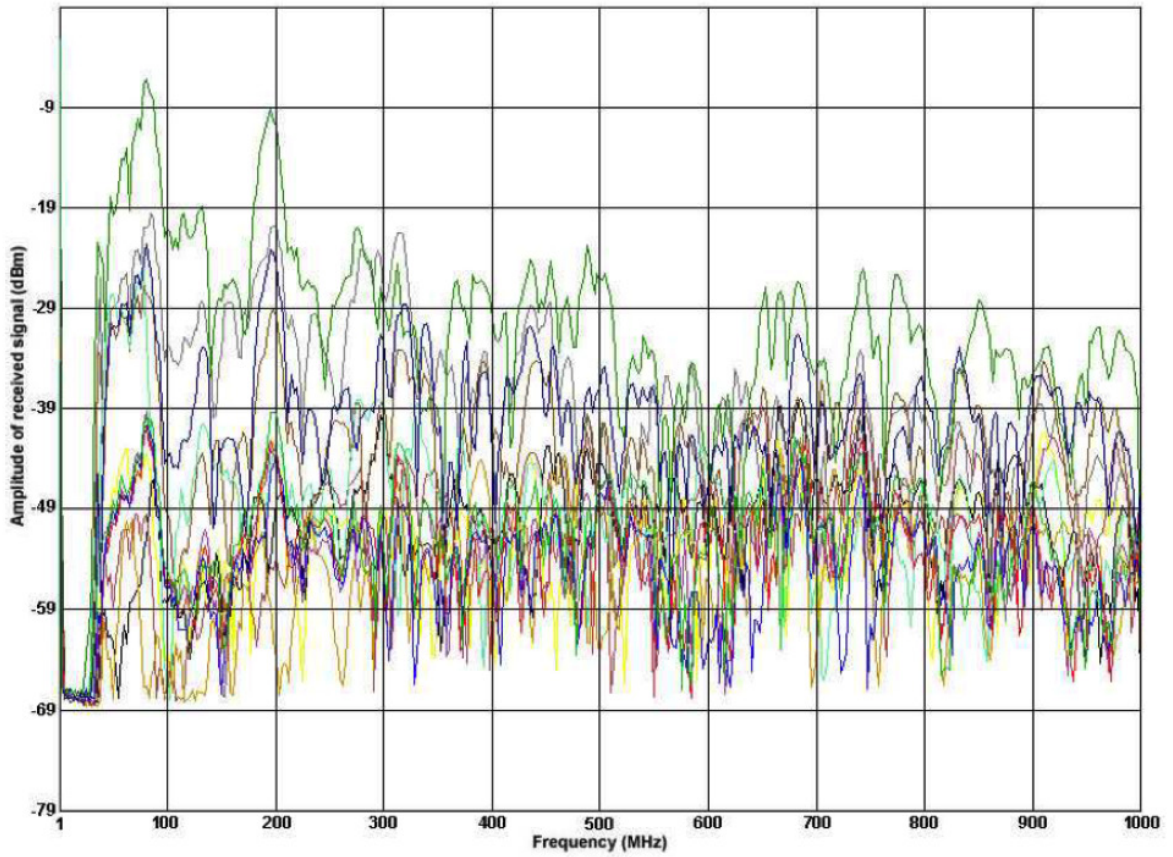
Plot 4: Colour coded plots of all 13 cables.

Colour code	Market	Designation	Screen	F Connectors
(green)	Consumer	CTF100	double screen	screw-on
(blue)	Professional	RG59	tri-screen	compression
(red)	Professional		double screen	crimped
(purple)	Professional	RG59	double-screen	compression
(navy)	Consumer	CT100	double screen	screw-on
(orange)	Professional		double screen	premanufactured
(dark green)	Consumer		single screen	screw-on
(light green)	Professional		double screen	Crimped
(brown)	Consumer		double screen	screw-on
(dark red)	Consumer		double screen	screw-on
(black)	Professional	RG59	quad-screen	compression
(grey)	Consumer	RG6	double screen	compression
(yellow)	Professional		double screen	compression

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As a last component of the referenced cable testing, the actual shielding effectiveness was calculated from the best and worst cases in Plot 1. Graph 1 below shows the results.[13]

Shielding effectiveness of coaxial cables
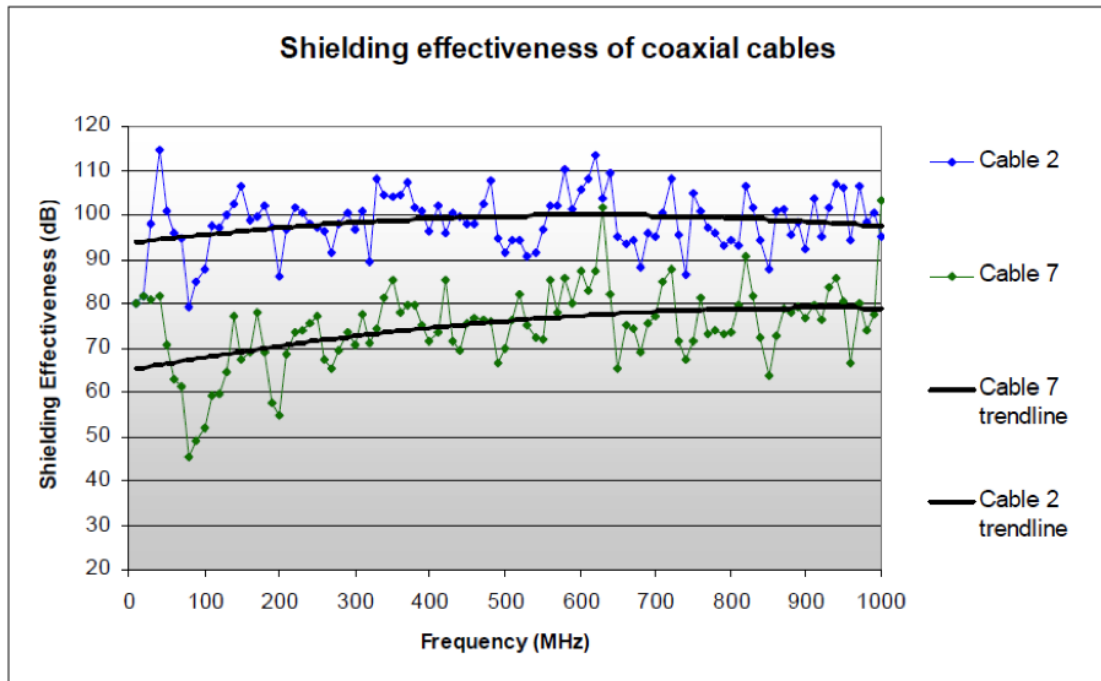
Graph 1: Shielding effectiveness of the cables at either extreme of the effectiveness scale

The trend lines on Graph 1 clearly show that whilst the screening of the least effectively shielded cable on test lies between 65-80 dB, the trend line showing the screening of the most effectively shielded cable on test lies between 95-100 B. Note that the professional cable's shielding is effective across the frequency range.

Given these references, there is an expectation that there will be occasions where signals generated by LTE user equipment will enter through weak points in the home network and cause co–channel interference to content transmitted at LTE frequencies. As such, there will likely be occasions when the cable technician is required to troubleshoot the location of this weakness and the source location of the ingress and the deficient shielding. From the references, shielding effectiveness in the range of –90 to –100 dB/m would seem to be a threshold as to what potentially may be required. From this perspective, a reasonable question is what sensitivity of leak detector would be required in order to measure SE in range –90 to –100 dB/m for home certification or troubleshooting purposes?

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[13] Ibid., page 35

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The SE parameter is defined by formula:

$$SE \ (dB/m) = E_{field} \ (dBV/m) - U_{cable} \ (dBV), \tag{11}$$

where

E_{field} – is field strength of interfering signal;

U_{cable} – is voltage detected on cable center conductor.

Actually SE is nothing more than the antenna factor if one considers cable to act like some sort of antenna. If so, then SE also may defined by known formula for antenna factor AF

$$AF \ (dB/m) = SE \ (dB/m) = 20 \ log(F(MHz) - 29.7707(dB) - G_{Rx}(dBi), \tag{12}$$

where

G_{Rx} – is gain of receiving antenna.

If one uses the above assumption that the gain of the leak source antenna is the same for the Rx and Tx signals ($G_{Leak} = G_{Rx} = G_{Tx}$), then combining formula (7) and (12) the interrelation between SE and detected leak level E leak at LTE band 750 MHz is defined by the simple formula.

$$E_{Leak} \ (dB\mu V/m) = U_{qam}(dBmV) - SE(dB/m) + 74.21 \ (dB) \tag{13}$$

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The family of graphs in Fig. 23 below shows the interrelation of leak level with SE for different levels of QAM signal typically found in the home.
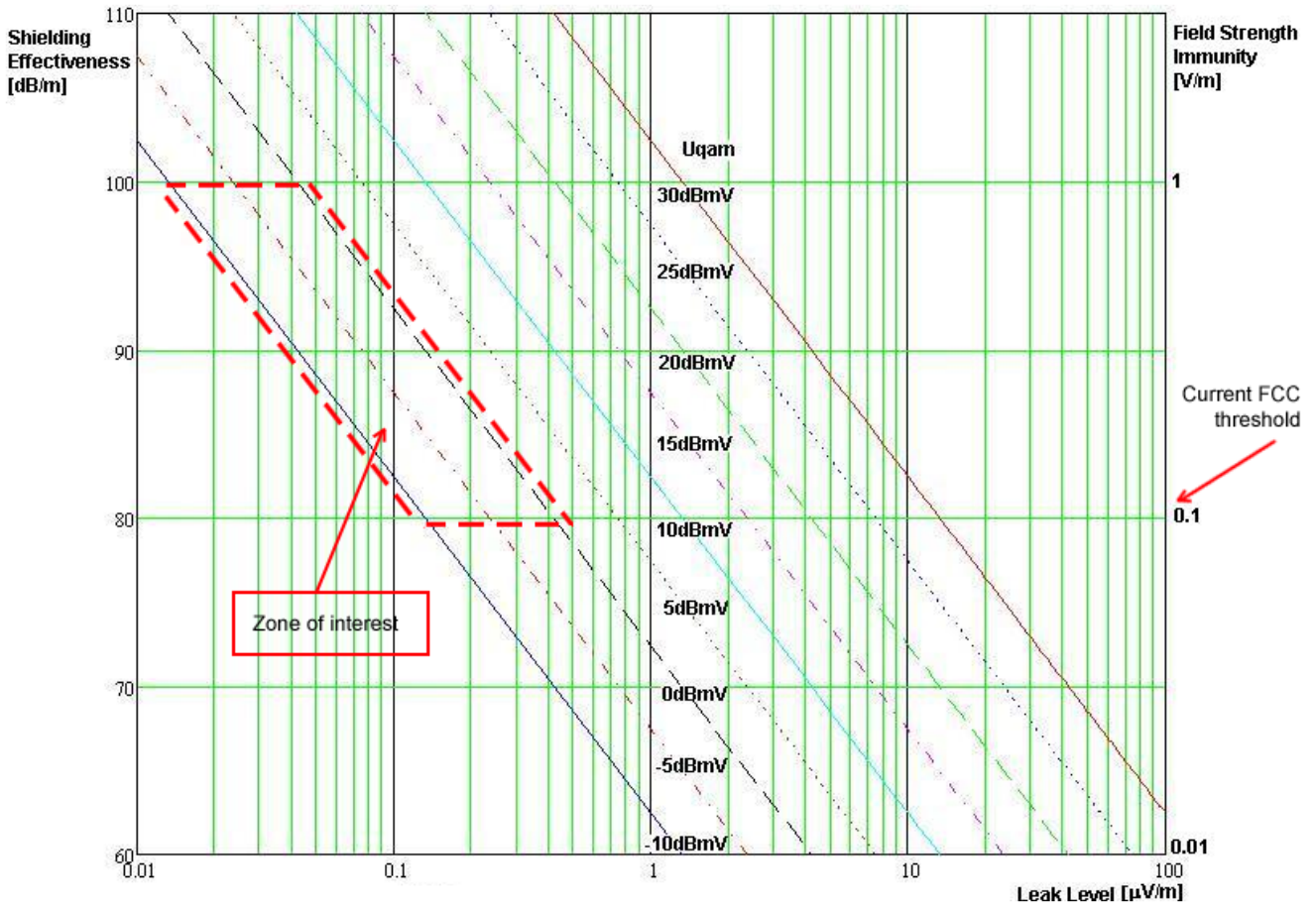
Fig.23. Interrelation between shielding efficiency and leak level for different level of QAM signal in cable

For SE = –90 to – 100 dB/m (E_{field} = 0.3 to 1V/m) and QAM signal level at home cable U_{qam} = 0 dBmV the sensitivity of a leak detector capable of measuring and troubleshooting would need to be from –15.79 dBμV/m to –25.79 dBμV/m or 0.051 μV/m to 0.165 μV/m. This number is well correlated with the results shown in Fig. 16–21 for interference from LTE UE within the home.

STATISTICS SHOWING LEAK DISTRIBUTION BY LEVEL

In order to define business rules as to which leaks make sense to repair, it would be helpful to have some idea as to the expected percentages of leaks of various sizes that exist. As such, summary data was accumulated for a large quantity of leaks in about 20 networks in both urban and suburban locations. The charts in Figure 22 illustrate the expected trend of leaks increasing proportionately with reduced level.

Quantity of leaks grouped by 10 ft. scaled level - 3,464 detected leaks

	<25 µV/m	25 < 50 µV/m	50 < 75 µV/m	75 < 100 µV/m	>100 µV/m
Leak quantity	1508	957	526	142	331

Leak level - total of 3,464 leaks

>100 µV/m 10%
75 < 100 µV/m 4%
50 < 75 µV/m 15%
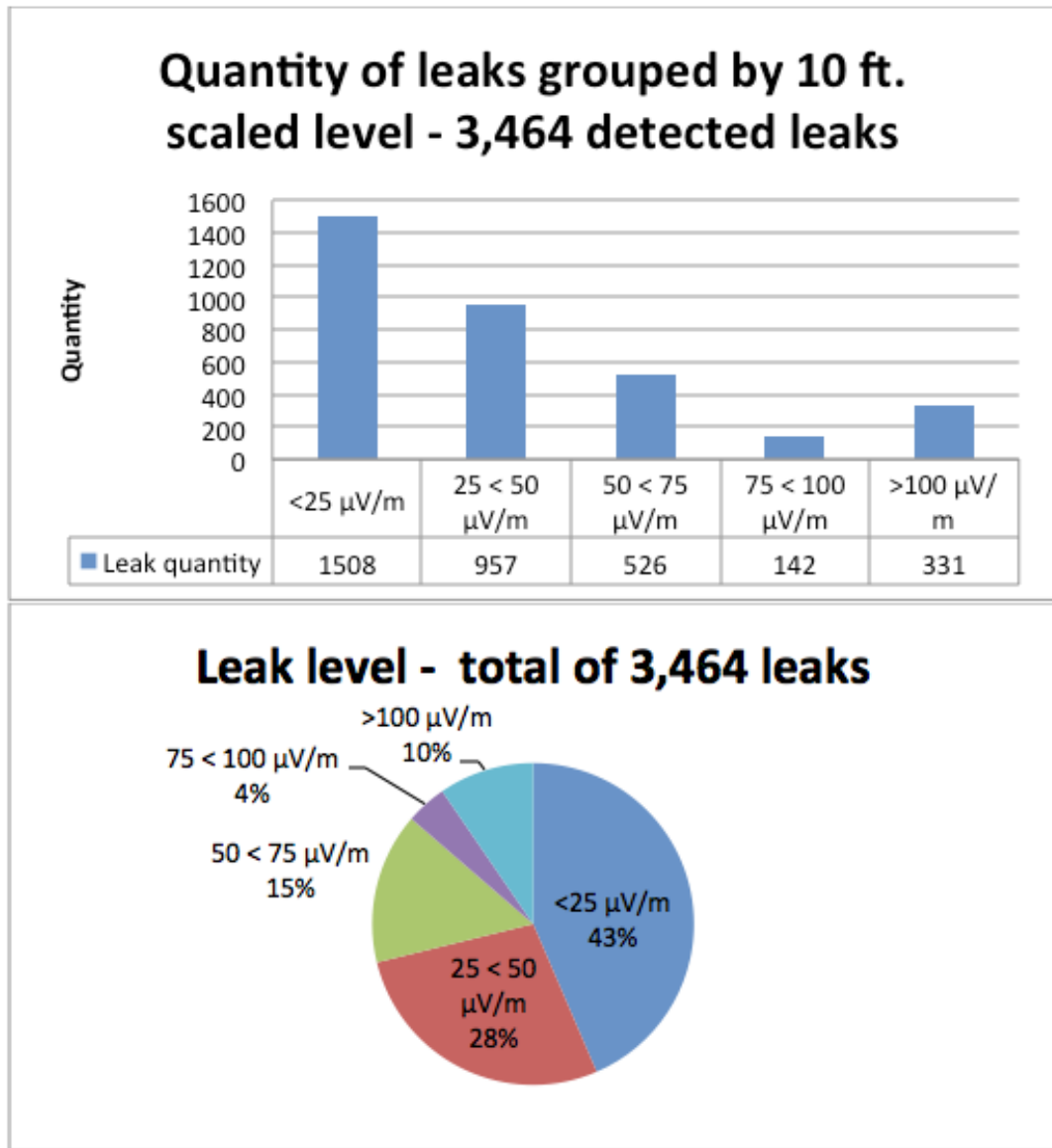<25 µV/m 43%
25 < 50 µV/m 28%

Fig. 24. Actual high frequency leak statistics

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CONCLUSIONS

1. **As pertains to LTE base stations affected by QAM egress:**

   a. QAM leaks can adversely affect the noise floor of LTE base station receivers based upon the distance from the leak to the tower, leak magnitude, and line of sight conditions. With an unobstructed line of sight a 20 µV/m leak can adversely affect the threshold noise floor from 20 meters, a 50µV/m from 50 meters, a 100µV/m from 100 meters, a 250µV/m from 275 meters, a 500µV/m from 500 meters, etc.

   b. In order to most efficiently and cost effectively establish mitigation rules such that interference to the LTE BS does not occur, an initial thought was that the location of LTE BS within an geographic area can be added to a database, and repair rules can be established based upon the receive power equation (3)[14] utilizing the BS GPS coordinates, leak location GPS coordinates, and leak magnitude. This approach however proved to be unrealistic and completely ineffective because subsequent testing showed that tower proximity was a very weak indicator of LTE signal strength at any given location. Factors such as directionality of antennas and geographic features such as tower height resulted in situations where locations far from the transmitter have significantly greater signal levels than locations close to the transmitter.[15] Additionally, the location of towers is often unknown and it is uncertain as to whether the transmitter is being used at a relevant LTE band co-channel with the frequencies on the cable network. Furthermore, the trend of small LTE microcells that are often hidden is problematic to the approach. Because of this, a better and extremely effective method is to simply measure the LTE signal strength at each leakage detection point and include this data integral to the leakage database, to be used as an important component of repair rules, along with detected leak level and QAM signal level.

2. **As pertains to LTE user equipment affected by QAM egress:**

   a. QAM leaks can adversely affect the noise floor of LTE user equipment. With clear line of sight, a 50µV/m leak can deteriorate the threshold noise floor of the user equipment from a distance of 3 meters, a 100µV/m from 6 meters, a 250µV/m from 15 meters, a 500µV/m from 30 meters, etc.

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[14] Equation (3) is found on page 5 herein.
[15] Supporting data available upon request

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3. **As pertains to LTE base station ingress affecting QAM CNR:**

   a. Location of QAM egress also provides the mechanism for LTE signal ingress which adversely affects the QAM CNR. This interference is shown to be highly dependent upon the QAM signal level at the leak location, with the relationship that every dB of signal level decrease results in two dB decrease of CNR due to the interference.

   b. For a given leak location in broad proximity to an LTE BS, CNR performance is more susceptible to deterioration and is more likely to occur than is LTE BS performance deterioration.

   c. Given the dependency on QAM signal level, even a small 5μV/m leak 700 meters from a transmitter could begin to cause CNR deterioration for all downstream subscribers.

4. **As pertains to LTE user equipment affecting QAM CNR in the home:**

   a. The home portion of the network is clearly the most susceptible to CNR deterioration due to interference from LTE user equipment because of the low signal level and short distances.

   b. Even leaks less than 1 μV/m can cause interference.

   c. Shielding effectiveness has a relationship with leak level, and in order to locate devices in the home with SE in the range of –80dB/m (current FCC requirement for cable ready devices – 0.1V/m) to –100 dB/m (expected potential requirement of 1V/m), detector sensitivity needs to be less than 1μV/m. While it is possible to achieve such sensitivity with modern leakage equipment, it would create some practical problems because this very sensitive detector would also pick up signal leaks external to the home (the amplifier outside for example) creating false alarms that would be very difficult and time consuming for the technician to resolve. As such, a better approach to troubleshooting and mitigation of these very small leaks is to disconnect the home from the cable network at the grounding block, and temporarily insert high level pilot signals which can be easily detected using equipment having the same sensitivity or even less than that used in the outside plant.

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