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A Novel Technique To Reduce Interference In Broadcast Bands From Mobile Bands

N.SAI SRAVAN[1], Dr.B.CHANDRA MOHAN[2], N.V.RAMANA[3]

M.Tech Student, Department of ECE, Bapatla Engineering College, Bapatla, Andhra Pradesh, India[1]

Professor, Department of ECE, Bapatla Engineering College, Bapatla, Andhra Pradesh, India[2]

Director/Engineer, Prasar Bharati, Doordarshan Kendra, Ramantapur, Hyderabad, India[3]

Abstract: The ever increasing demand for multimedia wireless communication systems is a key feature of more advanced markets. The buzzword of personal communications, meant to provide “access to anyone, anywhere, at any time” to the wanted service, implies that spectrum demands are dramatically increasing in most developed markets. To cope with these needs, and in order to exploit the released spectrum resulting from the Digital Switchover, the last World Radio communication Conference (WRC-07) allocated on a co-primary basis the upper part of the UHF band to mobile services as from 2015. This will cause potentially harmful mutual interference between TV and mobile radio services that needs to be carefully analyzed. . In my paper, it is being suggested a novel based technique as an in-line filter to enhance protection level to DTT services.

Index Terms: Co-channel interference, Digital Dividend, UHF band, DVB-T, LTE

I. INTRODUCTION

The world of mobile telecommunications, in the last 20 years, has been characterized by a surprising technological evolution that has never slowed down. Mobile phones are now at the gates of the fourth generation and this will lead to innovative technological developments as well as large economical investments. The fourth-generation mobile systems, whose starting point is the 3GPP Long Term Evolution (LTE), and the technological evolution of mobile WiMAX (802.16e), 802.16m, will guarantee higher data speed as well as high quality new multimedia services and will ensure convergence towards all-IP networks. As a result of the spectrum reframing process, the most likely designated frequency bands where the new services could operate are the ones at present used by UMTS and GSM, as well as new bands at 2.6 GHz.

However, the best option to open up these services would be, definitely, the digital dividend portion of the UHF spectrum (from 790 MHz to 862 MHz), resulting from the digital switchover (DSO) process from analogue to digital television (DTV) whose conclusion is expected by the end of 2012. For both mobile operators and customers the benefits of carrying out this choice will be numerous including larger coverage areas and best penetration into buildings. All of this, of course, operating at the same radiated power.

During the last World Radio Conference (WRC-2007) was indicated to allocate the 790-862 MHz frequency band to mobile services in several world regions. Such position was supported also by main international radio communication organizations (CEPT, FCC, etc.). However, in order to make these systems fully interoperable with the existing ones, the problem of coexistence between DVB-T channels, operating in the lower part of the UHF band (470-790 MHz) and signals of future mobile communication systems, operating in the above mentioned band, must be carefully analysed and evaluated and the results of these studies should be taken into account in the implementation of the new broadband mobile networks.

The present work intends to investigate the interference issues above mentioned, especially considering the effects of signals emitted by new generation mobile stations (LTE, WiMax) on existing DVB-T systems, whose quality of service should still be guaranteed [1].

To carry out this analysis a specific parameter, which relates the quality of interfered audio-video signal to the power level of the interfering signal, will be considered: the Protection Ratio (PR). PR is a largely used parameter in this context [2], and is defined as the minimum value of the signal-to-interference ratio at the receiver input required to guarantee a specified quality reception level under specified conditions. Usually, PR is function of the frequency offset between the wanted and the interfering signals, over a specified frequency range. In this work, PR is referred to as “PR curve” and shows the ability of a receiver to discriminate interfering signals operating on frequencies differing from that used by the wanted signal.

In this paper an analysis of the co-existence of primary services is presented, focusing on the study of mutual interference between DVB-T broadcasting and 3GPP Long Term Evolution (LTE) mobile systems. A brief description of the UHF band regulatory aspects,an analytical method to estimate the PR.Characteristics of wanted and interfering signal parameters adopted in a simulation tool developed to calculate PR behavior. A novel based technique as an in-line filter to enhance protection level to DTT services.

II. UHF BAND REGULATORY ASPECTS

As previously mentioned, by the year 2012 is expected to end the transition process from analog to digital television

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system, but until that time the two signals will coexist in the same frequency bands: VHF band III (174-230 MHz) and UHF bands IV and V (470-862 MHz). In particular, in the UHF band channel carriers are separated by 8MHz. The switch off process will make possible to release the last portion of the UHF band V that ranging from 790 to 862 MHz (or from channel 61 to channel 69).

CEPT, starting from the results of WRC-2007, stated that in the 790-862 MHz band could be implemented networks for mobile telecommunication systems in both TDD or FDD duplexing technique [3]. In case of TDD implementation (or mixed TDD/FDD) has been set a guard band of 7 MHz, between the UHF channel 60 (782-790 MHz) and the 13 blocks of 5 MHz channels (see Fig.1), where radio mobile signals will be transmitted.

This channelization meets the requirements of country authorities having problems of spectral harmonization with neighboring countries or that have already allocated part of the UHF band V to other services.

790-797	797-802	802-807	807-812	812-817	817-822	822-827	827-832	832 – 837	837 – 842	842 – 847	847-852	852-857	857-862
Guard band													
7 MHz	65 MHz (13 blocks of 5 MHz)												

Fig. 1: CEPT Channelization proposal in case of TDD duplexing technique implementation.

In case of using the FDD technique, two 30 MHz bands have been established: one for downlink and one for uplink communications, separated by a duplex gap of 11 MHz (see Fig. 2). Each of these bands is splitted into 6 blocks of 5 MHz. The downlink frequency band starts at 791 MHz, while the corresponding uplink frequency band starts at 832 MHz, with a resultant guard band of 41 MHz. The reason of this choice is to protect the DVB-T broadcast signal transmitted on 60 UHF channel from interference produced by the uplink transmission of mobile ECN (Electronic Communication Networks) terminals, which represents a critical aspect for DVB-T receiving systems. From this point of view, the adoption of the above mentioned frequency allocation, determines a 41 MHz virtual guard band. In addition, the remaining 11 MHz duplex gap could be exploited by other unspecified services.

791-796	796-801	801-806	806-811	811-816	816-821	821 - 832	832-837	837-842	842-847	847-852	852-857	857-862
Downlink						Duplex gap	Uplink					
30 MHz (6 blocks of 5 MHz)						11 MHz	30 MHz (6 blocks of 5 MHz)					

Fig. 2: CEPT Channelization proposal in case of FDD duplexing technique implementation

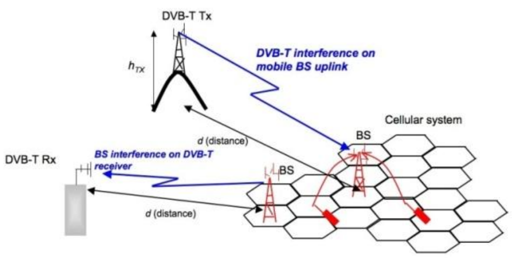

Fig. 3. InterferenceSimulation scenario

III. CELLULAR LAYOUT AND SYSTEM PARAMETERS

The main parameters are shown in Table I.

Table I.
MAIN SIMULATION PARAMETERS

Cell radius	2 Km
Simulation area	900 Km^2 (30x30 Km)
Operating frequency	800 MHz
Total number of base stations (BSs)	99
Number of BSs in central area	42
Cluster size	3
BS antenna height	30 m
BS Rx antenna gain	15dB
BS transmitted power	43 dBm
Number of User Equipments (UEs) generated for each Monte Carlo simulation	200
UE antenna height	1.5 m
UE Tx antenna gain	0 dB
UE transmitted power	23 dBm

We assumed a channel bandwidth of 5 MHz for LTE, as for this bandwidth the whole BS transmitted power is in the inband transfer function of the victim DVB-T receiver. Therefore, in case study 1, as the power spectrum of a DVB-T signal is approximately flat in its 8 MHz channel, the interference generated on the 5 MHz LTE channel can be assimilated to AWGN.

The adopted cellular layout is shown in Fig. 2. It comprises 99 base stations, but the statistics are collected only in the innermost 42 of them (enclosed in the smaller square in the figure), to avoid border effects.

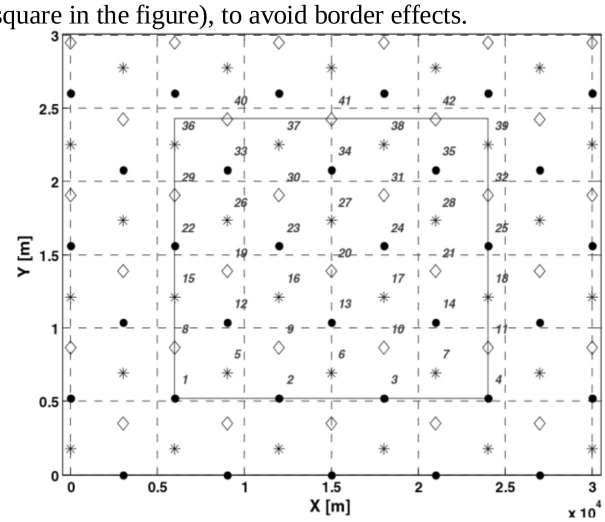

Fig. 4.Cellular layout (different markers are used for different frequencies)

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For the mobile radio signal assuming urban environment, while for the DVB-T interferer we used ITU-R P.1546 [6].

Table II.
THROUGHPUT AS A FUNCTION OF UPLINK SNR FOR LTE(5 MHZ CHANNEL)

Modulation	Code rate	SNR [dB]	Rate [bit/s/Hz]
QPSK	1/2	1	1.0000
	2/3	2.9	1.3200
16-QAM	1/2	6.6	2.0000
	2/3	10	2.6200
64-QAM	2/3	13.8	4.0000
	3/4	15.7	4.4700

We simulated the Link Adaptation behavior of LTE mobile system as a function of the SINR, which for the purpose of this work is assumed equivalent to Signal-to Noise-Ratio (SNR), owing to the assumption that the interferer behaves like an AWGN source. Among the different modulations admitted for LTE systems we have selected those in Table II as representative case. The corresponding throughput values as function of SNR thresholds are taken from [7] and are expressed in bits/s/Hz.

IV. DVB-T SYSTEM PARAMETERS

The main parameters are shown in Table III.

Table III.
MAIN SIMULATION PARAMETERS

Television Tower	
ERP	50 dBm or 70 dBm
Antenna height	100 m or 200 m
Antenna pattern	Omnidirectional in azimuth
Operating frequency	800 MHz
TV receiver	
Antenna gain	14.15 dBi
Antenna height	10 m
Antenna pattern	Mask taken from [8]
Receiver minimum SNR	21 dB
Noise figure	7 dB
Noise equivalent bandwidth	8 MHz
Number of TV receivers generated for each Monte Carlo simulation	200

Different DVB-T transmitter configurations have been considered in the simulations by varying the Effective Radiated Power (ERP) and the antenna height. The cell radius varies with the configuration and it is determined according to the Reference Planning Configurations (RPCs) defined inGE06 [9], assuming:

- Location Probability (LP): 95%
- Emed: 58.2 dBμV/m (see Annex 3.4 in [9])

Note that in order to obtain a 95% LP at the cell edge, a 9.05 dB must be added to the receiver minimum required SNR.In each simulation run the TV receiver positions have been randomly generated within the DVB-T coverage area.

V. RECEIVER PROTECTION RATIOS AND OVERLOAD THRESHOLDS

Protection ratio is the ratio of wanted/unwanted signal power before reception is affected by the interference – usually this is measured by fixing the wanted signal level and increasing the interference level until picture artefacts start to appear. At low wanted signal levels, this ratio is fixed, so for every dB increase in interference, the wanted signal level also has to be increased by the same amount. Here the receiver is showing ideal linear behavior. Typically the interferer is several 10s of dB higher than the wanted signal level in these conditions. But in locations where the wanted signal is much stronger, there will be a certain interference level beyond which the receiver cannot maintain this linear behavior due to non-linearity's caused by receiver overload as shown in Figure 2.

Tests have shown that some receivers do not behave in this ideal way, particularly when the LTE signal is time varying – such as when it is only carrying a small amount of user data. Some examples of different tuner C/I characteristics along with recommended ways to measure the protection ratio and overload threshold are given in reference 6.

Adding an external filter will attenuate the interference signal level thus helping to prevent receiver overload occurring.

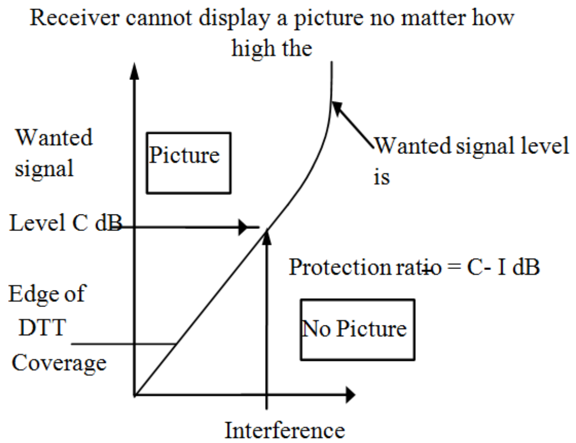

Figure 5 - Protection ratio and overload threshold of an ideal DTT receiver

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Calculation method adopted to estimate the Protection Ratio:

In this section is given a brief description of the approach adopted to calculate the Protection Ratio of the DVB-T signal in presence of an interfering radio mobile signal (BS and UE) that is based on the results reported on the ITU-R SM.337-5 recommendation [4].

The PR sets the margin between the power of the interfering signal (*Pr*) and the powerof the desired DVB-T signal (*Pd*), in order to determine the specific level of interfering signal that does not affect the quality of the DVB-T signal (see fig. 6). For a fixed value of power level *Pd*, it is possible to calculate the maximum interfering power *Pi* that does not cause critical interference on the DVB-T signal.

The interfering power is calculated by the Formula:

$$Pi= Pt+ Gr- Lp- OCR\ (\Delta f) =Pr+ Gr- OCR\ (\Delta f) \quad (1)$$

Where *Pt* is the e.i.r.p. (dBW) of the interfering transmitter, *Gr* is the receiver antenna gain (dBi), *Lp* is the path loss attenuation and *OCR* (Δf) is the off-channel-rejection factor (Measured in dB) that is given by:

$$OCR\ (\Delta f)=-10Log\frac{\int_{-\infty}^{\infty} P(f)|H(f+\Delta f)|^2}{\int_{-\infty}^{\infty} P(f)df} \quad (2)$$

In this expression, *P* (*f*) is the power density spectrum of the interfering signal, *H* (*f*) is the frequency response of the DVB-T receiver in RF band and Δf is the difference between the carrier frequencies of the interfering and the desired signals. As evidentiated in fig.6, the interfering power *Pi* results from the portion of the mobile signal spectral power causing interference on the DVB-T signal. It represents the co channel or adjacent channel interference depending whether the frequency offset Δf is null or equal to one (or more) channel spacing. Since the interfering power, according to the expression (1), is function of Δf and that the value of protection ratio, as above mentioned, depends on *Pi*, it can be concluded that exists the following relationship:

$$PR=\alpha\ (Pd, \Delta f)$$

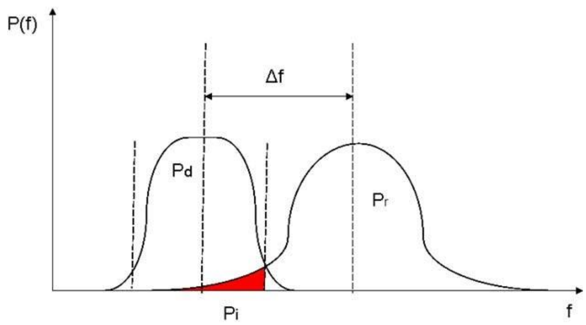

Fig. 6: Wanted/interfering signal modeling

The function $\alpha(Pd, \Delta f)$, could be empirically evaluated through a laboratory test, as illustrated in Figure 7, where an useful DVB-T signal and an interfering radio mobile signal

(E.g. LTE) opportunely attenuated, are generated, combined and finally sent to the DVB-T receiver.

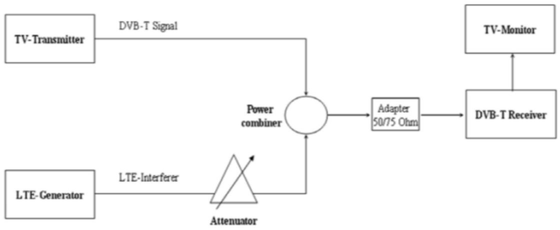

Fig. 7: Empirical process for the Protection Ratio evaluation

For a fixed power level of the desired DVB-T signal (P_d), an increasing power level of the interfering signal, generated with a frequency offset Δf from the DVB-T one, is added, until a degradation of the video signal quality becomes visible. The resulting power level of the interfering signal is noted and used to determine the protection ratio with reference to the power level P_d of DVB-T signal and the frequency offset Δf of the interfering signal.

A DVB-T receiver is characterized by several parameters including receiver sensitivity(S_x) and the minimum *C/N* ratio (CNR_{min}) required for a good quality reception of the DVBT signal. Table 1 provides a list of values for CNR_{min} extracted from the ETSI EN 300 744 V 1.6.1 recommendation [5].

Once the values of P_d and CNR_{min} are fixed, the maximum allowable interfering power P_i*, in the DVB-T signal bandwidth, can be defined by the below expression (4).

$$\frac{Pd}{(N+Pi)} \geq CNRmin \equiv \frac{Sx}{N} \quad (3)$$

$$Pi < N\left(\frac{Pd}{Sx-1}\right) \equiv \frac{(Pd-Sx)}{CNRmin} \equiv Pi^* \quad (4)$$

Considering an interfering signal at the front-end of the DVB-T receiver, characterized by a power *Pr* and a frequency offset $\Delta f1$, it will cause an interfering power *Pi* on the DVB-T signal bandwidth. In order to not have a clear degradation of TV signal quality, theexpression $Pi \leq Pi^*$ should be fulfilled.

		Required C/N (dB) for BER = 2×10^{-4} after Viterbi QEF after Reed-Solomon (see note 2)			Bitrate (Mbit/s) (see note 3)			
Constel-lation	Code rate	Gaussian Channel (AWGN)	Ricean channel (F_1)	Rayleigh channel (P_1)	Δ/T_U = 1/4	Δ/T_U = 1/8	Δ/T_U = 1/16	Δ/T_U = 1/32
QPSK	1/2	3,5	4,1	5,9	4,98	5,53	5,85	6,03
QPSK	2/3	5,3	6,1	9,6	6,64	7,37	7,81	8,04
QPSK	3/4	6,3	7,2	12,4	7,46	8,29	8,78	9,05
QPSK	5/6	7,3	8,5	15,6	8,29	9,22	9,76	10,05
QPSK	7/8	7,9	9,2	17,5	8,71	9,68	10,25	10,56
16-QAM	1/2	9,3	9,8	11,8	9,95	11,06	11,71	12,06
16-QAM	2/3	11,4	12,1	15,3	13,27	14,75	15,61	16,09
16-QAM	3/4	12,6	13,4	18,1	14,93	16,59	17,56	18,10
16-QAM	5/6	13,8	14,8	21,3	16,59	18,43	19,52	20,11
16-QAM	7/8	14,4	15,7	23,6	17,42	19,35	20,49	21,11
64-QAM	1/2	13,8	14,3	16,4	14,93	16,59	17,56	18,10
64-QAM	2/3	16,7	17,3	20,3	19,91	22,12	23,42	24,13
64-QAM	3/4	18,2	18,9	23,0	22,39	24,88	26,35	27,14
64-QAM	5/6	19,4	20,4	26,2	24,88	27,65	29,27	30,16
64-QAM	7/8	20,2	21,3	28,6	26,13	29,03	30,74	31,67

NOTE 1: Figures in italics are approximate values.
NOTE 2: Quasi Error Free (QEF) means less than one uncorrected error event per hour, corresponding to BER = 10^{-11} at the input of the MPEG-2 demultiplexer.
NOTE 3: Net bit rates are given after the Reed-Solomon decoder.

Table 1V: CNR_{min} for a DVB-T system

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Gradually increasing *Pr*, also *Pi* will raise, up to the value for which the expression (4)is not anymore satisfied and $Pi > Pi^*$. Suppose Pr^* is the value of *Pr* matching this condition. Consequently, the resulting protection ratio will be given by $\infty(\Delta f1) = Pd - Pr^*$.Repeating this procedure for increasing (and decreasing) values of the offset Δf, it is possible to figure out an interpolated version of the protection ratio α function.

VI. BOOSTER AMPLIFIERS

DTT receiver adjacent channel selectivity protection ratio and over loading vary as function of frequency offset relative to the DTT wanted signal channel/frequency. The general trend is that the protection ratio and overloading threshold increase with the increase of frequency offsets, and they can be very different for different DTT receivers (tuner type, manufacturer design, etc).

In many real DTT reception installations, DTT signal booster amplifiers are used by DTT users to amplify the DTT wanted signal. Most of the DTT booster power amplifiers installed in the field are the existing ones used for analog TV installed outside on the DTT reception antenna mast or inside the house before the DTT signal splitter box. These DTT power amplifiers were initially designed for covering the whole UHF frequency band from 470-862 MHz, including the sub-band (790-862 MHz) newly allocated to mobile services. When an adjacent channel LTE interference signal is input to a DTT booster power amplifier, due to its non linear behavior, the power amplification gain as function of frequency offset can be very different compared to the case without an adjacent channel interfering signal - the out of band amplification gain curve is raised following some inter modulation laws.

This nonlinear behavior of the DTT booster power amplifier will create DTT receiver overloading, not only to the immediate adjacent channels, but also to the far away DTT adjacent channels. The mitigation solution is to install an external filter before the DTT power amplifier to attenuate the LTE interference signal level.

VII. EFFECTS OF INTERMODULATION

Every time a multitude of signals multiplexed in the frequency domain is processed by a non-linear device, such as a wide-band distribution amplifier, inter modulation products are present at the output of that device, due to beats among the input frequencies. Distributions amplifiers are carefully regulated during the installation phase, in order to minimize inter modulation in normal operational conditions. However, if later on new high level signals (e.g. LTE signals) are received in the same area, inter modulation products significantly increase. The I/O characteristics of a non-linear amplifier can be modelled as its series expansion truncated at the 3rd order, as follows:

$Vo = k1\ Vi + k2\ Vi2 + k3\ Vi3$

Where

- *Vi* is the input voltage,
- *Vo* is the output voltage,
- *k*1 is the amplifier gain,

*k*2, *k*3 are the 2nd and 3rd order coefficients of the series expansion, and can be calculated from the values of 2nd and 3rd order Inter modulation Distortion (IMD) of the amplifier.

3rd order inter modulation products fall at frequencies like $f_1 \pm f_2 \pm f_3$, where f_1, f_2 and f_3 are any of the carriers belonging to the input signals (DVB or LTE): therefore they are potentially affecting all TV channels in the UHF band.

VIII. ASSUMED RECEPTION SCENARIOS

Figure 8 shows some likely cases of interference entry in roof top and indoor portable reception conditions. Figure 9 shows some likely interference entry points in a communal antenna system. Table 1 outlines each case briefly and summarizes the extent of its coverage in this study.

Fixed rooftop and indoor portable

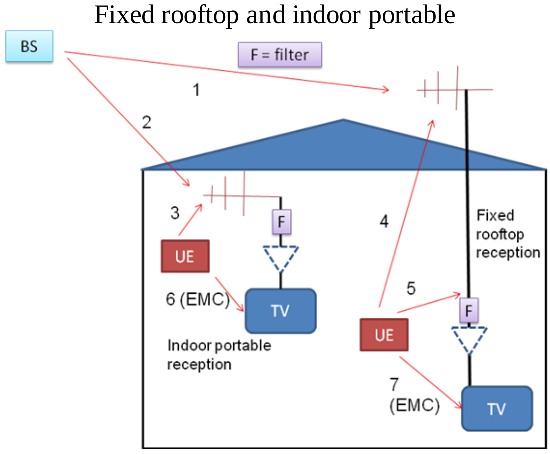

Fig.8: Possible interference entry points for rooftop and indoor portable reception showing location of the external filter

Communal antenna system (MATV)

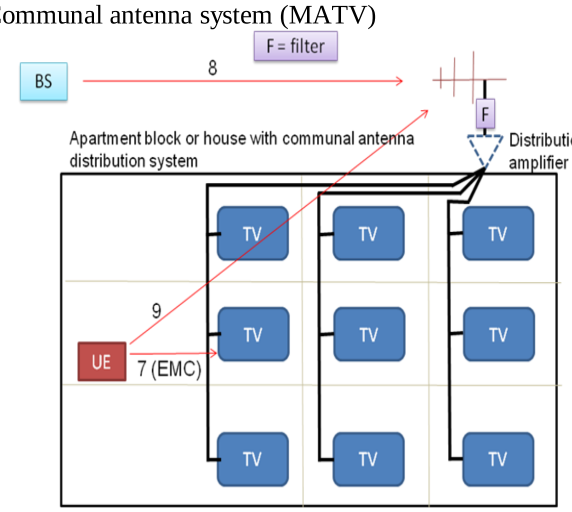

Fig.9: Possible interference entry points for communal antenna system showing location of the external filter

IX. EXTERNAL FILTERING AT RECEIVER END

Adding a low pass inline filter between the TV antenna and TV tuner input is currently the most effective solution

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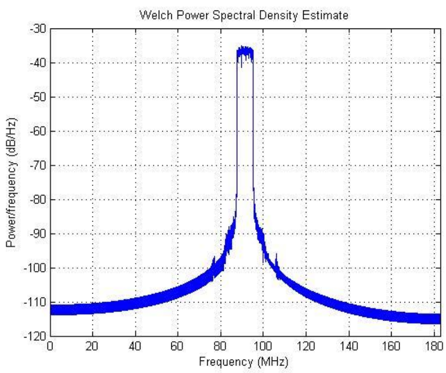
when the highest TV channel is below channel 59/60. Any such filter should be added before the first active component in the receiving chain, usually a broadband amplifier. However if the highest wanted TV channel is in the CH59/CH60 range, the limitations on the slope of the filter roll off when the cut-off is set to 790MHz (top edge of channel 60), means most filters cannot reach their stop band attenuation at a frequency below the lower edge of the LTE signal in block A. Reducing the filter cut-off frequency below 790MHz increases the amount of LTE interference rejection at the cost of increasing tilt and insertion loss across the wanted channels below 790MHz (ref. 8), which if operating at the edge of coverage, could result in loss of reception (ref. 14).

In case that an active indoor or outdoor antenna is used, there is no way for the user insert any kind of filter between the antenna itself and the low-noise amplifier. Such antennas may need to be replaced, in case that new models are on the market with filters integrated and/or being part of the Rf-design of the antenna.The maximum filter attenuation required also depends upon the BS out of band noise limits. If the out of band noise is very low, then the receiver is most affected by the adjacent channel interference power, so a good filter rejection can result in good rejection of the LTE interference. However if the BS out of band noise falling in band to the wanted TV signal is too high, this can dominate the total noise/interference seen by the receiver, and there is no advantage to having a filter with very high stop band attenuation. Roof top outdoor and indoor portable antennas can be designed to have a natural roll-off at 790MHz without the use of active circuitry, which helps to reduce the amount of interference reaching the input of booster amplifiers or TV tuners. However, this means that an existing antenna needs to be replaced.

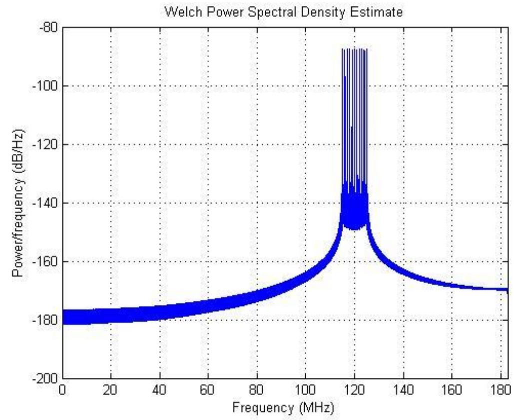
X. RESULTS

The first consideration that is made is that the OFDM spectrum is centered on f_c i.e., subcarrier 1 is 7.162 MHz to the left of the carrier and subcarrier 1,705 is 7.162 MHz to the right. The simplest method of achieving the centering is to use a 2N-IFFT and T/2 as the elementary period. As we can see in Table 1, the OFDM symbol duration T_U, is specified considering a 2,048- IFFT (N=2,048); therefore, we shall use a 54,096-IFFT.Same parameters are used for the LTE signal In my results my frequencies are in FM range For my convenience.

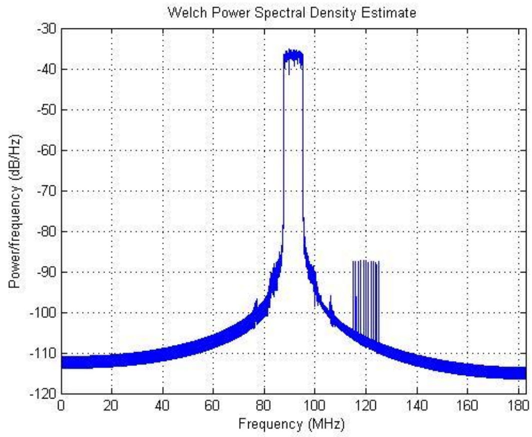
Generated DVB-T signal parameters are specified above



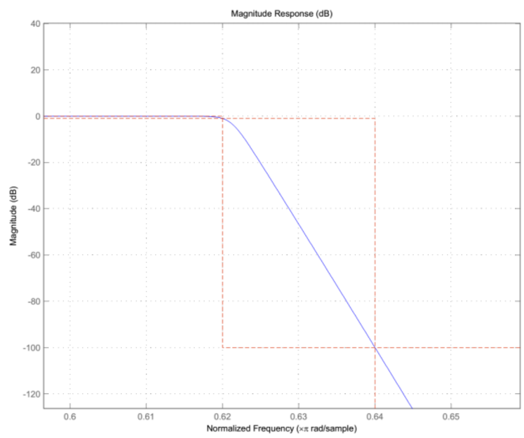
Interferance generated signal (LTE) for convenience



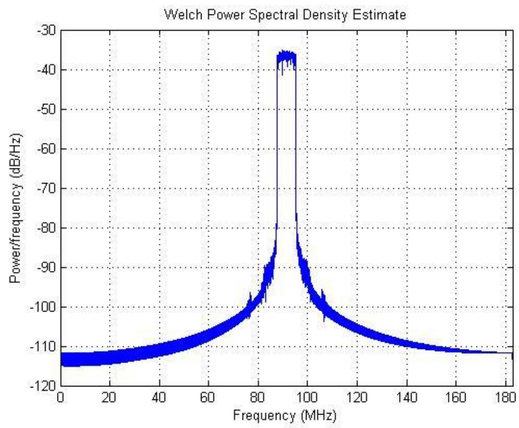
Interferance with DVB-T signal



Magnitude Response of Filter design



Filtered signal



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[7] "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios; (Release 8)," 3GPP TR 36.942 V8.1.0 (2008-12), Dec. 2008

[8] Rec. ITU-R BT.419-3, "Directivity and polarization discrimination of antennas in the reception of television broadcasting"

[9] ITU, "Final Acts of the Regional Radiocommunication Conference 2006 (RRC-06)," 2006