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700 MHz band LTE uplink interference to DTT reception system cabling

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***Abstract*—This paper studies the shielded screening attenuation of consumer-grade digital terrestrial television (DTT) antenna coaxial cables and presents a measurement campaign to determine their vulnerability to interference originating from uplink traffic of a nearby Long Term Evolution (LTE) user equipment (UE) operating on the 700 MHz frequency band. The interference scenario is novel as the LTE uplink traffic on the 700 MHz band is significantly closer in frequency to the DTT transmissions than previously with the 800 MHz LTE. The measurement results show that the antenna coaxial cables with weakest shielded screening attenuation can be interfered in realistic usage scenarios when the LTE UE uplink traffic is transmitted on the lowest frequencies in the 700 MHz band and the DTT channel highest in frequency is used.**

***Index Terms*—LTE, DTT, Interference, Cable shielding, Experimental measurements.**

I. INTRODUCTION

The 700 MHz band (694-790 MHz) was allocated to mobile broadband (MBB) in 2012 at World Radiocommunication Conference 2012 (WRC-12) [1]. Thus the European Commission mandated CEPT to develop harmonised technical conditions for the 700 MHz MBB in the European Union (EU) [2], [3]. The DTT transmissions currently transmitted in the 700 MHz band in Europe are in the process of being regrouped into 470-694 MHz frequency range with a common deadline for clearing the 700 MHz band for MBB in 2020. As shown in Figure 1, the 703-733 MHz frequency range is reserved for MBB uplink and the 758-788 MHz frequency range for MBB downlink. A European National Regulatory Authority (NRA) can decide to use the 700 MHz band also for an optional unpaired frequency arrangement of up to four blocks of 5 MHz for downlink-only Supplemental Downlink (SDL) in the 738-758 MHz frequency range, Public Protection and Disaster Relief (PPDR) uplink in 698-703 MHz / 733-736 MHz range, PPDR downlink in 753-758 MHz / 788-791 MHz range, machine-to-machine (M2M) uplink in 733-736 MHz range, M2M downlink in 788-791 MHz range, or for Programme Making and Special Events (PMSE) transmissions in 694-703 MHz or 733-758 MHz range.

In Finland, the 700 MHz band was auctioned to the mobile network operators (MNOs) already in 2016 [4] and the digital terrestrial television (DTT) transmissions were cleared from the band in January 2017 [5]. The band was auctioned to the three major Finnish MNOs for 17 years, and the first Long Term Evolution (LTE) base stations are already operating in the band [6]. The use of the sub-bands for SDL, PPDR, M2M or PMSE is still under review in Finland [7]. Turku University of Applied Sciences (TUAS) has an own 5G Test Network Turku (5GTNT) testbed [8], which has a license to operate on the 700 MHz band in Turku, Finland, until the commercial operators start using their frequency bands in this location.

As discussed in the survey article [9], the coexistence between MBB and DTT has already been widely studied. When the 800 MHz band was introduced to MBB use, the MBB downlink was closer in frequency to the DTT transmissions than the MBB uplink. The scenario is different when the 700 MHz band is taken into LTE use, as the LTE UE uplink is now closer in frequency to the DTT transmissions. They are separated only by a 9 MHz guard band. Thus, studies on interference originating from mobile terminal uplink traffic are more relevant with the 700 MHz band as the frequency separation is small and the LTE UEs are often used in the vicinity of DTT receivers.

Also, the LTE antennas transmitting on the 700 MHz band and installed on the same roof as the DTT reception antenna can overload the DTT reception system, especially if Master Antenna Television (MATV) systems are used. The 700 MHz LTE UEs operating indoors on the top floor of small houses can also be located very close to the outdoor DTT reception antennas. If the roof is made from tiles, bitumen, or other materials easily permeable to radio waves, the outdoor DTT reception antenna could be prone to interference originating from a LTE UE located indoors. LTE filter installation (before any possible amplifiers) might be needed to mitigate the interference in such scenarios [10]. Figure 2 illustrates possible scenarios where the LTE UEs could interfere DTT reception.

A study in [10] states that the interference of LTE uplink signals could be facilitated by a limited shielding of cables and components of the DTT distribution system. This paper extends the existing research on the shielded screening attenuation antenna coaxial cables [11] in a scenario where the DTT reception is interfered by LTE terminal uplink transmission. The hypothesis is that the consumer-grade cabling between the TV aerial socket and the TV set is the weakest part against interference originating from a nearby LTE UE uplink traffic. The interference scenario is novel as now the LTE uplink operates adjacent in frequency to the DTT transmissions.

The measurements in this paper study consumer-grade cables in a controlled interference scenario inside a shielded anechoic chamber. The focus is on the LTE UE uplink interference to the DTT antenna coaxial cabling between the TV aerial socket and the TV set. Other possible interference scenarios between LTE UEs and other parts of DTT reception

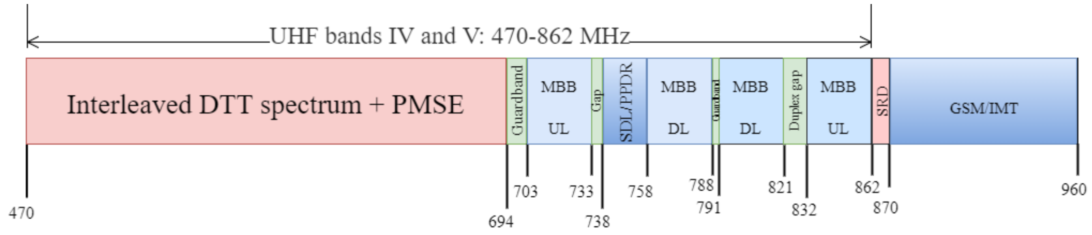


Fig. 1. UHF band utilization in Europe after the 700 MHz band is cleared for MBB.

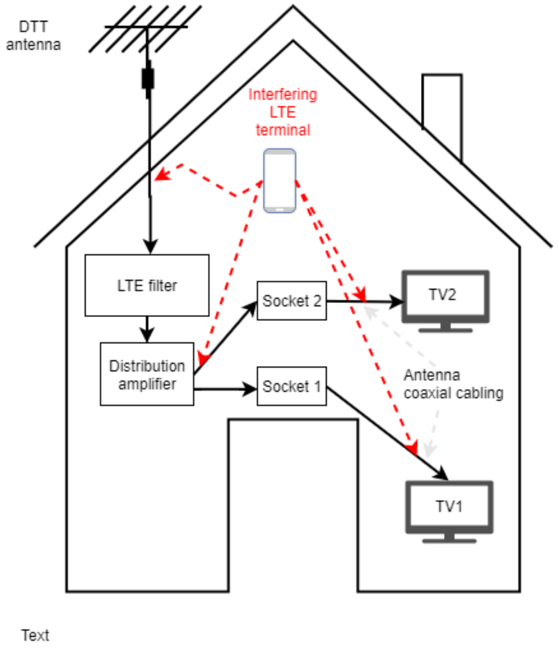


Fig. 2. An example LTE UE uplink traffic to DTT antenna coaxial cabling interference scenario in a typical small house DTT reception system with LTE filter, distribution amplifier, two TV aerial sockets and two TV sets.

system are not considered in this paper.

The rest of the paper is organized as follows: Section II presents the shielding characteristic measurements of the studied cables, Section III describes the interference measurement setup and covers the measurement results, and Section IV concludes the paper.

II. CABLE SHIELDING ATTENUATION MEASUREMENTS

10 different antenna coaxial cables from different price categories with lengths ranging from 1 m to 3 m were chosen to be studied in this paper. The lengths and the prices of the cables are presented in Table I. The cable selection was made so that the cables represent as many possible types and qualities of cables as is available on the consumer market.

The cable shielding attenuation measurements were conducted in the shielded anechoic chamber of TUAS EMC laboratory. Setup and calibration was made according to the radiated immunity test in IEC 61000-4-3 EMC standard [12]. Radio field was generated using Rohde & Schwarz SFU signal generator, 100W power amplifier and 30-3000 MHz broadband

TABLE I

THE LENGTHS AND PRICES OF THE MEASURED CONSUMER-GRADE ANTENNA COAXIAL CABLES.

	Length (m)	Price (€)
Cable 1	3.0	2.5
Cable 2	1.5	1.5
Cable 3	1.5	7.79
Cable 4	1.5	19.55
Cable 5	2.0	4.85
Cable 6	1.5	3.95
Cable 7	2.5	7.49
Cable 8	2.5	12.99
Cable 9	1.5	2.99
Cable 10	1.5	2.99

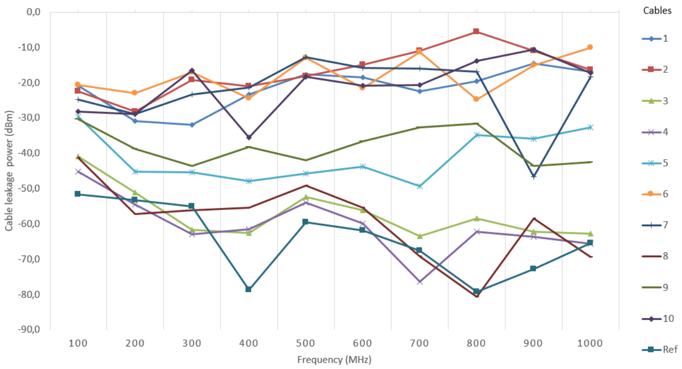


Fig. 3. Cable leakage power in dBm at 10V/m field strength in 100 MHz to 1000 MHz frequency bands.

log-periodic antenna. Measurement distance was 3 meters and the field strength was 10 V/m. This provided a dynamic range which was sufficient for the large variations between the cables.

The cables under test were on a wooden table in a 90 degree angle towards the antenna. Cable under test was terminated by 75 Ω RF terminator. The other end of the cable was connected to the Rohde & Schwarz ETL spectrum analyzer by a coaxial cable and 75-50 Ω impedance adapter. The cable loss and adapter attenuation are subtracted from the measurement results. The main spectrum analyzer settings in the measurements were the following: resolution bandwidth 100 kHz, video bandwidth 100 kHz, span 10 MHz and a sweep time 2.5 ms.

The measurement results are illustrated in Figure 3, which shows the leakage power of each cable in dBm in 100

MHz to 1000 MHz frequency range. In addition to the 10 cables studied in this paper, Huber+Suhner RF measurement cable was also measured to provide reference values. The Huber+Suhner reference cable had the highest cable shielding attenuation, as the measured cable leakage powers were between approximately -50 dBm and -80 dBm. The higher the attenuation is, the better the cable shielding quality is and the less interference-prone the cable is.

The measured cables can be categorized to three different groups in terms of the quality of their shielding:

1) Cables 3, 4, and 8 have a high attenuation in the whole frequency band, with cable leakage powers ranging from approximately -40 dBm to -80 dBm. The cable shielding performance is approximately on the same level as the reference cable. These cables were also the most expensive, so the cable price seems to have a correlation with the cable quality.
2) Cables 5 and 9 have a moderate attenuation in the whole frequency band, with cable leakage powers ranging from approximately -30 dBm to -50 dBm.
3) Cables 1, 2, 6, 7, and 10 have a low attenuation in the whole frequency band, with cable leakage powers ranging from approximately -5 dBm to -30 dBm. These cables should thus be most prone to interference.

The difference between the best and the worst cables is 60 dB in 700-800 MHz MBB bands. A 60 dB difference in attenuation results in a 30 times longer distance in interfering range.

III. INTERFERENCE MEASUREMENTS

Measurements were carried out in the same shielded anechoic chamber as the cable shielding attenuation measurements. A block diagram of the measurement setup is presented in Figure 4 and Figure 5 shows a photo from inside the anechoic chamber. The cables under test were on the wooden table in 90 degree angle towards the antenna. DVB-T2 standard TV signal (8 MHz, 256-QAM, 4/5 code rate, 32K FFT) was generated using a Rohde & Schwarz SFU signal generator. The signal was fed through a step attenuator to the TV antenna coaxial cable under test. The TV signal level was adjusted with each cable to 3 dB above the TV sensitivity level. Standard commercial Sony Bravia DTV set from 2016 was used to monitor the TV test signal. The interfering LTE UE uplink signal was generated by a commercial Samsung S8 cell phone. The cell phone was moved along a plane to discover the distance at which the DTV reception could be interfered.

Nokia Networks Flexi Multiradio LTE base station was set up outside the anechoic chamber to serve the LTE UE. The LTE signal level was adjusted to force the LTE UE to use maximum transmitted uplink power of 23 dBm. Downlink received power was monitored using Network Cell Info Lite application in the LTE UE. The Reference Signal Received Power (RSRP) was -118 to -121 dBm during the measurements. Voice over LTE (VoLTE) call was activated and maintained during the measurements and service mode monitoring was used in the LTE UE to confirm that the transmitted uplink power was 23 dBm during all measurements.

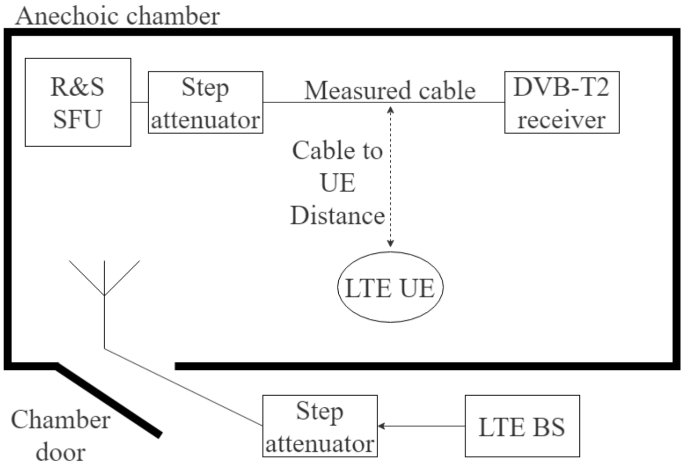


Fig. 4. Interference measurement block diagram. The LTE BS was located outside the anechoic chamber and a step attenuator was used to control the signal level so that the LTE UE needs to use the maximum uplink transmission power. The LTE BS antenna was brought inside the chamber. R&S SFU is used to generate the DVB-T2 signal, whose level is controlled by a step attenuator. The measured antenna coaxial cable delivers this signal to the DVB-T2 receiver and the LTE UE inside the chamber generates interference towards the antenna coaxial cable and DTT reception.

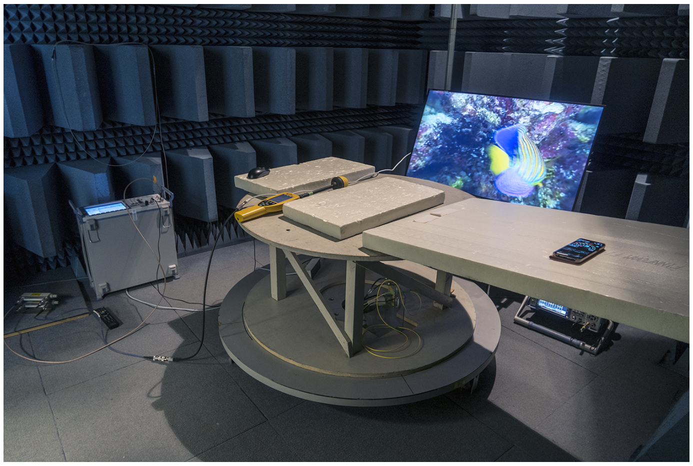


Fig. 5. The interference measurement setup inside the anechoic chamber. The interfering LTE UE is in the forefront. The DVB-T2 signal is generated with the R & S SFU on the left, the antenna cable under test is on the table and the Sony Bravia DTT receiver set on the right side of the table. Narda NBM-550 was used to measure the electromagnetic field strength. The LTE base station was outside the anechoic chamber.

The Erroneous Second Ratio 5 (ESR_5) [13] quality criterion was used to determine when the DTT reception is interfered. The ESR_5 quality criterion is fulfilled if the ratio of seconds with packet uncorrectable errors to all seconds in a 20 second interval does not exceed 5% (1 s), as the index in the name states. The measured distances present the longest distance between the antenna coaxial cable and the LTE UE where the DTT reception is still interfered. Narda field strength meter NBM-550 with 100 kHz to 3 GHz probe EF 0391 shown in

Figure 6 was used to monitor and measure the field strength on top of the measured antenna coaxial cable. If interference events did not occur, the LTE UE was put right next to the cable and the field strength measured on top of the cable.

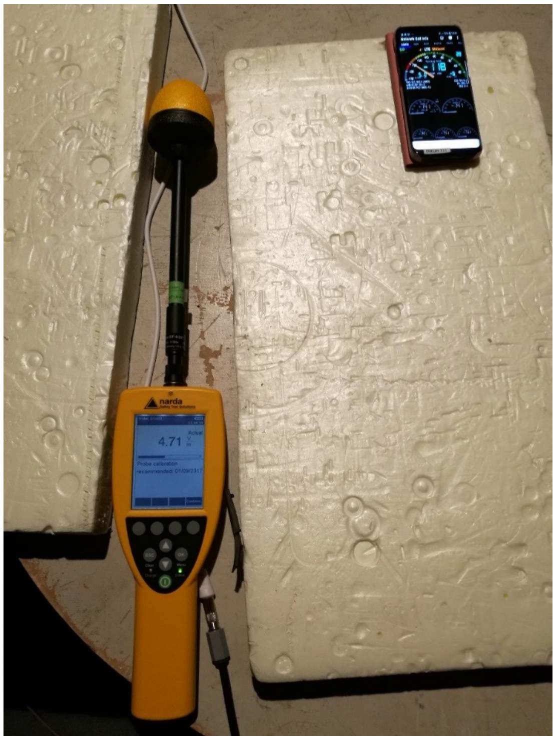


Fig. 6. Narda field strength meter NBM-550 with 100 kHz to 3 GHz probe EF 0391 measuring the field strength on the cable.

TABLE II
INTERFERENCE MEASUREMENT RESULTS

	1 MHz GB (702-703 MHz)		**9 MHz GB (694-703 MHz)**	
Cable	**Field Str (Cable/V/m)**	**Dist. (cm)**	**Field Str (Cable/V/m)**	**Dist. (cm)**
1	0.3	217	0.6	72
2	0.4	238	0.4	110
3	5.6	No errors	5.6	No errors
4	4.6	No errors	5.5	No errors
5	5.5	No errors	5.2	No errors
6	0.4	232	0.6	69
7	0.3	225	0.8	54
8	6.1	No errors	7.1	No errors
9	5.8	60	5.5	No errors
10	0.4	220	1.1	28

Out of curiosity, measurements where the guard band was only 1 MHz were also conducted even though this scenario is not possible in real life. As the used LTE base station can not be operated on the 600 MHz band, the DTT transmission was moved to channel 49 (694-702 MHz) to obtain the 1 MHz guard band with regard to the LTE UE uplink traffic on 703-713 MHz band. The most difficult possible interference scenario in Finland is when the highest possible DTT channel 48 (686 - 694 MHz) and the lowest possible LTE UE uplink channel (703-713 MHz) are used. The guard band between the transmissions is 9 MHz in this scenario. Table II shows the measurement results from i) the case with 1 MHz guard band, DTT on channel 49 (694-702 MHz) and LTE UE uplink on 703-713 MHz and ii) the worst possible real-life scenario with 9 MHz guard band, where DTT is transmitted on channel 48 (686 - 694 MHz) and LTE UE uplink on 703-713 MHz band. This scenario is already possible in Finland as the LTE services in the band are already active and the highest UHF channel is in use for DTV broadcasting.

The measurement results show that with the 1 MHz guard band cables 1, 2, 6, 7, and 10 could be interfered from distances of over two metres with a field strength of approximately 0.3-0.4 V/m. The longest distance where interference was noticed was 238 cm with cable number 2. This correlates perfectly with the cable shielding measurements in Section II, where the shielding of cable 2 had the worst performance in the 700 MHz band. Cable 9 performed better than the worst 5 cables and could only be interfered from a distance of 60 cm with a field strength of 5.8 V/m. Cables 3, 4, 5, and 8 could not be interfered in this scenario even when the LTE UE was in contact with the antenna coaxial cable.

With the real-life 9 MHz guard band only cables 1, 2, 6, 7, and 10 could be interfered. Cable number 2 had again the worst performance against interference and could be interfered from a distance of 110 cm with a field strength of 0.4 V/m. Cables 1, 6, 7, and 10 required distances of 28 to 72 cm and field strength of 0.6 to 1.1 V/m for the interference events to occur. Such interference distances could occur in real life, but are not very likely. Thus the measurement results indicate that the use of a 9 MHz guard band between DTT and LTE uplink transmissions seems to be well justified.

Figure 7 shows a spectrum analyzer view from R&S ETL spectrum analyzer during an interference event when cable 10 was measured with DTT transmission on channel 48 and LTE UE uplink transmission in 703-713 MHz band. The LTE UE is located 28 cm from the cable and the field strength on the cable is 1.1 V/m. The LTE UE uplink signal out-of-band skirts extends to the DTV channel when the LTE UE is near the cable and the field strength is in order of 5 V/m. The DTT receiver protection ratio defines how much interference from an adjacent channel the receiver can tolerate [9] and the antenna coaxial cable shielding effectiveness how much of the LTE UE signal power interferes the DTT reception.

Interference events in realistic usage scenarios become very unlikely when the frequency separation is larger than 9 MHz. Thus the measurement results in Table II do not cover the measurements with LTE UE uplink in higher frequency bands. LTE UE uplink transmissions at 713-723 MHz band (19 MHz frequency separation between the DTT transmission and the LTE UE uplink transmission) were also measured. Interference occurred only with cables 1, 2, 6, and 7 when the UE was located 5 to 20 cm from the antenna coaxial cable. Such usage scenarios are not very realistic, and thus 723-733 MHz LTE UE uplink was not measured as the even larger frequency separation means that realistic interference events do not occur anymore.

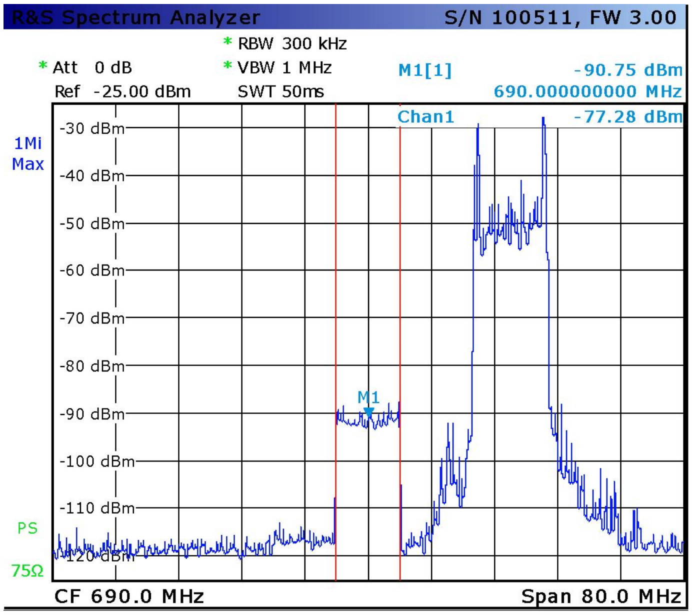


Fig. 7. Spectrum analyzer view from a scenario where DTT transmission on channel 48 (686-964 MHz) is interfered by an LTE UE transmission on 703-713 MHz.

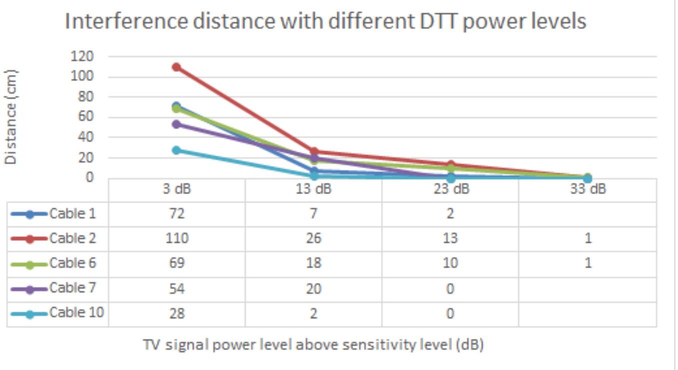
The measurement results in Table II were obtained when the DTT signal level was 3 dB above the TV receiver sensitivity level. A further study was made with the 5 cables that could be interfered in the 9 MHz guard band scenario to determine if they could be interfered when the DTT signal level is higher. Figure 8 shows the measurement results. Additional measurements were made with the signal levels 13, 23, and 33 dB above the TV sensitivity level.

With the DTT signal level 13 dB above the sensitivity level, the interference distances decreased to between 2 cm and 26 cm, which are already unrealistic usage scenarios. When the DTT signal level was 23 dB above the sensitivity level, the distances further decreased to 0-13 cm. A zero value means that interference occurs when the LTE UE is in contact with the antenna coaxial cable. With the DTT signal level 33 dB above the sensitivity level, interference occurred only with cables 2 and 6 from a distance of 1 cm. Thus, a conclusion can be made that interference events in realistic usage scenarios occur only if the DTT signal level is only a few dBs above the TV receiver sensitivity level.

IV. CONCLUSIONS

Based on the measurements conducted in this paper, commercially available coaxial TV antenna cables on the market have very significant variations in their shielding attenuation characteristics. The variations between the best and the worst cables are in the order of 60 dB. The correlation between shielding attenuation measurement values and measured interference distances is perfect.

The DTT receivers are most prone to interference from a channel adjacent to the DTT transmission and tolerate much higher amounts of interference from channels with larger frequency separation. The measurements in this paper demonstrated that if the channel adjacent to the lowest LTE uplink frequency band 703-713 MHz would not have been assigned as a guard band, the DTT receivers could have been very prone to adjacent channel interference. The interference distances with the low-quality antenna coaxial cables were in the order of 2 m. The existence of the guard band is thus well justified. Even though the best 4 cables could not be interfered with the LTE UE uplink traffic, the LTE UE could well cause interference towards other parts of the DTT reception system.



	3 dB	13 dB	23 dB	33 dB
Cable 1	72	7	2	
Cable 2	110	26	13	1
Cable 6	69	18	10	1
Cable 7	54	20	0	
Cable 10	28	2	0	

Fig. 8. Interference distances in cm with different DTT power levels. DTT is on channel 48 (686-694 MHz) and LTE UE uplink transmission on 703-713 MHz band.

Measured interference distances with the 5 worst measured cables were around 1 m in the worst case real-life scenario where the highest DTT transmission channel 48 was used with signal level 3 dB above the receiver sensitivity level and LTE UE uplink transmission was in the lowest possible frequency band 703-713 MHz. The interference distances were in the order of 5 to 20 cm when the LTE UE uplink traffic was transmitted on the 713-723 MHz band. Scenarios where the LTE UE is located right next to the cable are not very realistic usage scenarios. Thus, a conclusion can be made that interference events from LTE UE uplink transmissions to the antenna coaxial cable are not likely to occur unless a low-quality cable is used, the DTT transmission uses the highest possible channel, the LTE uplink traffic the lowest possible channel and the received DTT signal level is low.

As the interference measurements in this paper have been conducted with only one DTT receiver, these results can not be generalized to cover different DTT receivers. According to earlier measurements and studies on the protection ratio characteristics of DTVs and set top boxes, they can have even 30 dB differences in performance due to the receiver RF front-end quality and the type of tuner used [9], [14]. The Sony TV set used in the measurements performs well in terms of protection ratio against interference, and thus lower quality TVs could be interfered from much longer distances.

An observation was also made that the LTE UE interferes the DTT transmission more easily when the UE was held in the hands of a user. This scenario was not measured as it is difficult to reproduce.

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