APPENDIX I

THE POTENTIAL ADVERSE EFFECTS OF UNLICENSED OPERATION OF NEW DEVICES IN TV BROADCAST BANDS ON CABLE CUSTOMERS' RECEPTION OF CABLE SERVICE

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INTRODUCTION

The Federal Communications Commission ("FCC"), following its May, 2004 Notice of Proposed Rulemaking[2] and its subsequent First Report and Order and Further Notice of Proposed Rulemaking[3], has proposed to allow use of unlicensed transmitting devices within nominally-unused television channels, subject to rules which would prevent interference with reception of licensed television broadcast signals. The Commission proposes to create two new classes of devices: (1) unlicensed "personal/portable" devices which would be limited to 100 mW RF output power, with a maximum antenna gain of 6 dBi, and (2) "fixed/access" unlicensed devices which would be limited to 1 W RF output power, with a maximum antenna gain of 6 dBi (or if into a higher gain antenna a corresponding decrease in transmitter power such that the EIRP would not be greater than 4 W).

Such devices would be allowed to operate on television channels 5-13, 21-36 and 38-51 (and possibly channels 2-4 and 14-20), and would have to suppress out-of-band spurious transmissions to the levels defined in C.F.R. §15.209.

The Commission proposed several methods by which interference could be avoided, including:

- A prohibition from co-channel operation within the predicted Grade B contour of licensed broadcast stations.

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[2]FCC 04-113, adopted May 13, 2004.

[3]FCC 06-156, adopted October 12, 2006.

- A prohibition from adjacent channel operation by fixed/access devices within the predicted Grade B contour of licensed broadcast stations.

- Signal sensing by unlicensed devices as one means by which the presence of licensed broadcast station signals might be detected (specifically the sensing sensitivity would have to be at least -116 dBm, referenced to a 0 dBi antenna.)

- Sensing of “beacon” signals by unlicensed devices, whose presence would indicate that certain channels were available for unlicensed transmission.

- GPS location determination by unlicensed devices, combined with access to a database of authorized “white areas” where transmitting would be permitted.

The purpose of this report is to examine the technical impact of operation of fixed/access and personal/portable unlicensed transmitting devices upon the operations of cable television systems, and the restrictions that would have to be placed on the operations of such devices to prevent material degradation to such operations. The proposed technical standards and interference rejection methods are assumed and evaluated in the following analysis, which addresses, based on both theoretical calculations and my years of experience in the field, the measures that are required to ensure that neither fixed/access nor personal/portable devices interfere with the operations of franchised cable television operators and/or result in material degradation of the signals which they deliver to their customers, while not unnecessarily restricting operation of the proposed unlicensed devices.

Two classes of interference must be considered in this regard:

- Generation of co-channel and adjacent channel signals that may interfere with cable systems’ customers by being directly picked up by receivers which are not perfectly shielded (known as direct pickup interference, or DPU), and mitigation measures necessary to solve such interference when it does occur.

- Generation of co-channel and adjacent channel signals that interfere with reception of off-air licensed broadcast signals at cable headends.

1.0 SUMMARY

The concerns of the cable industry are different from those of broadcasters, who are primarily concerned with protection of over-air reception by individual viewers. By contrast, cable operators are primarily concerned with:

- The potential for direct pickup interference (DPU) affecting cable’s customers. Unlike the situation with off-air reception of signals, cable operators typically use every channel in the entire VHF and UHF broadcast spectrum, and thus there are no “unused channels” in which unlicensed devices can transmit without the potential for interference.

Furthermore, regardless of the rules eventually adopted to minimize interference, there will be situations where it does occur, and therefore cable operators are concerned that channels 2-4 be protected to allow the use of well-shielded converters, where necessary to solve such problems.

- Potential interference with reception of signals at cable headend facilities. Cable systems perform a service by providing television service outside major metropolitan areas, and thus system headends where signals are received may be located well beyond the predicted Grade B contour boundaries of television broadcast stations. In such locations, desired signal levels may be very low, especially near the ground, complicating the task of formulating adequate procedures to be followed by unlicensed devices which must somehow determine, in a fail-safe manner, which over-air channels are truly not in use before transmitting.

Proponents of the proposed new unlicensed service have adopted a transmitter-centric approach to their analysis, and thus have done their technical analyses based on protecting only over-air reception of signals and, further, providing such protection only within the predicted Grade B contour of each television transmitter. To cite one example, their interference analyses assume that unlicensed devices are only transmitting when outside that contour and thus are always received through the back of consumer antennas, where effective gain is reduced. They also make unrealistic assumptions about antenna gain characteristics, attenuation of walls, and other factors. As demonstrated below, their analyses are very optimistic, especially when desired signals are received outside the Grade B contour limits, as is often the case for both individuals and cable systems.

1.1 Protection of cable customers from direct pickup (DPU) interference

In light of the embedded base of over 200 million, long-life analog television receivers in U.S. households, the cable industry will undoubtedly continue to provide an analog reception service in which extended tuning range analog receivers are directly connected to cable outlets. Other subscribers will purchase digital cable-ready receivers which also do not require set-top converters.

The most common practice of cable operators is to transmit analog video signals in the lowest channels, with digital video signals above them. Unlike the situation in over-air broadcasting, every channel is used, including adjacent channels, to ensure that all signals received by extended-tuning-range receivers are, in fact, within the tuning range of such receivers. Given that video signals occupy the vast majority of the "downstream" spectrum (signals transmitted towards customers) and that most systems' spectrum is heavily utilized, there usually are few or no "unused channels" within the spectrum assigned to VHF and UHF over-air broadcasting, and thus no way to coordinate between the channels being received by a subscriber and those being used at any time by unlicensed transmitters in the vicinity.

Thus, a combination of adequate spacing between unlicensed transmitters and television receivers, combined with a limitation on maximum allowable power, must be provided to assure that the field strength of the unlicensed device is not sufficient to cause degraded reception, especially in cases where the receiver and unlicensed device are not under common ownership or control, as, for example, in the case of adjacent apartments.

The maximum tolerable external field strength is a function of the shielding effectiveness of the receiver and the inherent tolerance of the signal type (analog vs Quadrature Amplitude Modulation [QAM] digital) to interference. Section 15.118 of the FCC's rules sets forth technical performance requirements for cable ready consumer electronics equipment, including a "shielding standard" to protect against interference. That standard, however, only applies to analog receivers which are explicitly marketed as "cable-ready" or "cable-compatible." The Commission declined to apply those standards to all extended tuning range analog receivers. Cable Television Laboratories, Inc. (CableLabs) however, has tested a representative sample of analog receivers and determined the distribution of shielding effectiveness as a function of frequency. [4] In particular, it found that shielding effectiveness increases with frequency with, on average, very poor shielding at low VHF channels.

Based on the characteristics of the signals received and assuming that receivers' shielding meets the requirements of §15.118, straightforward field strength calculations show that 100 mW portable devices will have a high probability of causing interference on any VHF or UHF channel to a receiver located in the same room when operated on the same channel. Furthermore, the probability of causing interference to a receiver in an adjoining apartment (assuming a typical wood-frame intervening wall) is very high at 100 mW transmit power. If the power is reduced to 20 mW, then the required spacing between an unlicensed device transmitting on a UHF channel and a receiver tuned to the same channel is reduced to approximately 60 feet to ensure protection of digital signal reception and about 25 feet for protection of analog signal reception. At VHF, the potential for interference is worse, both because the attenuation of intervening walls is likely to be less and because the Carl T. Jones' results on typical receivers (discussed above and in detail below) show that shielding effectiveness is typically much worse at lower frequencies. Thus, based on the analysis below, it is my opinion that a maximum of 20 mW is the highest portable device transmit power that will ensure a lack of DPU interference in the case of adjacent apartments and then only if operation of portable devices is restricted to UHF channels.

Similar calculations for externally-mounted, fixed/access, one watt unlicensed devices (taking into account that the signal must pass through at least one exterior wall) suggests that a 400 foot spacing from the nearest residence is adequate for protection of both analog and digital signal reception, and that closer spacing may be possible in cases of masonry or similar higher-attenuation construction.

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[4] *Consumer Premises Equipment Performance and Compatibility Testing*, CableLabs, 1993, submitted to the Commission as an attachment to the January 1994 Comments of Joint Filers in ET Docket 93-7, FCC No. 93-495.

Even with the spacing and power levels suggested above, interference will sometimes occur and, given the contiguous use of channels by cable operators, may occur on any channel or on random channels, depending on the frequency assignment scheme used in the unlicensed transmitting device. When it does, the simplest solution is usually the addition of a well-shielded converter which does not pick up signals itself and which converts the incoming desired channel to one not used locally. Since, in any given television market, at least one of the lowest three channels is unused for over-air transmission, such converters typically are manufactured to, or may be switched to, send its output signals to television receivers on any of channels two through four. Therefore, in a scenario where unlicensed devices are permitted to operate on any channel not used locally for broadcasting, and given the fact that receivers are likely to be least shielded at low-VHF channels, protection of channels 2-4 is critical to effective protection of the reception of cable services in the home.

1.2 Headend reception protection

Cable systems are required to carry the signals of over-air broadcast television stations throughout their designated market areas, which often extend well beyond their predicted Grade B contour boundaries. They provide a valuable service to the public in so doing, since the antennas required to receive adequate signals in fringe areas may be very expensive or impractical for individual residents.

As shown below, because broadcast signals are often picked up by cable systems outside stations' predicted Grade B contours, forbidding unlicensed operation only inside those contours will result in situations in which unlicensed transmitters are located and transmitting between headends and broadcast stations and within the beamwidth of the headend receiving antenna.

For example, even assuming that received levels at headends that are 11 dB above the threshold for DTV receivers (as defined in ATSC A/74) and, further, allowing a level of interfering signal that will cause a desired to undesired signal ratio (D/U) of 23 dB and decrease the operating margin by 3 dB, the required distance between unlicensed transmitters and headends in order to avoid interference is significant. For any device located in the primary beamwidth of the receiving antenna, the required path loss is equivalent to a free-space distance of at least 200 miles. For devices located outside the primary beamwidth, the distances are shown in Table 1. In this table, the channels chosen for analysis were the lowest in each group -- low VHF, high VHF, and UHF respectively – where the free-space attenuation is the least.

Table 1: Minimum Off-Axis Distance Between Unlicensed Co-Channel Transmitter and Headend (in miles) to Assure Interference-Free Reception

Unlicensed Device Power	Channel 2	Channel 7	Channel 14
100 mW	87	38	14
1W	274	120	44

These long distances are a direct result of the relatively low signal levels encountered in digital television reception, as compared with analog reception: -45 dBm is considered a usable signal for analog, while digital signals may routinely be below -70 dBm at the input terminals of processing equipment. Based on these results, required protection areas around headends for fixed devices on any VHF channels and portable devices on low-VHF channels will be very large.

Assuming cable demodulation equipment has similar adjacent channel rejection to consumer receivers, adjacent channel operation by unlicensed devices is generally possible as shown in Table 2.

Table 2: Minimum Distance between Unlicensed Adjacent Channel Transmitter and Headend (in miles) to Assure Interference-Free Reception

Device	Channel	2	7	14
100 mW on-axis		2.4	1.1	0.4
100 mW off-axis		0.14	0.06	0.02
1 W on-axis		7.7	3.4	1.3
1W off-axis		0.43	0.19	0.07

As these results clearly show, even portable devices that are transmitting on adjacent channels within the beamwidth of headend receiving antennas can cause interference for a considerable distance.

As summarized above, and detailed later in this document, it is receiving locations, not transmitting locations that must be protected from interference. As discussed in detail below, some of the methods proposed, by which an unlicensed device could automatically and accurately determine which channels are eligible for use, are flawed:

- Signal sensing, a technique by which an unlicensed device first listens on a channel to determine occupancy before transmitting, suffers from the wide variation in signal levels over small distances, particularly in fringe areas, that would require an extreme sensitivity that, even if practical, would often forbid transmissions in many cases where potential interference would not occur. That is particularly true in headend reception cases, where cable's antennas might be located hundreds of feet in the air while the off-air signal is virtually undetectable near the ground. This is a prime example of the "hidden node" problem, but rather than resulting from the unlicensed device being behind an obstacle, is caused by the headend antenna being in a particularly good reception location.

- The use of a beacon transmitter to signify available channels suffers from a similar problem – that is, its transmission boundaries are difficult to predict and impossible to control.

- Of the proposed methods suggested by the Commission by which unlicensed devices might automatically determine which television channels are available, only the combination of auto-location (using GPS or equivalent methodology) and database lookup offers the hope of protecting television reception without unnecessarily restricting operation of unlicensed devices.

2.0 MINIMUM DISTANCES REQUIRED BETWEEN UNLICENSED DEVICES AND CABLE CUSTOMERS' RECEIVERS TO AVOID HARMFUL CO-CHANNEL INTERFERENCE VIA DIRECT PICKUP (DPU) INTERFERENCE

Direct pickup interference occurs when fields from external radio frequency signals whose frequencies are within the band of desired signals received through the normal antenna input port are coupled into the internal television set tuner circuitry and cause degraded reception for viewers. The degree of interference is a function of the strength of the external field, the integrity of the RF shielding around the tuner circuitry, and the tolerance of the desired signal format (e.g. analog NTSC or QAM digital) to the presence of undesired signals within the receiver pass band. Historically, the most common type of DPU was strong local television broadcast signals interfering with reception of signals transmitted through cable systems, which might be the same programming, but delayed by the difference in transmission time, or might be from an entirely different channel.

The cable industry has many years' experience with direct pickup (DPU) interference with its customers' television reception. It was, in fact, DPU that initially led to the development of external tuner boxes, which were well-shielded devices whose purpose was primarily to convert an incoming signal to a low-VHF channel that was not in use in the local market.

Although the proposed unlicensed devices operate at much lower power levels than television stations, they also may operate in close proximity to television receivers and thus generate strong local fields. Although unlicensed devices will be forbidden from transmitting on channels used locally for over-air transmission, cable operators typically use all the VHF channels as well as channels that extend throughout most or all the over-air UHF spectrum.

The Commission's general approach to Part 15 devices is that they are only likely to interfere with receivers (or other Part 15 devices) that are under common control, and thus the consumer will be aware of the source of any interference and will make the decision as to whether accept the degraded reception, relocate the Part 15 device, or otherwise take responsibility to eliminate the interference.

Following is an investigation as to whether this is a good assumption, or whether such devices might generate field strengths sufficient to potentially interfere with cable service reception.

2.1 What field strength will cause interference?

2.1.1 Selection of appropriate type of receiver and signal

It was recently reported that approximately one sixth of all homes in the US have at least one high-definition television receiver, and that 26% of those homes have more than one such receiver.[5] Furthermore, it was my recent personal experience, as a cable operator, that the average cable subscriber's home has, on average, about 2.6 televisions connected to cable service. If we assume that the 26% of homes with multiple HDTV receivers each have two such receivers, then the combination of these two statistics implies that, as of late 2006, the percentage of television receivers in cable subscribers' homes with DTV inputs (whether at RF or baseband) is 16.7% X 1.26/2.6 = 8.1%. While this percentage will obviously increase between now and February 2009, there will still likely be over one hundred million analog television receivers in operation.[6]

Furthermore, fewer than half of cable subscribers subscribe to digital video services (of any kind, not just HDTV), and then typically only on the primary receiver in the home The typical connection to all of the television receivers in non-digital homes (i.e. subscribers to basic or extended video service only) and the secondary receivers in homes of those who subscribe to digital video service consists usually of a direct connection between the cable service and the RF input of the receiver. In modern cable systems this service typically consists of around 80 analog television channels, extending from 54 to 550 MHz. While digital penetration will almost certainly continue to increase between now and February 2009, it is likely that many cable operators will continue to deliver an analog service to many subscribers, consisting of a combination of ad-supported cable networks and digital over-air channels which have been converted back to analog for delivery to homes.[7]

Thus, given the long service lifetimes of analog television receivers, many, if not most, cable systems will continue to deliver an analog video service tier that does not require the use of a set-top converter. That, in turn, means that customers will use the tuners in their receivers to select channels. While it seems likely that the spectrum devoted to the analog service tier will eventually decline as analog receivers are phased out and customers either agree to use a converter or replace their analog receivers, the timing is uncertain.

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[5] "HDTV Sales Strong – Among Wealthier Consumers, Study Says," David Lieberman, USAToday.com, posted October 24, 2006.

[6] The "2004 CE ownership and market potential study," June 2004, eBrain Consumer Research (a business unit of the Consumer Electronics Association) estimated that there are 287 million television receivers in American homes, as reported by the CEA in its November 30, 2004 filing in this matter.

[7] As an example, the RGB Networks "Simulcast Edge Processor" is designed to convert up to 80 digital channels to analog using just two rack units (3-1/5" vertical) space in a rack bay. Other vendors are proposing point-of-entry units at each home to accomplish that same function.

It would be prudent, therefore, to assume that existing television receivers will continue to be used to directly access analog video signals on frequencies as high as 552 MHz (the upper edge of channel 78). Thus, this study will analyze the potential for interference to analog video reception on channels between VHF channel 2 and UHF channel 27 (548-554 MHz).

In the case of owners of analog television receivers who subscribe to digital services, the connection between the converter box and receiver may be either at baseband or via modulated NTSC signals on one of VHF channels 2-4. Thus, DPU is potentially a problem on those channels, even for digital service subscribers.

Cable operators deliver digital television signals using QAM. While the FCC rules mandate that either 64 QAM or 256 QAM can be used to deliver signals to a digital cable-ready receiver[8], the industry is rapidly evolving to defacto standardization on 256 QAM because of its increased spectral efficiency. Thus, the appropriate standard for potential interference to digital television reception should be based on 256 QAM.

Given a determination that the appropriate standard for interference threshold is reception of analog video signals on channels up to (off-air UHF) 27 and reception of 256 QAM signals on higher channels, we will next examine the available evidence of the shielding effectiveness of television receivers.

2.1.2 Evidence of receiver shielding effectiveness

The FCC's rules mandate that analog receivers marketed as "cable-ready" be sufficiently well shielded that an external signal whose field strength is 100 mV/m will not result in a coupled signal, as measured at the tuner output, that is stronger than 45 dB below a desired signal (50 dB average across six tested channels) which enters the receiver through its normal antenna input at the minimum level mandated by the commission for cable systems of 0 dBmV[9] (-48.75 dBm).[10]

There are two problems, however, in adopting a 100 mV/m standard for the maximum acceptable field from an unlicensed device operated in the vicinity of a television receiver.

First, when the Part 15.118 rules were defined as part of ET Docket 93-7 (FCC No. 93-495) in 1994, the FCC declined to require that level of shielding protection for any receivers that were not specifically marketed as "cable ready" or "cable compatible," with the result that millions of receivers were manufactured and sold both before and after the adoption of these rules for which the shielding performance is unknown.

[8] 47 C.F.R §76.640(b)(1)(i), which references SCTE 40 2003 which in turn, requires 64 or 256 QAM transmission.

[9] 47 C.F.R §76.605(a)(3) defines the minimum acceptable signal level

[10] 47 C.F.R §15.118(b)(3) defines the required shielding performance

Second, the 45 dB D/U standard represents the ratio between the sync peak level of the desired signal and the level of an unmodulated interfering signal and was adopted by the FCC as a maximum tolerable level of interference to an analog television signal from a discrete frequency interfering signal, whereas the presumption made in the current rulemaking is that the signals from unlicensed devices will be "noise-like" in character, and thus any DPU interference will manifest itself as an effective degradation to the C/N of the received signal. Since noise-like signals and discrete frequency signals cause visually different effects on displayed pictures, it is not obvious that the same D/U ratio is relevant to both types of interference. Therefore the appropriate ratio of desired signal to noise-like interfering signal is calculated below for both analog and QAM digital signals.

To determine the state of shielding in then-current television receivers, CableLabs, at the request of the NCTA/EIA Joint Engineering Committee (JEC), in late 1992, contracted with Carl T. Jones to conduct DPU interference studies on 35 new television receivers, representing a cross section of models and manufacturers. The Jones' report was submitted to the Commission in connection with the development of rules for implementation of Section 17 of the Cable Act of 1992. In summary, their tests showed that the least-effectively-shielded television receiver would have reached 45 dB D/U, when receiving a 0 dBmV signal on channel 6 and oriented for maximum sensitivity to the external field, with an external field of only 2.4 mV/m (missing the requirements of §15.118 by over 32 dB), with the median across all receivers and all field directions on this channel being 44 mV/m (the comparable median for cable converters on channel 6 was 312 mV/m). In general the Jones' detailed results show a continuous spectrum of shielding effectiveness among the tested receivers, rather than a few outliers. Also, shielding effectiveness varied across the spectrum with the effectiveness at channel 6, averaged across all receivers and field orientations,13 dB less effective than at channel 12, the effectiveness at channel 78 (550 MHz), 2.25 better and the effectiveness at broadcast channel 59 (740 MHz) 6.3 dB better.

Receivers at least as good as the median among those tested would miss the requirements of §15.118 by 13 dB on channel 6, by 1.3 dB on channel 12, by 0.9 dB on cable channel 78 (off-air channel 26) and by 2.5 dB on off-air channel 59, when oriented for maximum sensitivity to external fields. More significantly than the data regarding the average performance across the sampled receivers, Jones' data show that the range of shielding effectiveness at all channels varied widely among the tested receivers (35 dB on channel 6, 44 dB on channel 12, 44 dB on cable channel 78 and 42 dB on off-air channel 59 between the best and worst receiver tested), which indicates that a significant number of receivers fail the requirements by a wide margin on every channel.

To reach an estimate of shielding effectiveness for likely receivers, this report first eliminated the worst-shielded 1/3 of the samples (11 receivers). Then, to judge the effectiveness of VHF channel shielding, given the dramatic reduction in effectiveness between channel 12 and channel 6, the measured effectiveness of the worst remaining receiver at channel 6 was used. Similarly, to judge the effectiveness of shielding in UHF channels, the measured effectiveness of the similarly-ranked receiver at cable channel 78, which is at approximately the same frequency as off-air UHF channel 27 was used.

Summarizing these results, it can be said that, of this representative sample of receivers, the best-shielded two-thirds, when exposed to an optimally oriented VHF field of 8 mV/m (78 dBμV/m) will exhibit internal interference levels no worse than 45 dB below a desired signal whose level is 0 dBmV at the antenna terminals. Similarly, this same sample of receivers will withstand a UHF field of 72 mV/m (97 dBμV/m) on channel 27. By contrast, if all the receivers had just met the shielding standard of §15.118, a field of 100 mV/m (100 dBμV/m) would be required on the least-shielded channel to produce that level of interference and a field of 312 mV/m (105 dBμV/m) averaged across all tested channels. In summary, while some of the tested receivers met the requirements of §15.118 (which had not been formalized at the time of the measurement), the average receiver did not, and a significant percentage missed by a wide margin.

To date no filing submitted by any party in this action includes data demonstrating that shielding of television receivers, on average, has improved over the representative sample of receivers tested. Furthermore, given the long lifetime of television receivers, many sets that were new in 1994 are still in service. Thus it is concluded that the shielding effectiveness measured by Carl T. Jones is still representative of analog receivers in the field.

2.1.3 Applicability of the §15.118 shielding requirement to reception of analog signals in the presence of noise-like interfering signals

The FCC, since 1995, has required that cable operators deliver analog television signals to its customers at a minimum level of 0 dBmV and with a C/N of at least 43 dB.[11] Since noise in an analog television signal is measured over a bandwidth of 4 MHz, this corresponds to a C/N of about 41 dB, referenced to the entire 6-MHz channel. This requirement is consistent with tests showing that the C/N judged by viewers to be "slightly annoying" is about 45 dB.[12] In order to account for operational variances and for the degradation that takes place in converters (for those homes which use them), cable systems are routinely designed to provide a 4-MHz C/N of around 48 dB at customer's taps under normal conditions, with the expectation that, with operational variations, the minimum C/N at outlets will be 46 dB, which when combined with a typical converter noise figure of 13 dB, will result in a composite C/N at the subscriber's receiver of just 43 dB. For customers using extended-range television receivers, therefore 46-48 dB is the C/N delivered to their receiver's input terminals. 48-51 dB C/N was rated as "perceptible, but not annoying" in the Bronwen Jones study just cited.

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[11] 47 C.F.R 76.605(a).

[12] "Subjective assessment of the quality of cable impairments on television picture quality," B.L. Jones and J.A. Turner, 1991, *NCTA Technical Papers*, p92, NCTA. The tests were conducted using weighted video noise which is numerically almost identical to 4-MHz-referenced RF C/N.

Random noise accumulates at every active device in a cable system, from the input noise figure of the first processor or demodulator, to the last system amplifier. If noise contributed by a signal picked up at a consumer's receiver is not to degrade the signal below the "slightly annoying" level, it must therefore induce noise-like signals that are no greater than 46 dB (4-MHz bandwidth) below a 0 dBmV received signal (at which level it will degrade the total C/N by about 3dB). Referencing the level of the noise signal to the entire 6-MHz band, therefore, the induced interfering signal must be no greater than 44 dB below the received signal, or -44 dBmV referenced to a 0 dBmV input signal.

The review of the characteristics of typical receivers, above, showed that an external field of 8 mV/m (78 dBμV/m) would cause an interfering signal to be induced with a magnitude of -45 dBmV (referenced to the input terminals). Therefore, an external field of 8.9 mV/m (79 dBμV/m) is the maximum external field that can be tolerated at channel 6 (and will be used as a reference point for VHF channels). Similarly, for off-air channel 27, a field of 72 mV/m (97 dBμV/m) will produce -45 dBmV induced fields, so that an external field of 79 mV/m (98 dBμV/m) can be tolerated at channel 27 (and will used as a reference point for UHF channels. For receivers just meeting the requirements of §15.118, the maximum field would be 112 mV/m (101 dBμV/m) for all channels. These are the external field strengths used in this analysis.

2.1.4 A similar process can be used to determine the maximum tolerable signal level for a DTV receiver which is receiving digital signals.

The FCC requires that DTV signals be delivered to digital cable-ready receivers at a minimum level of -15 dBmV for 64 QAM signals and -12 dBmV for 256 QAM signals. The required 6-MHz C/N is 27 dB for 64 QAM signals and 33 dB for 256 QAM signals.[13] As with analog signals, cable operators design their systems to deliver higher quality signals to account for normal operational variations and the inevitable degradation in set-top signal processing devices which are required to interface with non-cable-compatible digital receivers. Typically, the design performance for 256 QAM signals at nominal end-of-line conditions is about 40 dB C/N, with occasional operational variances down to perhaps as low as 37 dB, leaving a 4 dB margin above the minimum required by FCC rules.

A -12 dBmV 256 QAM signal with a 37 dB C/N will have a noise level equivalent of -49 dBmV, referenced to the input terminals of the receiver. In order to cause no more than a 2 dB reduction in the operational margin (50% of the total), the equivalent interfering signal must be 2 dB below the as-received noise (39 dB D/U) or -51 dBmV referenced to the input terminals (as with analog receivers, it can be assumed that the relatively high received signal and noise will be much higher than the tuner's input noise contribution).

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[13] SCTE 40 2004, Table B, P16. SCTE 40 is included in the FCC's rules at 76.640(b)(1)(i) and defines the required characteristics of signals delivered by cable television systems to unidirectional digital cable products.

Although not a requirement under the FCC's rules, the cable industry and CE manufacturers developed a voluntary national standard covering unidirectional digital cable-ready receivers that requires compliance with the shielding standard requirement of section 15.118.[14] That requirement, as previously noted, mandates that a 100 mV/m (100 dBμV/m) signal cause an internal interfering signal that is no stronger than 45 dB below a 0 dBmV received signal, equivalent to 33 dB below a signal received at -12 dBmV. Since the interfering signal must be no stronger than 39 dB below the incoming signal, the maximum tolerable external field strength may be no higher than 50 mV/m (94 dBμV/m) on any channel.

If signals are modulated using 64 QAM, the minimum receive level is 3 dB lower (-15 dBmV), and the system C/N is typically also reduced by 4 dB relative to 256 QAM signals (33 dB including operational variation). To result in no more than 2 dB reduction in operational margin, therefore, the induced field must be no stronger than 2 dB below the received noise level, or -15 - 33 - 2 = -50 dBmV). Thus, the field required to degrade a 64 QAM signal to the same degree as a 256 QAM signal is within about 1 dB of that for 256 QAM signals.

Otherwise stated, in a typical cable system an external 6-MHz noise-like signal at a level of 50 mV/m (94 dBμV/m) will cause about a 2 dB reduction in operational margin (about half of that normally provided) in the reception of a QAM signal by a digital cable-ready television receiver that meets the requirements of ANSI/SCTE 105 2005, the Uni-Directional Receiving Device Standard for Digital Cable. This is the external field standard used to analyze the potential for interference to customer reception of digital cable signals.

Note that the maximum tolerable external field with QAM reception is 7 dB lower than the maximum tolerable field strength required to protect typical analog receivers which meet the same shielding requirements (as delineated in §15.118). This reduced tolerable field reflects the fact that, although QAM signals have increased tolerance to interference when compared with analog video signals, their minimum delivered signal levels are 12 dB lower (-12 dBmV *vs.* 0 dBmV for 256 QAM), while the minimum required C/N is only 10 dB lower (33 *vs.* 43 dB). Secondly, while analog signals degrade gracefully below defined quality limits, digital receivers have a sharp "cliff effect" below which reception degrades from subjectively perfect to no reception at all with a very small decrease in C/N. Because of this, a higher margin is maintained above that threshold to assure reliable reception.

2.2 What distance is required between unlicensed devices and television receivers in the same room to avoid interference?

Based on free-space transmission, the field strength from a transmitting device can be calculated using:

$$E = 115.32 + P + G - 20 \log(d)$$

[14] *ANSI/SCTE 105 2005 Unidirectional Receiving Device Standard for Digital Cable*, Section 23, Requirement 202. Available for download from SCTE.

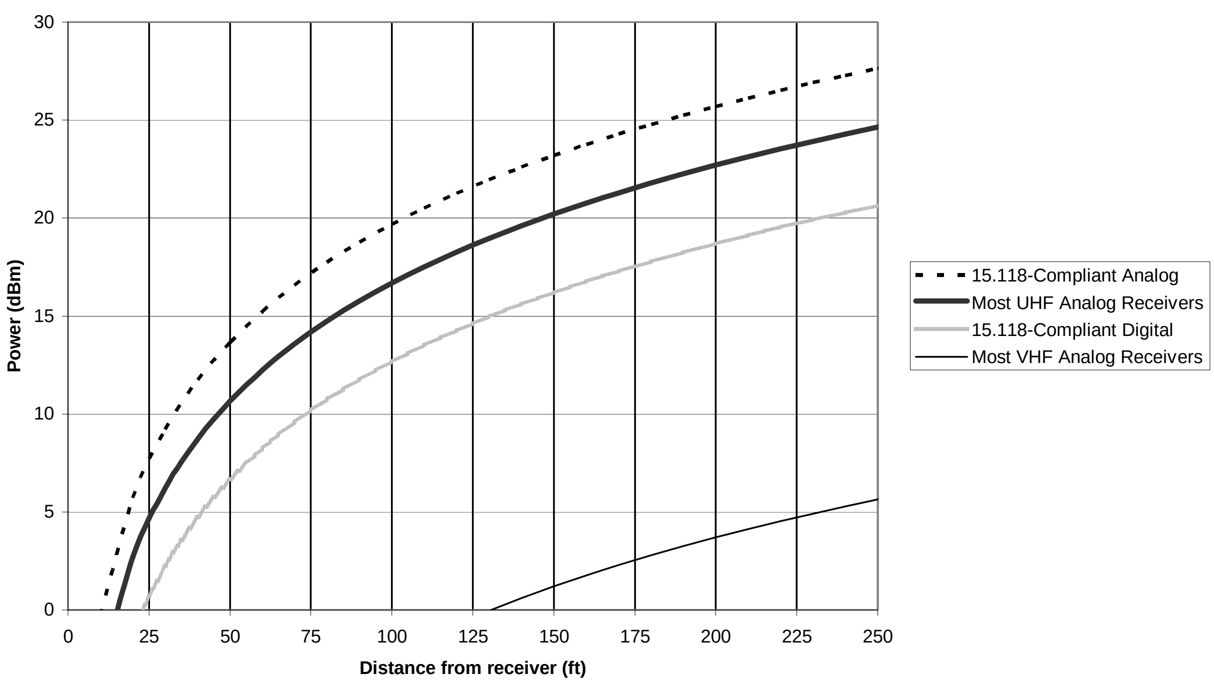
Where: E is the field strength in dBμV/m
P is the transmit power in dBm
G is the transmit antenna gain in dBi in the direction of the measurement
d is the distance to the point of measurement in feet

Solving this for the minimum required distance, given maximum tolerable field strength we get:

$$P = E - 115.32 - G + 20 \log(d)$$

Figure 1 shows the maximum power vs. distance for 101 dBμV/m (the threshold for analog receivers meeting §15.118 shielding requirements), 98 dBμV/m (the threshold for most analog receivers when tuned to UHF channels), 94 dBμV/m (the value for a 2 dB reduction in margin for QAM signals), and 79 dBμV/m (the requirement for most analog receivers when tuned to VHF channels). As can be seen, even a 20 dBm (100 mW) device operating in the same room with a television receiver will cause degraded reception if it happens to be transmitting on the channel to which the receiver is tuned. Unfortunately, there are typically no "unused" channels in a cable system and no obvious way for the unlicensed device to know to which channel the television receiver is tuned.

Figure 1: Transmit Power(dBm) vs Distance to Receiver for Maximum Tolerable DPU Reception Interference Based on Free-Space Transmission and 6 dBi Unlicensed Device Antenna Gain



2.3 What distance is required between unlicensed devices and television receivers in adjoining apartments to avoid interference?

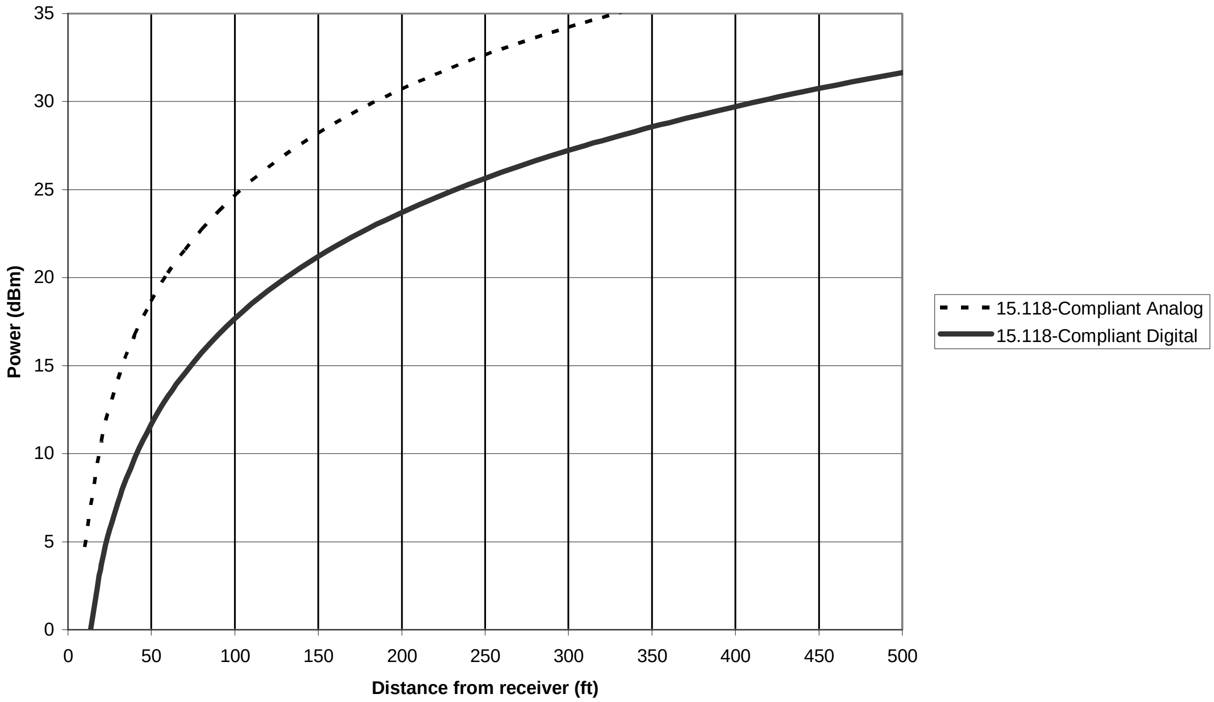
The more challenging problem is avoiding interference to receivers in adjoining apartments in multi-dwelling units. In that situation, as opposed to that implied by the Part 15 (accept whatever interference you create to your own reception), the user of the television receiver will have no way of knowing the source of the interference, nor any control over it. Thus, the regulations must set limits on transmissions from unlicensed devices to assure, with high probability, that reception is not materially degraded.

In the case of adjoining apartments, there will be at least one intervening wall through which the interfering signal must pass. In its research on behalf of MSTV,[15] the Communications Research Centre Canada (CRC) measured the effective attenuation of a typical interior wall structure indirectly as part of its study on desensitization effects. The effective attenuation implied from their results averaged somewhat less than 5 dB for UHF signals. No results were reported for VHF signals, but the likelihood is that the attenuation would be less at the lower frequencies.

Figure 2 shows the possible transmit power as a function of spacing at UHF with an assumed intervening wall whose attenuation is 5 dB. Data is shown for analog and digital receivers meeting the shielding requirements of §15.118. This data indicates that a distance of 60 feet would be adequate to protect analog reception from portable devices operating on UHF channels, but that the distance required to protect UHF QAM signals (about 130 feet) is much longer than would commonly occur between devices in adjacent apartments.

[15] "Interference from the operation of unlicensed devices in the broadcast TV bands," Engineering Study, November 2004, MSTV, Section 2: Laboratory evaluation of interference from unlicensed devices in the broadcast TV band, Figure 4 (page 12).

Figure 2: Transmit Power(dBm) vs Distance to Receiver for Maximum Tolerable DPU Reception Interference In Adjoining Apartment With One Intervening Wall



If, as suggested by CEA,[16] the power level of portable devices were limited to 20 mW (13dBm), then the required distances would be reduced to about 30 feet to protect analog reception and 60 feet to protect QAM digital reception. However, as previously noted, the wall attenuation number of 5 dB cited in the MSTV study may be optimistic at lower frequencies. CEA's suggestion of reducing the maximum transmit power of portable devices to 20 mW may reduce the possibility of interference to receivers which are not under common control with the operator of the unlicensed device, so long as operation of portable devices is restricted to UHF channels. But if VHF channels are included, then operation of unlicensed portable devices at even this power level may be optimistic.

Interference to reception in adjacent, non-attached, single-family homes does not appear to be a problem at least at UHF. Adding another 5 dB for a second wall reduces the required spacing to around 75 feet to adequately protect QAM digital signal reception from 100 mW portable devices, so long as the receiver meets the shielding requirements of §15.118.

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[16] Comments of the Consumer Electronics Association, in ET Docket No. 04-186 and ET Docket No. 02-380, filed November 30, 2004, p5.

2.4 What distance is required between fixed, externally-mounted, devices and receivers in nearby buildings to avoid interference?

The problem of avoiding interference between externally-mounted fixed (1W) unlicensed devices and television receivers is similar to the adjacent apartment problem, except that power levels are much higher and the attenuation of building walls can vary widely, from simple wood-frame construction to steel-reinforced concrete to metallic siding. Although fixed devices may be located farther from ground-level receivers in many single-family homes, they may just as easily be on the same level as upper-story apartments in MDU complexes.

A summary of available data related to attenuation of signals passing through exterior walls of homes is included in the CableLabs report previously cited, at Section 6 "Mitigating Factors." In addition, a 1984 AT&T Bell Labs study found that average ground floor building attenuation was 5.5 dB for typical suburban houses at 800 MHz.[17] An IEEE publication of 1977 reported an average attenuation by walls of houses to vertically polarized signals at 860 MHz of 4.6 dB and for horizontally polarized signals of 6.4 dB.[18] Another IEEE publication reported studies of two detached residential houses, with the first showing an attenuation of 0 to 7.5 dB and the second an attenuation of 5.5 to 12.5 dB for frequencies between 50 and 500 MHz.[19] From these studies, we can estimate that the typical horizontal attenuation through the walls of a typical single family house is approximately 6 dB, on average.

By contrast, a Bell System study from 1983 reported results from measurement on three urban and eleven suburban multi-story office buildings, whose attenuations may be taken as similar to typical apartment dwellings. The overall average attenuation for these buildings was 14.2 dB at 850 MHz.[20] A similar Bell System study from 1959 on the attenuation of eleven multi-story office buildings at 150 MHz showed an average attenuation of 22 dB.[21] These studies suggest that an attenuation of around 18 dB for typical high-rise apartment complexes, but with wide variances depending on construction.

Small apartment buildings (4-8 units) and duplexes, especially on the west coast, are typically built using similar wood-frame construction to that used for homes and, thus, the attenuation to external signals may be similar to that found in homes.

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[17] D.C Cox et al., "800-MHz attenuation measured in and around suburban houses," *AT&T Bell Laboratories Technical Journal*, Vol. 63, No 6 (July-August 1984), 921-955.

[18] Paul I. Wells, "The attenuation of UHF radio signals by houses," *IEEE Transactions on Vehicular Technology*, Vol. VT-26, No. 4 (November 1977), 358-362.

[19] Albert A. Smith, Jr., "Attenuation of electric and magnetic fields by buildings," *IEEE Transactions of Electromagnetic Compatibility*, Vol. EMC-20, No. 3 (August 1978), 411-418.

[20] E. H. Walker, "Penetration of radio signals into buildings in the cellular radio environment," *The Bell System Technical Journal*, Vol. 62, No. 9 (November, 1983), 2719-2734.

[21] L. P. Rice, "Radio transmission into buildings at 35 and 150 mc," *The Bell System Technical Journal* (January 1959), 197-211.

Given this wide variation (5-22 dB) it is difficult to suggest measures to adequately protect reception without unduly restricting unlicensed device operation. For small-unit wood-frame Multiple Dwelling Units (MDU), Figure 2, above, suggests that the minimum distance between any fixed 1W unlicensed transmitter and the external wall of the apartment house should be at least 400 feet, assuming UHF operation only. Where building construction is more typical of urban high-rises, a distance of 130 feet appears to be adequate. Given this variation, this study suggests a 400 foot minimum spacing, but allow operators of fixed/access devices to make showings, based on actual field strength measurements from inside the closest dwellings, that would support closer spacing on a case-by-case basis. Given lower probable attenuation by building walls, combined with evidence of poorer receiver shielding at VHF (and especially low-VHF) channels, the distances will have to be increased if the FCC allows operation on those channels

2.5 Operation on VHF channels 2-4

Cable television operators, direct broadcast satellite operators, and others with a need to transmit analog video signals to television receivers as NTSC modulated RF signals typically choose one of the lowest three VHF channels for this purpose, selecting one that is not a strong local signal to avoid the direct pickup problems from broadcast stations detailed above.

A long-standing technical issue with the cable industry is that the transmission delay of local broadcast signals through the coaxial distribution networks is longer than the direct over-air path to customer's homes, with the result that the signal delivered by cable, even if the same as the corresponding off-air signal is delayed, resulting in a ghost when the over-air signal enters the television receiver through direct pickup. This is not typically an issue when homeowners use external antennas, as the time delay between the signals is below the threshold of visibility, and thus has resulted in the design of receivers which are fine for over-air reception, but inadequately shielded for cable reception in strong signal areas. The cable industry's historical response to this issue has been to provide an external, well-shielded converter ahead of the receiver and convert all incoming signals to an unused low-VHF channel where there are no interfering signals.

The previous analysis of the DPU problem demonstrates conclusively that DPU will be a problem where unlicensed devices are operated in the same room as television receivers and will potentially be a problem to reception in adjacent apartments or duplex residences, even when operation is restricted to UHF and/or where analog receivers fully comply with the requirements of §15.118 with respect to shielding.

More seriously, however, as demonstrated by the C.T. Jones' measurements on actual production receivers, many (and perhaps most) deployed analog receivers are seriously lacking in shielding at channel 6 and below, with the result that interference from unlicensed devices transmitting on VHF, and especially low-VHF, channels will likely extend throughout adjacent apartments. Lacking mandatory regulations that all receivers that tune cable channels comply with the shielding requirements of §15.118, the operation and power level of unlicensed devices must now be restricted to compensate.

In summary, in order to minimize the number of cases of DPU interference, it is recommend forbidding operation on VHF channels altogether. This study concurs with CEA that personal/portable devices be limited to 20 mW or less, preferably with omnidirectional (0 dBi gain) antennas. Given that DPU interference will still sometimes occur, the simplest solution is through the use of a well-shielded set-top converter, combined with an absolute prohibition against operation on VHF channels 2-4. Thus, whatever decision is made regarding the remainder of the VHF band, I strongly recommend that operation on channels 2 through 4 be prohibited.

3.0 INTEFERENCE WITH OFF-AIR SIGNAL RECEPTION AT CABLE HEADENDS

Although cable companies sometimes have direct links to television stations, it is common for systems to receive some or all of their over-air broadcast television signals using antennas, especially for systems which may be located in fringe reception areas. Thus, the presence of unlicensed transmitters on the channels being received or on adjacent channels is of concern to cable operators. This section of the report analyzes the restrictions on the operation of the unlicensed devices which will be required to avoid material interference with the normal operations of those systems.

3.1 Minimum Distances Required Between Unlicensed Devices and Receiving Antennas at Cable Headends to Avoid Harmful Co-Channel Interference with Off-Air Signal Reception

With respect to any given cable television system, current FCC regulations consider as "local" any analog UHF station that delivers a signal strength of greater than -45 dBm, or analog VHF station that delivers a signal strength of greater than -49 dBm, to the input terminals of the signal processing equipment in a cable headend, provided that the community served by the cable system lies within the same television market as the station.[22] The FCC has further established the minimum required DTV station signal strength for this test at -61 dBm, following the cessation of analog broadcasting.[23] Significantly, the rule does not specify what antenna configuration is to be used ahead of the measurement point, nor does it make any provisions for the quality of the signal, though stations are allowed to provide equipment to meet the requirement (the minimum required C/N for analog video signals is waived for signals which are first received and then delivered outside any station's predicted Grade B contour[24]). As a result, stations can provide pre-amplification for weak signals and thus deliver an adequately-strong, but noisy, signal to the cable operator's equipment.

[22] 47 C.F.R. §76.55(c)
[23] Carriage of Digital Television Broadcast Signals, 16 FCC Rcd 2598 (2001)
[24] 47 C.F.R §76.605(a)(7)(iv)

The must-carry requirement has created many situations in which cable television systems receive must-carry signals well outside the predicted Grade B contours. For example, SuddenLink Communications picks up significantly-viewed, must-carry-qualified signals outside their grade B contours to serve approximately 25,000 customers in at least 18 communities (see Appendix I). Fringe-area signals (hereinafter defined as signals as received beyond the predicted Grade B contour boundaries) are often received by cable systems using antennas placed on tall towers (often hundreds of feet tall) whose locations are carefully chosen to maximize the percentage of time that adequate reception will be possible.

Reception of signals beyond the Grade B contour of licensed broadcast stations, whether directly or via a franchised cable television system, private cable system, or translator is not only common, but the primary means of reception for many US households. Thus, the general limitation on operation of Part 15-regulated devices is that "no harmful interference is caused[25]," where harmful interference is defined as "any emission, radiation, or induction that . . . seriously degrades, obstructs or repeatedly interrupts radiocommunications service operating in accordance with this chapter[26]". This also governs protection to reception of television signals outside the predicted Grade B contours of broadcasting stations.

With respect to the current rulemaking, this requires that the Commission adopt rules that ensure that the "white space" that is to be allocated for the proposed unlicensed devices is truly unused, considering <u>both ends</u> of the communications path. As a practical matter, it is the receiver, not the transmitter that needs to be protected from interfering signals. In the case of cable television systems, that means headend facilities at which over-air broadcast television signals are first received.

In order to determine the level of unlicensed radiation that will not cause material degradation to headend reception, a model has been constructed of a typical fringe reception situation, keeping in mind that actual headend practices vary widely, depending on where signals are best (considering strength, stability, multipath, electrical interference, and other factors).

For purposes of this model, it is assumed that the signal level at the terminals of the channel processor or demodulator is adequate to provide reasonably-error-free digital demodulation (digital signals are almost always demodulated to baseband, then re-modulated using 64 or 256 QAM for delivery to customers). While the ATSC A/74 DTV Recommended Practice: Receiver Performance Guidelines suggest usability with signals as low as -83 dBm, typical cable processing equipment is guaranteed only down to -80 dBm (-31 dBmV),[27] so it is assumed that signal levels might vary over time down to that level. Furthermore, it is assumed that cable operators will, in general, configure antennas such that the normal level is at least -72 dBm to allow for 8 dB of fade margin.

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[25] 47 C.F.R §15.5(b)

[26] 47 C.F.R §15.3(m)

[27] Data sheet for Wegener model DTV 720 Transport Stream Multiplexer with optional 8VSB tuner.

In weak signal situations, it is common to use a low-noise preamplifier mounted close to the antennas to overcome feedline loss and improve the overall effective noise figure of the system. Thus, it is assumed that the use of a preamplifier with a noise figure comparable to that of the processing equipment and sufficient gain that the added contribution from the demodulator is negligible. Thus, the net effect is the same as if the demodulator were directly connected to the antenna's terminals.

Headend antenna can vary from a single Yagi or log-periodic antenna to horizontally and vertically-stacked arrays. The choice depends on both available signal strengths and on the need to discriminate against multi-path reflections. Stacked arrays offer higher gain (which would make them more sensitive to radiation from unlicensed radiators within the antenna beamwidth), but narrower beamwidths (and thus greater protection from signals arriving well outside the beamwidth). Log periodic antennas are frequently chosen when multiple signals are received from the same azimuth, while Yagi antennas are used for single-channel reception. As examples of possible antenna configurations, the following table lists the performance of typical log periodic antennas, both single and in a quad array at channels 2-6, 7-13 and UHF.[28]

Table 3: Typical Headend Antenna Characteristics

Configuration	Single Log-Periodic			Quad Array of Log-Periodics		
	Ch 2-6	Ch 7-13	Ch 14-51	Ch 2-6	Ch 7-13	Ch 14-51
Forward Gain(dBi)	8.5	11.5	12.5	14	17	17
Vertical/ Horizontal Beamwidth (degrees)	95/70	65/50	65/50	30/28	22/20	25/28
Sidelobe/ back suppression (dB)	25	25	25	25	25	25

Performance using Yagi antennas would be similar, except that sidelobe suppression and front-to-back ratios of individual antennas might more typically be 18-20 dB, depending on whether the antennas are optimized for forward gain or sidelobe suppression.[29] In weak signal areas, however, operators will normally use antenna arrays rather than single antennas, so that 25 dB sidelobe suppression and F/B ratios will likely be achieved, even with Yagi arrays.

[28] From data sheets for Scientific Atlanta Model QCA single and QCS four antenna arrays.

[29] *The CATV Engineer's Antenna Handbook*, Steven Biro, Society of Cable Telecommunications Engineers, 1998, Chapters 3-6.

Note that the sidelobe/back suppression levels are typically achieved only for signals which are received at least 50-60 degrees off axis.

Assuming the likelihood of higher-gain antenna configurations in fringe signal areas, the signal strength at the antenna input required to produce a signal of -72 dBm at the processing equipment input at various channels is shown as Desired DTV Field Strength in Table 4.

Table 4: Desired and Maximum Tolerable Undesired Field Strengths at Headend

	Field strengths (in dBµV/m) required to produce -72dBm signal at processing equipment and maximum allowable interfering signal level to guarantee 23 dB D/U					
Channel	2	6	7	13	14	51
Desired DTV Field Strength	26.0	29.6	33.2	34.8	41.8	45.1
Maximum Unlicensed Device Field Strength (on-axis)	+3	+6.6	+10.2	+11.8	+18.8	+22.1
off-axis (side or rear)	+28	+31.6	+35.7	+36.8	+43.8	+47.1

Another way of looking at the situation is as follows:

The specified minimum input to the headend demodulator is -80 dBm. This implies that the internal noise level is about -95 dBm, since DTV receivers are recommended to operate with a minimum DTV-into-DTV D/U ratio of 15.5 dB with desired signals well above threshold, and the undesired DTV signal is assumed to be noise-like.[30] While the noise figure of the cable television demodulator modeled is not specified, VSB demodulation techniques are comparable for most devices. If a potentially-interfering co-channel signal from an unlicensed transmitter is to cause no more than a 3 dB decrease in the effective sensitivity of the demodulator, its level, as received at the antenna terminals must be equal to or less than the internal noise level, or -95 dBm maximum. With that level of interfering signal, the fade margin for the headend, as a whole, will be decreased from 8 dB to 5 dB for that DTV station. Thus, this fade margin analysis is consistent with the above analysis based on maintaining a 23 dB D/U ratio at minimum average receive levels.

[30] ATSC A/74 *ATSC Recommended Practice: Receiver Performance Guidelines*, Advanced Television Systems Committee, June 18, 2004, paragraph 4.4.1.

The signal levels defining the proposed "protected contour" of DTV stations are +28 dBµV/m for low-VHF stations, +36 dBµV/m for high-VHF stations and +41 dBµV/m for UHF stations respectively.[31] As can be seen, the desired DTV levels are comparable to the defined Grade B contour levels for both VHF and UHF stations. They are, however, 7-9 dB higher than the minimum usable levels if a consumer receiver meeting ATSC A/74 specifications were connected to an antenna with 12 dBi gain (17 dBµV/m at channel 2, 27 dBµV/m at channel 7 and 36 dBµV/m at channel 14) and are consistent with the practice of cable television operators in securing better and more reliable reception for their customer base than that which an individual viewer using a roof-top antenna might tolerate.

Given the need to provide at least 23 dB D/U ratio between the desired DTV station and noise-like interfering signal from an unlicensed transmitter, the maximum allowable signal strength from the unlicensed device is shown in the next two lines of the table – the first for radiators within the primary beam of the antenna and the second for radiators located sufficiently off-axis to ensure that they are within the specified azimuth for sidelobe or rear rejection.

The problem is that these headends are not located within the predicted Grade B coverage areas, but far beyond those boundaries, with the antennas typically in high, exposed places because that is where they need to be to find adequate signal strength to ensure reliable reception for their customers. In many of these communities, off-air signals from those stations are unusable and sometimes virtually undetectable by homeowners using standard roof-top antennas.

Beyond the Grade B predicted contour limit, there is no assurance that any unlicensed device will not be located within the primary beamwidth of the headend receiving antenna, or that the assumed 6 dBi antenna will not be oriented towards the headend antenna. In such a case, the required path loss between a device and the headend antenna needed to ensure no more than a 3 dB reduction in fade margin for the headend demodulation can be calculated using:

$$L_P = - P_D + D/U + P_U + G_U + G_R$$

Where:
L_P = path loss in dB
P_D = desired DTV signal level at receiver input terminals
D/U = the minimum desired/undesired signal level ratio
P_U = unlicensed device transmit level in dBm
G_U = gain of unlicensed device antenna in the direction of the HE in dB
G_R = gain of headend antenna in direction of unlicensed device in dB

[31] NPRM at paragraph 29

For example, the required channel 4 (14 dBi antenna gain) path loss can be calculated for a 100 mW device as follows:

-Level of desired signal at receiver input:	72 dBm
+Required D/U ratio	23 dB
+ receiving antenna gain	14 dB
+Undesired transmit level	20 dBm
+undesired antenna gain	6 dB
=Required path loss	135 dB

For a 1W fixed/access device, the required path loss is 10 dB higher, or 145 dB.

Note that the total loss, considering all elements, between receiver input terminals and unlicensed transmitter (before antenna) is actually less than that used in New America Foundation (NAF)'s analysis, as analyzed by MSTV[32]. The required loss to protect the headend from portable unlicensed devices is only 115 dB [20 dBm+23 dB D/U-(-72 dBm receive level)], whereas NAF was analyzing the case for a hypothetical ATSC A/74-compliant receiver operated at threshold, which requires 126 dB. The differences in the analysis that follows, however, are many:

- NAF assumed that the unlicensed transmitter would always be located behind the receiving antenna, and thus benefit from the off-axis reduction in antenna gain, whereas this study analyzed both on-axis and off-axis situation, since either case can arise in the field.

- Furthermore, they assumed that the antenna gain off-axis would be -14 dB, whereas the FCC standard antenna is assumed to have a 12 dBi forward gain and a F/B ratio of 14 dB. Thus its off-axis gain would be -2 dB, not -14 dB. In the case of off-axis transmission, this study assumed sidelobe suppression and F/B ratio of 25 dB, which is superior to typical residential antennas.

- NAF assumed that the unlicensed device would be located inside a building, which would attenuate the signals by 6 dB, whereas there is no assurance that unlicensed devices would be so-located. In fact, in WiFi-equipped communities, users commonly use laptops with WiFi capability in parks and outside seating areas of restaurants. In any case, fixed/access devices will generally be located outside with antennas oriented to get as much coverage as possible, thereby combining higher transmit power with the lack of any building attenuation.

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[32] "Why unlicensed use of vacant TV spectrum will cause interference to DTV viewers," Victor Tawil and Bruce Franca, MSTV.

- NAF assumed that the unlicensed device gain in the direction of the receiving antenna is 0 dB, whereas the FCC has proposed allowing antenna gains of up to 6 dBi and there is no reason to assume those antennas might not sometimes be oriented in the direction of the DTV receiving antenna.

- NAF analyzed the situation only at 600 MHz, where path loss is much higher than at VHF channels.

Using more realistic assumptions, the required signal loss is shown in Table 5 for three representative channels.

Table 5: Required Path Loss to Avoid Interference with Headend DTV Reception

Unlicensed Device Power	Required Path Loss (dB) to Ensure Interference-Free Reception With Minimum Usable Desired Field Strength When 6 dBi Unlicensed Antenna is Oriented Towards Headend Antenna		
	Chan 2	Chan 7	Chan 14
100 mW on-axis	135	138	138
100 mW off-axis	110	113	113
1 W on-axis	145	148	148
1W off-axis	120	123	123

As a first approximation to determining required spacing between unlicensed devices and headend antenna, it is assumed an unrestricted path between the unlicensed device and headend receive antenna. Free-space path loss in dB can be calculated using the formula

$$L = 36.6+20\log(f)+20\log(d)$$ [33]

Where: L is the loss in dB
f is the frequency in MHz
d is the distance in miles.

Using this formula, the minimum distance required to achieve this required path loss is over 200 miles for a 100 mW co-channel unlicensed transmitter which is positioned within the beamwidth of the headend receiving antenna for any VHF or UHF channel. Thus, any unlicensed transmitter, portable or fixed, that is positioned between the headend and the DTV station and within the primary beamwidth of the receiving antenna and which transmits on a channel that is being received at a cable system headend will cause an unacceptable degree of interference to reception of the DTV station.

[33] *Reference Data for Radio Engineers*, Howard W. Sams & Co, 1977, Page 28-19.

In the case of unlicensed radiators which are located to the side or rear of the receiving antenna, the required distance is listed in Table 6. In each case, the required path loss is taken from Table 5, and the required distance to achieve that loss is calculated by solving the previous equation for distance.

Table 6: Required Distance between Off-Axis Unlicensed Devices and Headends

Unlicensed Device Power	Required Distance in Miles Between Off-Axis Unlicensed Transmitter and Cable Headend Antenna to Ensure Interference-Free Reception When 6 dBi Unlicensed Antenna is Oriented Towards Headend		
	Chan 2	Chan 7	Chan 14
100 mW off-axis	87	38	14
1W off-axis	274	120	44

Given the longest distances listed, the next question is over what distances might a free-space path calculation be valid.

Part of the art of cable television signal reception is finding optimal receiving locations in terms of both signal strength and freedom from multipath signals. In hilly country, this often means finding a mountaintop location, whereas in flat country, tall towers are the norm. As an example, a former employer of mine used several towers of 500-550' height for reception of Nashville signals that were provided to a number of smaller communities that were located roughly midway between Nashville and Memphis Tennessee. Towers in excess of 1000' were used by some operators. The approximate distance from an antenna at height T above the ground to the point of tangent contact with the earth is approximately:

$$D(mi) = (2\pi R/360)(90-\arcsin(1-T/R)$$

Where D is the path distance, R is the radius of the earth and T is the antenna height, all in consistent units.

An unlicensed, fixed transmitter using an antenna 30' off the ground would have a line of sight to a receiving antenna 500' above the ground if it was within about 48 miles. In the relatively flat terrain of Midwest, such situations could easily arise. If the receiving site were on a 1500' hill, the line-of-sight distance would increase to 77 miles.

What these calculations show is that it might be impractical to protect low-VHF receiving locations from even 100 mW co-channel unlicensed transmitters due to the low path-loss attenuation as a function of distance, while high-VHF operation may be practical for 100 mW devices and UHF operation may be practical for devices with power levels up to 1 W, provided adequate means can be found to define and protect receiving locations.

3.2 Minimum Distances Required Between Unlicensed Devices and Receiving Antennas at Cable Headends to Avoid Harmful Adjacent Channel Interference with Off-Air Signal Reception

The ATSC A/74 guidelines suggest that consumer receivers should be able to tolerate adjacent DTV signals as much as 33 dB higher in level than the desired DTV signal for small or moderate signals (up to -53 dBm), declining to 20 dB higher for strong signals (-28 dBm), probably due to intermodulation effects.[34] Although cable television DTV demodulators are not specified for adjacent channel DTV rejection, it is reasonable to assume that their adjacent channel protection capabilities are similar.

Further, it is assumed that either adjacent DTV signals or adjacent signals from unlicensed transmitting devices will appear noise-like to the demodulator and thus similar in their effect on reception.

Having said that, it is noted that the Commission has not specified bandwidth for unlicensed devices. Should the bandwidth of each television channel be subdivided, this raises the possibility of multiple interfering signals being received simultaneously and thus the total interfering signal power being higher than if devices used bandwidth of at least 6 MHz. Based upon the comments of some potential users regarding the likely uses of proposed unlicensed devices, operating bandwidth should either coincident with existing television channelization, or integral multiples of those channels.

Although there is certainly the possibility of high desired DTV signal levels at the input of headend demodulators, the reception conditions there are significantly different there than those presented to consumer receivers. While a consumer receiver will typically be tuned to many stations, whose strength may vary widely at the consumer's antenna, headend demodulators are tuned to a single channel and fed by a fixed antenna. Thus, any problem due to overload due to excessive signal level can easily be solved by inserting attenuation between the antenna and demodulator input. Given that, it is assumed that demodulators will always be working at or below the center of their dynamic range so that their adjacent channel rejection will not be degraded due to strong desired signals, and thus an adjacent channel rejection of 33 dB.

Using the analysis above, a headend in a weak-signal area should be able to tolerate unlicensed device field strengths on channels adjacent to those of DTV signals being received that do not exceed those listed in Table 7 (33 dB above the desired signal for on-axis unlicensed radiators and 58 dB above the desired signal for off-axis unlicensed radiators). The following rows show the field attenuation required to assure that unlicensed device fields are within the required limits, and the last rows show the required minimum distance between the unlicensed devices and headend receiving antenna, either on-axis or off-axis from that antenna.

[34] ATSC A/74, Paragraph 4.4.2.

Table 7: Factors Necessary to Protect Headend Reception of DTV Signals from Adjacent Channel Unlicensed Device Signals

Channel	2	7	14
Desired DTV Field Strength (dBμV/m)	26	33.2	41.8
Maximum Unlicensed Device Field Strength (dBμV/m),			
On-axis	+59	+66.2	+74.8
Side or rear	+84	+91.2	+99.8
Minimum Required Path Loss (rounded to nearest dB)			
100 mW on-axis	79	82	82
100 mW off-axis	54	57	57
1 W on-axis	89	92	92
1W off-axis	64	67	67
Minimum Required Distance Between Unlicensed Device and Headend (miles)			
100 mW on-axis	2.4	1.1	0.4
100 mW off-axis	0.14	0.06	0.02
1 W on-axis	7.7	3.4	1.3
1W off-axis	0.43	0.19	0.07

In summary:

- <u>Adjacent channel operation of 1W fixed/access devices is possible, but requires coordination at all channels and at all orientations relative to the receiving station's antenna azimuth.</u>

- <u>Adjacent channel operation of 100 mW portable devices is possible but, contrary to the Commission's tentative proposals, will require coordination to avoid interference, even if located off-axis of the receive antennas.</u>

3.3 Methods for Determining Television Channel Availability for Unlicensed Transmission

As the above analysis shows, unlicensed devices transmitting on either received or adjacent channels at levels as low as 100 mW have the potential for creating interference, even if prohibited from either co-channel or adjacent channel transmission within the predicted Grade B contours of DTV stations. No quantitative analysis was done to determine necessary distances to protect headend reception from 10-20 mW portable devices, but clearly, even at that level, coordination of some sort would be required. Furthermore, as is well known to the Commission and borne out by many years of experience:

- Television signals do not respect "predicted contour" levels. Many places within the contour boundaries have much lower than predicted levels, while signals may be received at Grade B reference levels or well beyond the predicted contour boundary.

- Both consumers and headends regularly receive signals beyond the predicted contour boundaries, either because of favorable signal paths, or because (especially in the case of cable) tall towers are constructed and favorable locations utilized to access signals which are not usable at lower elevations.

Because signals are, and will be, received outside the predicted Grade B contours, an adequate method must be found to protect reception of those signals. While NCTA represents franchised cable operators, the same concerns are valid for private cable operators, repeaters and individual homeowners using off-air antennas.

The Commission has proposed several means by which channel availability (or, conversely, occupancy) can be determined.

Prohibition of co-channel transmissions by either fixed or portable devices within the Predicted Grade B Contour Boundaries.

Based on the above analysis, this is certainly a mandatory restriction.

Prohibition of adjacent channel transmissions by fixed devices within the Predicted Grade B Contour Boundaries.

Based on the above analysis, this is certainly required to avoid interference. <u>Furthermore, such restriction must be extended to portable devices, given that such a device could cause destructive interference from as far as 2.4 miles away for a low-VHF station or as far as 0.4 miles away for a UHF station if it happened to be located within the beamwidth of the receiving station's antenna</u>.

Signal sensing to determine channel occupancy.

MSTV has discussed the problems with signal sensing at length in their filing. The basic problem, for residential reception, is that signal transmission is so highly variable, particularly in fringe areas, that they may be undetectable at the location of the unlicensed device, yet perfectly adequate at the consumer's antenna. This is not typically a situation where shared reception among a group of unlicensed devices (in which no device is allowed to sense a signal above some threshold) is of assistance, since the cluster of devices could be close together and all behind a building or small hill that is blocking reception, yet within clear line-of-sight to the DTV receiving antenna.

The situation is far worse for cable headend reception, where the cable system antenna may well be hundreds of feet above average terrain, and thus receiving adequate signals, while the level even 30' above the ground is undetectable or extremely low. As pointed out earlier, even a 500-foot tower extends the line-of-sight to a remote television transmitting antenna by about 29 miles, relative to a sensing antenna located 30' above the ground and by about 35 miles, relative to a sensing antenna located 6' above the ground.

The comparison to protection for radar installations is simply not valid, as both transmitter and receiver are co-located in a radar installation, with the result that the path loss from transmitter to unlicensed device sensing antenna is equal to the loss from the unlicensed device transmitting antenna to the radar receiver. Thus, if the unlicensed device detects a low radar signal, it can be assured that the radar receiver will receive only a small signal from the unlicensed device. This methodology clearly has no applicability to the current situation, in which receiving locations are widely dispersed and can be, in some cases, 100 or more miles distant from the television transmitting antenna (as was, for instance, the case at some cable systems owned by a previous employer of mine.)

Even if it were economically possible to build a super-sensitive receiver that could detect, at ground level, the residual signals from a distant television station at a level that would ensure no interference in any possible situation, it would likely cause the devices to avoid channels where there is no possibility of interference, and thus unnecessarily restrict the operation of such devices.

Simply put, the variability of signal transmission, combined with the sometimes-extreme measures taken by cable operators to receive adequate signals, make signal sensing a poor technology for determining available spectrum for unlicensed device transmission.

Receiving "beacon" signals from stations which include lists of available channels within the station's service area

The problem with the beacon signal idea is the same one as using Predicted Grade B Contour boundaries: there is no well-defined boundary beyond which the signals from the beacon signal transmitter will not be receivable. Even nominally line-of-site VHF and UHF signals have very irregular actual service areas that do not approximate Predicted Grade B Contours except in areas without hills or significant buildings.

While one approach might be to require that the unlicensed device receivers that detect these “beacon” signals require a strong signal in order to “un-squelch,” that has the same potential problems as with over-air signal sensing: it may unnecessarily restrict operation because of some local signal path obstruction.

Unlicensed device auto-location, combined with database access

The final approach proposed by the commission calls for unlicensed devices to include means to self-locate, such as through use of GPS. GPS receivers have greatly reduced in cost to the degree that they are included in new cellular phones as a means of facilitating 911 calls. The method is inherently fail-safe, since if the unlicensed device fails to acquire a good self-location signal, it will not transmit.

In addition to an adequate means of self-location, this method requires a cost-effective method by which the unlicensed device can access a reliable database which would contain identification of usable channels in that location. A system based on this combination of self-location-determination combined with reception of or access to a database containing information on eligible channels as a function of location offers a method of coordinating between operation of unlicensed devices (either fixed or portable) and headend receiving facilities, but requires further study.

APPENDIX I

COMMUNITIES WHERE SUDDENLINK PICKS UP LOCAL TELEVISION SIGNALS BEYOND THE PREDICTED GRADE B USING OFF-AIR ANTENNAS USUALLY LOCATED ON TALL TOWERS

DMA	Community	Customers
Oklahoma City		
	Blackwell	1,199
	Woodward	2,685
	Fairview	622
	Total:	4,506
Amarillo		
	Canadian/Childress	602
	Wellington	1,771
	Paducah	359
	Shamrock	594
	Total:	3,326
Odessa/Midland		
	Pecos	2,119
	Big Lake	628
	Total:	2,747
San Antonio		
	Ingram	1,305
Wichita Falls		
	Quanah	609
Houston		
	Trinity	841
Dallas		
	Clarksville	2,362
Shreveport		
	Idabel	961
Kansas City		
	Trenton, MO*	1,431
	Brookfield, MO*	1,074
	Total:	2,505
Pittsburgh		
	Oakland, MD	2,576
Los Angeles		
	Bishop	3,214
	Total Affected Subscribers:	24,952