AN OVERVIEW OF TV WHITE SPACE FOR THE CABLE INDUSTRY

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Abstract

After years of study, public comment and testing, the FCC has adopted rules for unlicensed operation of TV Band Devices (TVBDs). The TV spectrum's desirable propagation properties and the promise of significant amounts of usable spectrum make this band attractive. TVBDs are expected to support a wide range of applications, from providing broadband wireless internet connectivity in rural areas to consumer-based whole house automation and networking solutions. This paper provides an overview of the TVBD rules and their impact, including some potential TVBD applications and key cable operator concerns.

INTRODUCTION

In the United States, 402 MHz of spectrum in the range of 54 MHz to 806 MHz has been allocated for TV broadcasting as shown in Figure 1. Coincident with the DTV transition, now scheduled for completion June 12, 2009, the uppermost 108 MHz of that spectrum, referred to as the 700 MHz band, will be vacated from all TV broadcasting and the spectrum has been reallocated for commercial and public safety systems. The auctions for this spectrum have brought almost $20B[1] to the government with one block still unsold. The remaining 294 MHz of this prime radio spectrum will remain for over-the-air (OTA) TV and other licensed operations. However, throughout the United States, portions of this 294 MHz resource remain unused.

After the DTV transition, all of the full power analog TV transmitters will go off the air, freeing up additional spectrum compared to today. This is often termed the "Digital Dividend" by regulators. The amount and exact frequencies of unused spectrum, i.e., unused channels not assigned to any TV broadcast stations, varies from location to location. These unused segments of spectrum are referred to as TV White Space (TVWS).

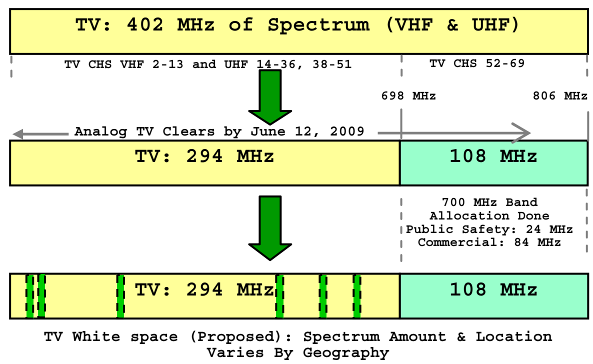

Figure 1. US TV Spectrum Before and After the DTV Transition

Since each market has different TV channel assignments, the potential "white space" in each market is different. For example, in Baltimore, Channel 25 is available for use as white space after the DTV transition while in neighboring Washington DC, it will not be available as a low power analog station, WZDC, will still be using that spectrum. Unlicensed TVBDs will be regulated under the FCC Part 15 rules and are allowed to operate at relatively low power levels.

Making this white space spectrum available is intended to address the need for more spectrum for Wireless Internet Service

Providers (WISPs), home WiFi-type wireless devices and other wireless services.

This white space spectrum should not be confused with the spectrum above 700 MHz that is going to become available after the digital TV transition. As noted, the spectrum above 700 MHz has been re-allocated to licensed commercial services and public safety services and will no longer be used for TV broadcasts. TV stations currently broadcasting in the 700 MHz band will move to lower parts of the TV band.

APPLICATIONS

Many potential TVWS applications have been identified. Wireless rural broadband service (Figure 2) is an application that has received significant attention and could potentially be a good fit in the TVWS bands since rural areas tend to have fewer TV stations, and thus have more spectrum available. In addition, these rural areas are less likely to have wired broadband options due to the low population densities.

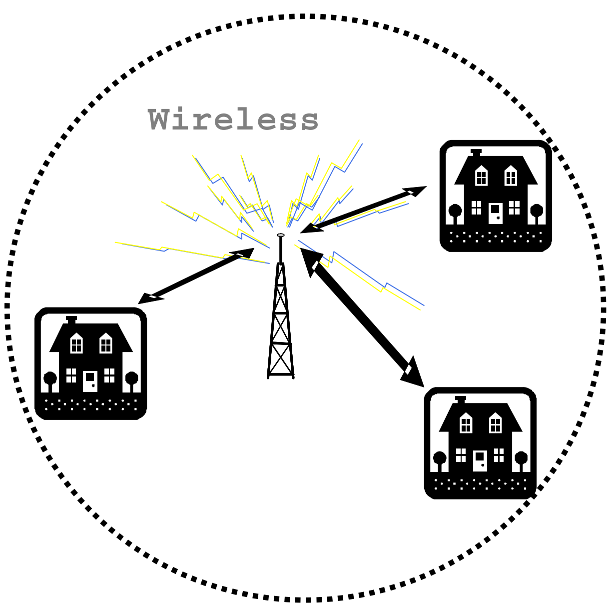

Figure 2. Wireless Consumer Broadband Service

Similarly, the favorable propagation characteristics of the TV spectrum compared to traditional WiFi spectrum potentially allow wireless Internet Service Providers (WISPs) to service rural communities with fewer transmission towers. Such wireless broadband is not limited to rural areas, however, and could also be offered in certain limited suburban areas as an alternative or supplement to other licensed mobile data services or unlicensed (WiFi) wireless data services.

TVBDs may also potentially be used for wireless home networking, both for home automation applications as well as high speed wireless HD video streaming. Thermostats, lights, and the alarm system could all be networked with TVBD technology in order to allow the homeowner seamless wireless integration which permits operation from anywhere in the home. TVBDs could further be incorporated into a smart power grid solution where home appliances communicate in real-time with the local utility company in order to more efficiently utilize both generation and distribution capacity by balancing the real-time price against the timing of when major appliances are operated in order to provide better efficiencies for the utility and lower power costs for the consumer. TVBD networking applications need not be mutually exclusive of other network technologies; a home automation application might connect through a wired broadband service permitting the homeowner to securely peer into the TVBD-enabled wireless camera at the front door. Smart grid applications would also most likely include a combination of networking technologies.

TVBDs may be used to provide the networking infrastructure for a whole home video entertainment network, and can also be used to augment existing WiFi data networks. Where there is sufficient white space available, multiple vacant TV channels can be used to concurrently and wirelessly stream multiple HD videos around the home from a digital video recorder in one room to multiple

TVs in other rooms. TVBDs could also be embedded in consumer camcorders and enable wireless streaming from an HD camcorder directly to the home entertainment system for easy wireless viewing or to a PC for wireless file transfer.

Another potential TVBD application area is data networking for enterprise and public safety applications. Such applications already use licensed spectrum and public safety will get additional spectrum in the 700 MHz spectrum, so these TVBD applications may allow supplemental services. A university or large business might use TVBDs to add high quality video conferencing between campus buildings without impacting existing LAN infrastructure.

FCC TVBD RULES OVERVIEW

In November, 2008, the FCC released the first draft of the Second Report and Order detailing Unlicensed Operation in the TV Broadcast Bands [2]. The order covers the initial operating rules for unlicensed TV Band Devices. The order provides for unlicensed operation of TVBDs using geo-location database as the primary method of incumbent protection mechanism, along with sensing as a secondary method of incumbent protection.

Geo-location database enabled TVBDs must determine their location to ≤ 50 m accuracy and access a geo-location database via the internet to determine open channels in that location. The geo-location database contains protection information for analog and digital OTA TV broadcast services, as well as for cable headend and TV translator receive sites, radiotelephone services, and certain (e.g., FCC Part 74) fixed wireless microphone deployments. Generally, broadcast TV stations are protected from any co-channel TVBD operations in their grade A and Grade B service areas to avoid harmful interference. A white space database coalition consisting of several major technology companies including Motorola and Google [3] has been recently formed to address the need for industry standard geo-location databases.

There are also provisions in the rules for sensing-only TVBDs, but such devices must go through an additional testing and certification process that is not yet fully defined. Therefore, one can expect that geo-location enabled TVBDs will be the first to reach the market, once third party database providers are established.

The FCC order allows for operation of two classes of unlicensed TVBDs: fixed and personal/portable devices. Fixed TVBDs may output up to 4 W EIRP, and operate on OTA channels 2, 5-36, and 38-51, while personal/portable TVBDs may output up to 100 mW EIRP, and operate on channels 21-36 and 38-51. Sensing-only TVBDs would be limited to 50 mW EIRP. Table 1 summarizes the operating restrictions for the different devices. There are two classes of personal portable TVBDs: Mode I client devices, and Mode II master devices. Mode II master portable TVBDs utilize geo-location databases to determine usable channels in their area, as do fixed TVBDs. Mode I client portable TVBDs must rely upon a master device (fixed or portable) to acquire a list of usable channels for a geographic area. Portable TVBDs are permitted to operate at locations inside of an adjacent (TV) channel service contour at a maximum power level of 40mW. Fixed devices are presently not allowed to operate on adjacent channels. Note that the FCC has left the record open regarding fixed TVBD operation on adjacent channels, and higher powered rural fixed TVBDs. The FCC prohibited TVBD use of Channels 3 and 4 because of the widespread use of home RF remodulator interconnects on these channels between set top boxes, VCRs, and TVs.

Specification	Personal/ Portable TVBDs	Fixed TVBD
Tx EIRP max	100 mW 40 mW adj ch	4 Watts
Tx TPO max	100 mW 40 mW adj ch	1 Watt
Geo-location	yes, from host or self	yes
Sensing	yes	yes
Prohibited channels	2-20, 37	3, 4, 37
TVBD database registration	no	yes
Tx ID	no	yes
Tx power control	yes	yes
FCC certification	yes	yes
Tx antenna height	n/a	≤ 30 m
Rx antenna height	n/a	≥ 10 m
Tx Spectral Mask	-55 dBr (measured in 100 kHz BW)	
Sensing threshold	-114 dBm with 0 dBi antenna (ATSC, NTSC and wireless microphones)	
Border restrictions	32 km from Canada 40 km from Mexico UHF 60 km from Mexico VHF	
Database check period	at power up and relocation	once per day

Table 1. Summary of FCC TVBD Rules

While, the database is the primary method of protecting OTA TV broadcasts, sensing must also be utilized by all TVBDs to detect the presence of incumbents. TVBDs sensing ATSC or NTSC signals above the -114 dBm threshold must report the detection to the equipment operator and give the operator the option to vacate the channel (i.e., TVBDs are not required to vacate a channel when sensing detects a TV signal if the database indicates that the channel is open). Wireless microphones must also be sensed and TVBDs must vacate the channel when a wireless microphone transmission is detected (regardless of the database). In general, TVBDs must sense a channel for a minimum of 30 seconds before using it, and sense at least every minute during use to determine the presence of incumbents. Cable system issues and protections are discussed in detail in the next section.

There are no FCC restrictions as to the types of modulation or bandwidth that TVBDs may utilize. Vendors are free to innovate in this area and some IEEE groups have expressed interest in developing standards for operation. The IEEE 802.22 group has been developing a standard for wide area networking (i.e., broadband wireless internet service) for well over two years.

POTENTIAL CABLE OPERATOR ISSUES

The deployment of TVBDs can impact cable systems in several ways. There are possible interference issues as well as possible business opportunities as cable operators may want to extend their wired networks to wirelessly support additional applications. The interference issues fall into two broad categories:

1) Interference to the reception of weak OTA TV signals at the headend , and,
2) Interference due to direct pickup (DPU) at the subscriber's residence.

Interference in the cable distribution plant between the headend and the subscriber taps of the cable system is not expected to be an issue. This is because the distribution portion operates at higher RF levels and employs well shielded hardware. Shielding weakness in this portion of the system would cause a cable operator to fail their Cumulative Leakage Index (CLI) requirements and require immediate remediation. The fiber portion of a Hybrid Fiber Coax (HFC) system is also immune to RF interference.

Cable Headend Protection

The newly adopted FCC TVBD rules afford protection for OTA cable headend receive sites. As noted previously, a TVBD device is not allowed to operate co-channel to a TV station within the TV station's Grade A and B service contour. This provides protection to cable headend receive sites and TV viewers alike. Cable headend receivers that operate outside of OTA TV protected service contours are afforded specific protection by the geo-location database, as requested of the FCC by both NCTA and Motorola [4][5]. A TVBD is allowed to operate beyond the grade B contour, but not within specified distances of a headend that is registered in the geo-location database as detailed in Table 2 and Figure 3. Note that both co-channel and adjacent channel operation is prohibited within the "keyhole zones" although the area of protection for adjacent channel is much smaller than that for co-channel as shown in Figure 3.

	Within Grade B Contour	**Beyond Grade B Contour**
Co-channel protection	TV station in data base	Headend in data base establishes "keyhole protection zone"
Adj channel protection	no protection	Headend in data base establishes "keyhole protection zone"

Table 2. Geo-location Protection Mechanisms for Headend ATSC Reception

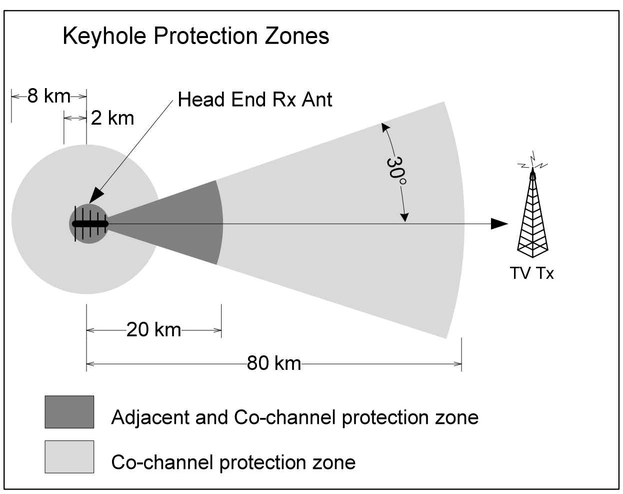

Figure 3. Distant Cable Headend Database Protection

Cable operators will need to register information about these cable headend receiver sites including their location and affected channel(s) with the TV white space database provider.

There is no specific protection given to cable headend receivers that operate inside of the grade B channel contours from adjacent channel TVBD interference. Recall that portable TVBDs are allowed to transmit up to 40 mW EIRP within the grade B contour on the adjacent channel of a TV station. Cable headend receivers as well as TV receivers could potentially be adversely affected by adjacent channel interference from TVBDs. Therefore, it is important that cable headend OTA receivers have excellent adjacent channel rejection, and that the OTA antennas be as high and directional as possible.

Direct Pickup (DPU) Interference at the Subscriber's Residence

As stated above, the newly adopted TVBD operating rules allow up to 100mW EIRP levels for personal/portable devices. It was shown during several FCC tests that direct pick-up (DPU) to cable systems can occur at levels well below 100 mW [6][7]. Both Motorola and the NCTA recommended limiting in-home devices to much lower power levels (i.e., 10 mW) to avoid the DPU interference issue [5][4]. However, the FCC chose to allow higher power levels in the TVWS ruling. Remediation of DPU interference will become more critical in cable systems when TVBDs are deployed.

DPU Analysis

Interference from TVBDs to the cable system headend is addressed by the geo-location database and sensing. These are the same mechanisms designed to protect OTA TV reception. However, interference can also occur at the other end of the cable system, at the subscriber's home as shown in Figure 4.

This is the result of co-channel ingress or leakage into the cable system. Ingress can enter the cable system anywhere there is a weakness in the system shield including poorly shielded or damaged coaxial cable, poor quality, loose or corroded F-connectors, open system ports on splitters and wall plates, and poor shielding in TVs, PC tuner cards, VCRs, set top boxes, cable modems, or multimedia terminal adapters (MTAs).

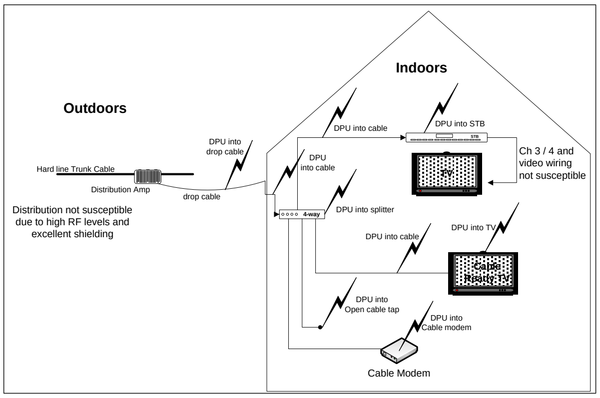

Figure 4. Home Cable System Ingress Points

The interference due to DPU from TVBDs is similar to DPU interference that cable operators have experienced in the past from over the air signals including those directly from TV stations, ham radio operators, land mobile police and fire radios etc. More recently, as some cable system operation has extended above 800 MHz, DPU interference from cell-phones has also occurred. After the digital TV transition, the 700 MHz to 800 MHz band will become occupied with high powered 4G wireless transmitters (e.g., 700 MHz base stations EIRP levels can exceed 1 kW) as well as additional mobile handsets (e.g., with typical 200 mW transmit power levels). The possibility of DPU interference due to these services will also need to be addressed through the same remediation techniques.

It is interesting to note, that after the digital transition, what was previously one of the most troublesome forms of cable system DPU, pickup from analog TV transmissions, will become less troublesome, as the full power analog TV transmitters go off the air. In the VHF range, the OTA and cable TV video carriers were often on the same channel and DPU caused severe beat interference and ghosting. After the transition when the off air analog signals are replaced with 8-VSB digital signals, the high energy video carriers will no longer be present and the visually severe DPU interference will be replaced by a lower level of snow-like DPU interference for on-channel analog cable services. Offsetting this, however, the wide-spread deployment of 700 MHz 4G mobile handsets as noted above, along with nearby lower powered TVBDs have the potential to significantly increase the instances of DPU becoming a problem. Sufficiently strong DPU can completely disrupt services on the affected channel, which may include multiple SD and HD video, high speed data, or telephony services. Some operators have chosen to stop using some cable channels in the 800 MHz band that were suffering from widespread severe DPU, caused by mobile handsets.

The fundamental interference protection mechanism used by TVBDs to protect OTA reception is the selection of an unused frequency or white space. Unused OTA frequencies, however, have little relationship to unused cable channels. There are very few, if any, white spaces on a cable plant, especially with the growing demands for more HD, on-demand and data services. This means that every TVBD has the potential to interfere with one or more services on the cable plant via DPU. The remaining interference, or DPU, protection mechanism is the "shielding effectiveness" (SE) of the cable system, which includes the entire residential cabling system including all the devices attached to it such as TVs, set tops, and modems. Once an interfering signal has entered the cable system, this undesired interferer travels throughout the home along with the desired cable signals. As such, a TVBD causing interference may be located at the opposite end of the home well removed from where the interference is observed.

The FCC has established the RF DPU standard for analog cable ready TV receivers in 47 CFR 15.118 as 0.1 V/m. The rules do not explicitly refer to digital cable ready digital TV's but we can assume the same requirement applies. The FCC acknowledged the widespread use of Channels 3 and 4 as the in-home interconnect frequency and has prohibited TVBDs from operating on those channels. Subscribers using a set-top box (STB) with a Ch3/4 connection from the STB to the TV will be protected from interference in this interconnect. Likewise systems using a baseband audio / video (e.g., composite, s-video, component, DVI, or HDMI) connection should not suffer from interference to this connection. However, for those subscribers not using a STB but instead using a cable ready TV connected directly to the cable, the TV itself may be susceptible to DPU as shown in tests conducted by the FCC [4].

Figure 5 shows the free space far field strength at various distances radiated by TVBDs operating at 40 mW, 100mW and 4 Watts. The dashed horizontal line at 0.1 V/m represents the minimum FCC specification 47 CFR 15.118 for cable ready TV set immunity. The lines cross at about 40, 60 and 400 feet respectively. Thus we can expect the possibility of DPU interference directly to a cable ready TV that just meets minimum FCC DPU specifications at these distances in free space.

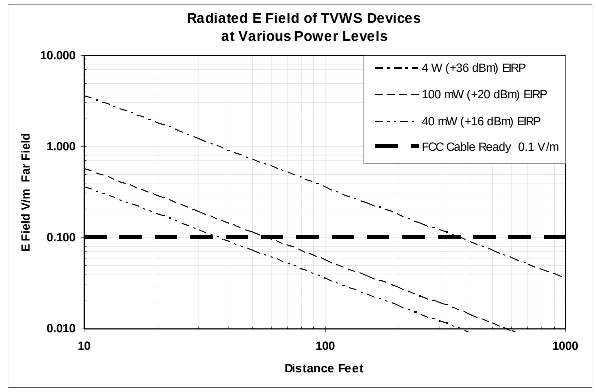

Figure 5. Susceptibility as a Function of Radiated Power and Distance

Even when a cable ready TV is not being used, the in-home cable wiring itself can be susceptible to DPU [5]. Motorola conducted tests on various home wiring components including a selection of retail purchased cables and splitters and found a wide range of shielding effectiveness. For the purposes of these tests, the shielding effectiveness (SE) of a sample of cable is the ratio between the external electric field measured in V/m and the induced voltage on a 75 Ω load connected to the cable. For example, if a cable exposed to 1V/m (60 dBmV/m) induces 0 dBmV into the load, the shielding effectiveness is 60 dB.

For comparison, the shielding effectiveness of an FCC 47 CFR 15.118 compliant TV set was calculated. FCC 47 CFR 15.118 specifies that with a desired signal level of 0 dBmV and a 0.1V/m interfering field, the DPU interference must be better than -45 dBc. Thus a 40 dBmV/m interference field must induce an equivalent interference signal below -45 dBmV. Therefore the minimum required shielding effectiveness is 85 dB.

The specified minimum tap level for 256 QAM is usually -12 dBmV. The C/I ratio for Threshold of Visibility (TOV) for 256 QAM is about -27 dBc. Therefore any interfering DPU signal above -39 dBmV will disrupt the QAM signal. Note that in the case of an analog signal, the DPU interference becomes visible above -45 dBmV but will not completely degrade the picture or sound. In the case of 256 QAM digital signals, interference above -39 dBmV will not just become visible but will completely destroy the picture and sound. This is due to the "cliff effect" of the digital video systems. This difference needs to be kept in mind when considering the ramifications of various levels of interference. Subscribers may be expected to tolerate some level of visible DPU interference to analog signals but cannot be expected to tolerate a total loss of picture and sound due to DPU interference to digital signals.

Motorola tested the shielding effectiveness (SE) of various coaxial cables and wiring components and provided this information to the FCC [5]. An example of the SE test data is shown in Figure 6.

The best cables had a SE measured around 130 dB which was the limit of the test equipment. The worst cables were in the range of 70 to 80 dB. The type of termination on the end of the cable was also found to have a large impact on SE, and hence DPU interference susceptibility.

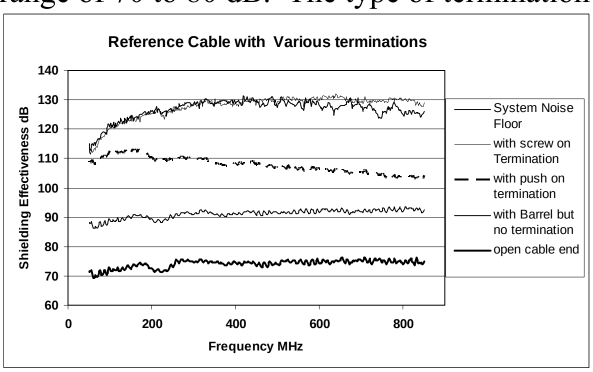

Figure 6. Shielding Effectiveness of Various Cables

Table 3 summarizes the mid-band 500 MHz value of shielding effectiveness we found for various samples of cables, terminations and splitters.

Sample	Typ SE at 500 MHz
Noise floor of test system	130 dB
High Quality Cable with barrel and termination	110 dB
High Quality Cable with barrel, NO termination	90 dB
High Quality Cable, open F connector	75 dB
Splitter with soldered back, all ports terminated	125 dB
Splitter with glued back, all ports terminated	80 dB
Splitter with soldered back, all ports open	95 dB
Retail cable, RG6 Quad Shield, Snap 'n Seal	130 dB
Retail cable, RG59, Molded connector assemblies	85 dB

Table 3. Shielding Effectiveness of Various Cables and Terminations

Figure 7 shows the effect of the common practice of leaving an unused cable end exposed (i.e., unterminated) which causes large degradation to the SE. This is likely to be typical of pre-wired homes in rooms without TVs or other devices connected to the cable system.

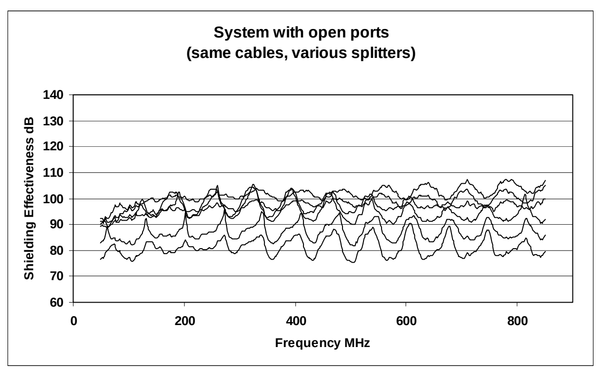

Figure 7. The Effects of Unterminated Ports (Open Wall Plates)

DPU Mitigation

There are several steps a cable operator can take to mitigate interference from TVBDs, the new 700 MHz services, and the existing 800 MHz mobile services. In the case of TVBD interference to the headend, the operator must register headends receiving OTA signals beyond the grade B contour in the TVBD geo-location database and keep these records accurate.

For all headends receiving OTA signals, the OTA antenna(s) should be highly directional, properly pointed, and mounted as high and as far as possible from likely locations for portable/handheld TVBDs. ATSC headend receivers should also have good adjacent channel rejection characteristics and quality low-loss cabling between the antennas and receivers.

A combination of remediation approaches may be needed to resolve DPU interference in subscriber homes. One of the most important techniques is to properly terminate open ports. Cable drops, splitters and terminations should all be of high quality and properly installed. TVBDs and cell phones should be located away from the cable system and TVs. Old or unused cabling/splitters in the home should be disconnected from the system. And in extreme cases, it may be necessary to disconnect poorly shielded cable ready TVs and install well shielded set top boxes in front of them. Cable operators may also want to work with local retailers to insure that cable components with high shielding effectiveness are readily available in retail outlets. And cable operators may want to prepare and distribute information to their subscribers explaining self-help remediation procedures.

There is another technical step the cable operator can consider. Increasing the signal levels on the in-home wiring directly reduces the effect of DPU interference. Signal levels delivered to the inputs of set top boxes and cable ready TVs should be set to levels that are well above minimum system and regulatory requirements. Every extra dB of signal level here provides another dB of DPU immunity. As analog signals are replaced with digital signals, the need to maintain very low levels of composite second-order (CSO) and composite triple beat (CTB) are reduced. Amplifiers can be used at the residential point-of-entry to increase the signal level on the in-home wiring without having to raise the signal levels throughout the entire distribution plant.

Figure 8 shows the E Field DPU susceptibility for 256 QAM against a range of cable shielding effectiveness for several levels of QAM operating level.

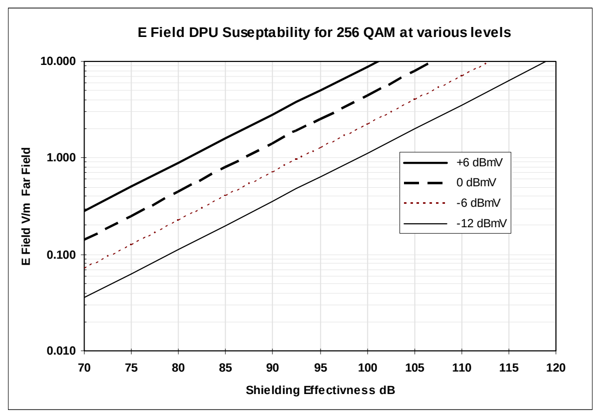

Figure 8. DPU Susceptibility as a Function of SE

For example, using a cable with 100 dB SE and a 256 QAM operating level of -12 dBmV yields a DPU susceptibility of 1 V/meter. We can use Figure 5 and Figure 8 together to examine the relationship between desired signal level, and system SE vs. TVBD power level and separation distance. Using the 1 V/meter level we obtained from Figure 8, and referring to Figure 5, we should not expect DPU problems from a 4 Watt TVBD at a distance of about 35 feet or greater free space. Note that any intervening walls or structures between the TVBD and the affected cable device would decrease the required separation distance.

CONCLUSION

TV White Space presents interesting opportunities to utilize the TV broadcast spectrum for a wide range of unlicensed applications. The FCC rules currently provide for two classes of TVWS devices: fixed and personal/portable TVBDs; each are permitted different maximum power levels. The primary protection mechanism for licensed users of the TV spectrum is the mandatory use of a geo-location database. Sensing is defined as a secondary protection mechanism. Additionally, the FCC rules allow for a class of sensing-only products at a lower power level, but such devices will have to undergo additional testing and qualification by the FCC before such devices may be sold.

For cable operators, TVWS presents both the opportunities for additional wireless applications and services as well as risks to their current cable system operations. The risks include the potential for TVBDs to cause interference in cable systems.

The FCC acknowledged the NCTA and Motorola comments on the potential of TVBD interference to headend OTA reception of distant ATSC TV signals and the FCC provided a specific protection mechanism in the TVBD rules. Such headends are permitted to register in the geo-location database and are granted a keyhole protection zone to facilitate these distant OTA reception requirements.

Cable systems today typically operate up to 750 MHz, 860 MHz, or 1GHz and often have no white space due to the high subscriber demand for more HD, on-demand and data services. As such, all TVBDs operating in broadcast TV spectrum "white space" are, by definition, transmitting co-channel to one or more cable services. As such, any ingress of a TVBD into the cable system will cause interference and possibly even loss of service on the affected channels. Such ingress, referred to as DPU, is most likely to occur in subscriber residences both due to the lower signal levels used within subscriber drops and homes versus the main cable plant as well as the wide variety of cabling, device types, quality and installation of the home wiring systems. Additionally, many of the potential TVBD applications are consumer focused, and such TVBDs are likely to be in close proximity to subscriber cable systems.

The TVBD rules that the FCC decided to adopt, allow higher in-home power levels than either NCTA or Motorola recommended in FCC comments [4][5], as well as power levels higher than the levels at which the FCC found caused cable system DPU interference in its own field tests [6]. As a result, many subscriber homes may experience DPU interference resulting from the deployment of TVBDs and remediation would be required to resolve these issues. These interference issues are likely to be similar to those that some operators have already experienced with existing mobile phones in the 800 MHz band. With the reallocation of the 700 MHz band including significant spectrum licensed for high powered 4G mobile services, cable services on those frequencies are likely to see additional interference as well. Fortunately, the same remediation techniques can resolve all these potential interference issues.

Consumer demand for bandwidth continues to grow, and this demand provides continuing growth prospects for cable operators. TVBDs provide unlicensed access to significant spectrum, thereby enabling additional cable operator wireless applications expansion. Cable operators will have to lead DPU remediation efforts with both their subscribers and local retailers in order to maintain and grow the capacity of their current cable systems, paving the way for these additional wireless applications.

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