Interference Analysis of Co-Sited DTV and NTSC Translators

Gary Sgrignoli

DTV Transmission Consultant

Abstract

Digital Television service has begun in all the major urban areas within the United States but has yet to significantly reach the rural areas. Often, translators are the only means of providing *free*, over-the-air television service to people living in these areas. One challenge is that while specific rules for operation and spectrum allocation exist for full-service stations in urban areas, there are currently no rules yet for DTV translator stations in rural areas. Another challenge is overcoming the scarcity of spectrum that exists under the old analog taboo interference rules. A key component in overcoming these challenges is to determine interference parameters in the form of desired-to-undesired (D/U) field strength ratios that will allow as many DTV and NTSC signals to co-exist as possible. Also, co-sited analog and digital translator sites utilizing low radiated power can be used for adjacent/taboo channel operation (NTSC next to DTV or DTV next to DTV) if careful engineering and planning are employed. Even *first* adjacent channel operation can be accomplished if proper effective radiated power (ERP) ratios are selected. This paper shows that a 10-dB NTSC-to-DTV power ratio and a 0-dB DTV-to-DTV power ratio is acceptable at a co-sited repeater site in order to avoid receiver interference among the co-sited signals. The choice of *absolute* radiated power levels depend on the desired coverage areas, the surrounding terrain, and required interference avoidance of potential weak signals from distant stations (if present). Co-siting repeaters and sharing as many of the common elements as possible such as combiners, feedlines, broadband antennas, test equipment, etc. allow many low-power DTV and NTSC signals to be transmitted together under well-controlled conditions, thereby allowing the most efficient use of precious spectrum. Further independent lab testing with current consumer DTV receivers is vital for improved channel allocation planning.

Introduction

Black and white analog television, commonly referred to by its historical name of National Television Systems Committee (NTSC), was adopted as the standard in the United States in 1941 (the color TV system was adopted in December 1953). In 1987, proceedings began in the U.S. when television broadcasters asked the Federal Communications Commission (FCC) to develop high definition television (HDTV) standards. This development turned into what today is known as digital television (DTV). When the FCC adopted the Advanced Television Systems Committee (ATSC) digital television system (**Ref 1**) as the U.S. standard on December 24, 1996, the transition from analog to digital television officially began. Rules for *full-service* digital television stations were developed and published (**Ref 2**). Likewise, the FCC's Office of Engineering and Technology (OET) published a set of guidelines on "Longley-Rice Methodology for Evaluating TV Coverage and Interference" (**Ref 3**) to aid broadcasters.

Great interest has been shown in recent years regarding the conversion from analog to digital television in the rural areas. Translators are often the primary means of bringing *free*, *over-the-air* television to rural viewers. However, television translators are secondary services, and must yield to full-service stations and Class A stations. This means that they may be displaced in frequency at any time (with an appropriate amount of advanced warning). So it is advantageous to develop methods that can best utilize the scarce spectrum presently available in order to bring more television signals to the rural areas, especially in this digital age when DTV is emerging. Of course, this cannot happen until the FCC determines and publishes their rules for television translators, and develops planning factors for spectrum use in the rural areas. An FCC Notice of Proposed Rulemaking (NPRM) came out in August of 2003 to start the rule-making process (**Ref 4**).

One way to improve rural spectral efficiency is to follow the same or similar FCC methodology used in the full-service station deployment over the past few years. However, in doing so, careful system engineering must be applied when deploying channels in a crowded spectral region. One of the primary goals is to avoid interference among the various analog and digital signals that are required to co-exist for a period of time (until analog turns off, i.e., goes "dark"). That is why spectrum-planning factors that employ interference limits and transmitter adjacent channel splatter limits via an emission mask must be developed for DTV translators. Some translator emission masks have already been proposed (**Ref 5**) for FCC consideration in their rule-making process.

In the field, interference occurs when "undesired" (U) signals become large enough to overload receiver front-end circuitry (i.e. the tuner) that is trying to receive a "desired" (D) signal. The ratio of the desired to undesired signal power levels, referred to as the D/U ratio, describes the interference level that causes a particular amount of distortion. While translator analysis in the past used transmitter power output (TPO) as the determining interference factor, more recent analysis used the actual effective radiated power (ERP) at the antenna output as the determining interference factor (which takes into account feedline loss and antenna gain). However, even this is not the final determining factor. Propagation effects, which are determined by height above average terrain (HAAT), transmitter and receiver antenna patterns, and terrain conditions over which the signal travels, must be included in the analysis. In reality, it is the net effect of *all* the signal powers at the input to the television receiver that will affect overload conditions along with tuner overload performance. Therefore, interference is not solely dependent upon TPO and ERP but rather the whole transmission system. Thus, a 1-Watt ERP undesired signal transmitter site may cause significant amounts of interference to a desired signal that is being received if the undesired signal is in close proximity to the receiver while the desired signal transmitter is a far distance away. Therefore, it is difficult to create rules that are based solely on TPO or even ERP of a transmitter site. Spectrum (channel) allocation must be accomplished using D/U planning factors based on typical receiver performance in the presence of both *relative* signal powers (e.g. D/U ratio) as well as *absolute* signal powers (e.g. strong, moderate, weak).

The following material describes interference between DTV and either existing analog NTSC signals or other DTV signals from *co-sited* transmitters, such as might be the case from a multiple-channel television translator site. That is, all the desired and undesired signals are co-sited, and share as much of the transmitter site infrastructure as possible such as *common* towers, feedlines, broadband antennas, directional coupler test points, and test equipment. The advantage of such an arrangement is that the *relative* DTV and NTSC signal levels observed and measured in the field will vary minimally. So the advantage of using co-sited transmitters (i.e. translator sites) leaves only differential propagation effects due to the use of different RF channels. Therefore, desired-to-undesired (D/U) signal power ratios can be essentially controlled in these co-sited cases by carefully adjusting the transmitter power output of each of the analog and digital transmitters.

Interference ratios depend upon careful determination and development of the planning factors. This is typically accomplished through precise laboratory testing of reference receivers (both analog and digital). The FCC's Advisory Committee on Advanced Television Services (ACATS) carefully administered this testing process during the Grand Alliance (GA) period. ACATS laboratory testing was performed from April 19 through July 21, 1995 at the Advanced Television Test Center (ATTC), a private, non-profit organization in Alexandria, VA that was supported by the television broadcast and consumer electronics industries. The GA HDTV receiver (8-VSB modulation system, MPEG-2 video coding, AC-3 audio coding, and MPEG transport data packet communication) was extensively tested under a variety of impairment and interference conditions. Likewise, 24 reference NTSC receivers were also tested in an optimally-designed viewing room at ATTC, and represented a good statistical cross-section of the consumer television receiver market from the early 1990s. The test plan used by ATTC (**Ref 6**) was approved by the FCC's ACATS group on March 24, 1995. After this date, including during the course of the GA test period at ATTC, various interpretations of, or actions on, the test plan were taken by the designated ACATS specialist group: System Subcommittee Working Party 2, System Evaluation and Testing (SS/WP2). The summary of these test results is documented in **Ref 7**, which was published in October of 1995. The original ATTC lab test results of the GA system and several subsequent lab tests, also performed at ATTC, are currently the only "official" and thorough interference lab tests readily available to the broadcast industry. These test results, which document the effects of interference on DTV and NTSC, will be used extensively in this paper. However, more "official" independent lab testing of *current* consumer DTV receivers is still needed for improved DTV channel allocation planning after the transition.

After all the testing and analysis was completed, ACATS then recommended the Grand Alliance HDTV system to the FCC on November 28, 1995. The FCC approved the standard (minus the video formats in Table 3) and published rules at the end of 1996, and OET guidelines were published shortly thereafter. A summary of the FCC planning factors for interference is shown in **Appendix 1**, along with a comparison to the OET Bulletin #69 interference ratios and the ATTC lab test results on which the planning factors are based. There were a few discrepancies identified in the original (July 1997) set of planning factors, but they were subsequently corrected in an updated version of the bulletin (February 2004). It should be noted that some of the fundamental aspects of the planning factors are currently in question, such as the use of *one* set of D/U ratios for *all* levels of desired signal power (weak, moderate, strong) at the receiver input. Likewise, the selection of interference impairment threshold criteria for given interference parameters is also being re-evaluated. For example, it should be determined whether the "just barely visible" distortion criterion (threshold of visibility, or TOV) should be used rather than a "slightly annoying" subjective CCIR-3 impairment rating (see notes in **Appendix 1** for a definition of the CCIR impairment ratings). The planning factors for a typical DTV receive site (e.g. antenna gain and front-to-back ratio, downlead loss, receiver noise figure, threshold signal-to-noise ratio, etc.) are not shown in the **Appendix 1** table. These DTV receiver parameters, while not addressed in this evaluation, are also being re-evaluated in order to provide more accurate spectrum allocation and service availability prediction (see **Ref 8** and **Ref 9**).

Since all the television signals considered in this evaluation are *co-sited* and assumed to *essentially* keep their relative signal strengths over the entire service area, the more stringent TOV interference into NTSC is considered rather than the CCIR-3 rating. This is due to the fact that nearby sites with strong signal would still have the same interference effects as those in the outlying areas. However, the typical methodology for TOV interference tests performed at ATTC is to *pulse* the interference on and off at approximately a 3-second repetition rate, which allows for repeatable subjective video and audio evaluation. This represents a "worst case" type of condition (i.e., there is some margin in this method). Also, given the scarcity of spectrum in many parts of the country, especially during the DTV transition period, it may be preferred to allow *some* further interference into the existing analog signals to a CCIR-4 rating level (i.e., "perceptible impairment, but not annoying"). This may be acceptable in the rural areas since many viewers do not even have this quality of video (and audio) even though they may be close to the translator site where NTSC signals are strong. A CCIR-4 rating (equivalent to a 40 - 43 dB C/N ratio) is still a very good picture, and is believed to be acceptable to a vast majority of people (urban or rural, terrestrial or cable). This is similar in philosophy to the 2% de-minimus interference allowance that the FCC used in allocating a second channel to the full-service stations in the mid-1990s. This may be the "thinking outside the box" that is needed during the transition years, especially towards the end of this period.

The following analysis is essentially based on the official laboratory measurements taken at the ATTC during the Grand Alliance HDTV system evaluation (April 19 – July 21, 1995). This is the primary official testing that was performed during this crucial time.

Its importance can be underscored by the fact that no other set of 24 analog reference NTSC receivers has been tested and evaluated as thoroughly and carefully as the ones at ATTC during this period. Therefore, the importance of this lab test data cannot be overemphasized. However, additional laboratory testing was found to be necessary, and was subsequently performed at ATTC over a period of time, using the same equipment as the original testing. Several supplemental ATTC documents were created as well (**Ref 10-13**). It should also be pointed out that the *only* DTV receiver tested during this time period was the Grand Alliance prototype receiver, since no other DTV receivers existed. It should be noted that the FCC planning factors were also based on the laboratory test results from this one DTV receiver.

The results and analysis described below are for interference testing between analog NTSC and digital ATSC (commonly referred to as digital television, or DTV). Of particular interest to digital translator rules is the amount of acceptable interference of DTV-into-NTSC, NTSC-into-DTV, and DTV-into-DTV, specifically quantifying the results in terms of desired-to-undesired (D/U) signal power ratios at the input terminals of the receiver. The ATTC lab testing concentrated on *single*-interference sources (e.g. adjacent channel or taboo) rather than multiple-interference sources (e.g. N+2 / N+4). However, from these single-interferer lab tests, some recommendations can be made for co-sited translator applications that will efficiently use scarce spectrum for DTV purposes. However, more “official” independent lab testing of *current* DTV receivers with *multiple* interferers is crucial for improved channel allocation planning.

DTV-Into-NTSC Interference Ratios - *No* Splatter

Interference into NTSC during the transition to digital television is a very important topic. Analog and digital signals must co-exist for a period of time until the analog signals go “dark”. For quite some time, the FCC has been collecting data relative to the interference rejection characteristics of NTSC receivers under different taboo relationships and signal level conditions. However, the FCC did *not* collect data relating to the front-end overload characteristics of these receivers. That is, the data obtained had been under weak and moderate desired NTSC signal levels (rather than strong) when determining the taboo channel interference levels (D/U ratios). The original FCC NTSC table of allocations was not designed to ensure that these receivers were not exposed to extremely high, undesired signal levels. This situation can be rectified in the current transition to digital by determining DTV interference limits to NTSC receivers at various desired signal levels (strong, moderate, and weak).

Table 1 summarizes the *entire* original DTV-into-NTSC interference lab testing performed at ATTC using the 24 reference NTSC television sets. Included in this chart are all the co-channel, adjacent channel, and taboo channel tests with *single* interferers, per the ACATS recommended test plan. Taboo channel interference from N-8 to N+8 is caused by inter-modulation and /or cross-modulation. There are exceptions such as N+4, N+14, and N+15 that have different mechanisms than the rest of the taboos. N+4 is the “half IF” case where the second harmonic of the local oscillator beats with the second harmonic of the undesired signal, causing the beat frequency falling in the television IF band. N+14 and N+15 are *linear* mechanisms that produce a sound and picture image, respectively.

Television receivers typically have low-Q front-end tracking filters that pass the desired signals and reject most of the undesired signals. However, they are not narrow bandwidth filters nor are they constant bandwidth filters since their bandwidth changes with center frequency. Often multiple adjacent channel signals pass through the filter to the preamplifier and mixer to cause overload. Automatic gain control (AGC) in NTSC receivers is derived from the desired signal to adjust the gain for a fixed baseband level. Both of these receiver subsystems (AGC and tracking filter) have an effect on taboo channel interference performance. In DTV receivers, it is possible that AGC will be derived from the combination of the desired signal and any undesired signals that pass through the front-end tracking filter, and this may provide significant improvement in DTV tuner overload performance.

Median D/U results are typically used for the interference values in laboratory analysis, which means that half of the reference NTSC televisions are below TOV interference at this ratio. This is the philosophy adopted by the ACATS lab test group as well as the FCC when channel allocation planning factors were selected for the full-service DTV station rules. However, a more conservative approach (whenever possible) can sometimes be used. For example, the D/U interference results for 83% of the sets (20 of the 24 reference TV sets) can be evaluated, which means that 83% of the NTSC TV sets will have TOV or better interference performance at this ratio. **Table 1** also contains this data as a comparison to the normative median values.

As previously stated, the FCC uses these *median* D/U values as planning factors in channel allocation. These values represent the interference D/U ratios that the *median* reference NTSC receiver exhibits in the field. Note that while these values in **Table 1** are for a DTV interferer with ***no*** adjacent channel splatter (per the ACATS test plan), only the *first* adjacent channel D/U interference ratios would be affected by this situation. That is, all the DTV-into-NTSC interference results in **Table 1** other than upper and lower *first* adjacent channel are still valid. Adjacent channel splatter will be addressed later in this paper, with valid interference numbers for DTV splatter being supplied.

The D/U ratios (for TOV) in **Table 1** describe all of the *weak* desired level tests. All test values (except N+8 *moderate* desired level, which reach the test bed’s dynamic limit) came from the *original* ATTC tests (**Tables 3-10A, 3-11A, 3-12A,** and **3-13A** on pages **I-3-16** to **I-3-22** in **Ref 7**). The D/U ratios describing all of the *strong* and one of the moderate (N+8) desired levels came from the DTV Taboo Interference supplemental test (**Table 1** on page **3** in **Ref 13**). Both laboratory tests used the original 24 reference NTSC receivers in the optimized viewing room and averaged the D/U results from three expert observer scores for each of the receivers.

The reason for the two different tests is that the original GA tests (as prescribed by the ACATS committee) did *not* measure the taboo channels under strong desired NTSC conditions since it was assumed that the likelihood of this level of interference would be minimal. That is, it was believed that the DTV signals would never get that large, even at receive locations close to the DTV transmitter. The general consensus at the time was that maximum DTV power levels encountered at the input of NTSC receivers would be similar to the expected NTSC power levels, that is –15 dBm. Therefore, the ATTC test bed was not originally designed to provide these high-power undesired taboo DTV signal levels. As a result, DTV interferer power levels were not sufficient to cause interference to more than 50% of the reference TV sets on all UHF taboo channels for a strong desired NTSC signal. Only taboo channel interference data for weak and moderate desired NTSC signals was measured originally.

However, in light of the FCC's decision (Memo Opinion and Order on Reconsideration of 6th Report and Order in **Ref 17**) to allow UHF stations to increase (maximize) their radiated power on general principles as well as through antenna beam-tilting techniques, it was thought appropriate to re-examine the DTV-into-NTSC taboo interference for *strong* desired NTSC levels (i.e. –15 dBm). However, the Grand Alliance test plan, as derived by the ACATS group, called for a strong desired NTSC signal level of –25 dBm for *first* adjacent channel interference tests rather than the –15 dBm used in previous rounds of testing. It was at this time that the N+8 taboo at moderate desired NTSC level was re-tested since a strong enough undesired DTV level could not be reached in the test bed during the original testing. During the ATTC supplemental testing, higher interfering DTV signal levels were obtained by adding a very linear amplifier (splatter > 45 dB) and removing one of the 4-way splitters (i.e., 7 dB loss removed), requiring only one bank of 8 NTSC receivers to be tested at a time. Tests at a few other desired NTSC levels were performed at this time, duplicating the original testing at ATTC as a "sanity check" to verify consistency with previous test results, but are not included in the table below.

TABLE 1 DTV-Into-NTSC Interference Ratios

TOV Thresholds with No DTV Splatter

Digital-Into-Analog CH Offset	Median D/U Strong Level D = -15 dBm (dB)	83.3% D/U Strong Level D = -15 dBm (dB)	Median D/U Moderate Level D = -35 dBm (dB)	83.3% D/U Moderate Level D = -35 dBm (dB)	Median D/U Weak Level D = -55 dBm (dB)	83.3% D/U Weak Level D = -55 dBm (dB)
-8	-6.90	-1.90	-16.11	-12.27	-31.62	-26.28
-3	-1.73	+0.77	-18.28	-14.95	-29.73	-25.06
-2	-1.43	+0.73	-15.00	-10.00	-23.74	-20.57
-1 *	+0.23	+3.73	-0.77	+2.73	-5.92	-1.25
0	-----	-----	+51.27	+52.43	+47.74	+48.40
+1 *	+0.26	+9.59	-1.92	**+11.41**	-1.95	**+10.38**
+2	-3.80	+0.87	-17.47	-15.30	-27.94	-21.10
+3	-5.55	-2.38	-19.79	-17.13	-34.13	-28.46
+4	-5.60	-1.27	-18.22	-15.88	-24.96	-19.63
+8	-9.77	-6.10	-22.97	-20.30 *	-43.22	-38.38
+14	-8.40	-4.07	-22.24	-19.24	-29.55	-23.21
+15	+1.29	+4.45	-14.54	-10.20	-17.58	-11.41

NOTE: Strong level is defined as –15 dBm, except in the tests for *first* adjacent channel where it is defined as –25 dBm; also affected by *lack* of DTV splatter

"Strong signal" plus "N+8 moderate" results from supplemental ATTC tests; all others from original ATTC tests

The –1.92 dB value for *upper* adjacent channel D/U at moderate desired level is corrected from the –2.09 dB value given in the ATTC test results

Consider only the taboo channel results (i.e., excluding the *first* adjacent channels since there was no DTV splatter present during the original testing). A +10 dB NTSC/DTV power ratio (i.e., *peak* NTSC signal power above *average* DTV signal power by 10 dB) at the *co-sited* transmitter site will provide TOV or better interference performance in 83% of the NTSC receivers.

Another result of the supplemental taboo lab testing is that the audio was determined *not* to be the dominant interference mechanism, but rather video. This is the same result as the adjacent channel interference test with splatter that will be described later in this paper.

The results from **Table 1** also indicate that the D/U interference ratios are *not* constant with desired NTSC signal level. Tracking filters and AGC can affect the interference performance as well as the overload capabilities of the front-end tuner circuitry. Limiting total power reaching a receiver, especially its mixer, is important in order to minimize overload problems. Sometimes this overload by multiple interfering signals is called "brute force overload" of the tuner front-end circuitry. It is possible that the FCC single interferer D/U ratios can be met and still have the NTSC tuner overload from multiple interferers.

It should be noted that the FCC's planning factors (6th Report and Order – **Ref 16**), are based on the ATTC taboo test results performed with "weak" (-55 dBm) desired NTSC signal levels, which may not be appropriate in coverage areas where moderate or strong NTSC signal levels exist. FCC planning factors for interference D/U ratios should take into account the desired NTSC signal level rather than use a constant value everywhere in the coverage area. Often, three desired NTSC signal levels are considered: weak (-55 dBm), moderate (-35 dBm), and strong (-15 dBm). Consideration of the desired *absolute* NTSC signal level as well as the *relative* D/U ratios is especially important when DTV stations apply beam-tilting techniques to increase their transmitted power for improved urban indoor reception or when single frequency network (SFN) systems boost their on-channel signal level for coverage extension.

Upper Adjacent DTV-into-NTSC Channel Color Beat & Audio Interference - *No* Splatter

Most of the planning factors used by the FCC for interference D/U ratios came from the GA lab tests at ATTC in Alexandria, VA in 1995 (April 19 – July 21). During the adjacent channel interference testing, an unexpected result occurred in the *upper* adjacent channel DTV-into-NTSC test involving both the NTSC chroma and audio responses. This data can be found in the ATTC test results document (see pages **I-3-17** to **I-3-20** in **Ref 7**). It should be noted that the initial ATTC lab testing was performed with an interfering DTV signal with adjacent channel splatter that was at least 51 dB below the in-band DTV power (see **Figure 2-1** on page **I-2-3** in **Ref 7**), and probably as much as 60 dB below (based on conversations with former ATTC staff). In other words, there was essentially ***no*** DTV splatter from the interfering DTV signal. This situation did not take into account "real-world" adjacent channel splatter caused by high power amplifier non-linearity as allowed by the FCC rigid emission mask. Despite the lack of DTV splatter (which was corrected in subsequent ACATS testing at ATTC), the results described below still provide a good theoretical understanding of the interference mechanisms. The following paragraphs describe the test process and results, and subsequent supplemental tests that reflect these "real-world" DTV splatter conditions.

Adjacent channel tests were performed to determine *both* TOV and CCIR-3 impairment rating D/U ratios for DTV interference into NTSC. However, a CCIR-3 rating is used when determining D/U ratios that might be expected at the fringe of the coverage area, where two adjacent channel signals coming from different cities might be present. (CCIR-3 is *not* used when considering adjacent channel signals from co-located or near-co-located transmitter sites in the same city). As the interfering DTV signal was increased to determine CCIR-3 interference limits on the 24 reference NTSC receivers, the expert observers noted that *some* (not all) of the receivers exhibited a low-frequency "color beat" that occurred during the camera-pan portion of the "Texas Sign Dude" (M14) test image (where a man walks across the screen in the beginning part of the test clip). This occurred at all three desired NTSC signal levels (strong, moderate, and weak). The experts also noted that these *same* TV sets often had some color noise and color desaturation (and under some interference conditions, a few of the sets went "black and white" due to activation of the "color killer" circuitry). This color beat that was observed on some of the sets had an impairment equivalent to a CCIR-3 rating at a lower level of interference than what the final expert observer "vote" indicated. In other words, the color beat was ignored during the official "voting" for CCIR-3 interference levels in favor of the expected noise-like impairment. However, this phenomenon was disconcerting to the testers, and therefore investigated thoroughly by the ATTC labs and by the Grand Alliance.

The impairment observed by the expert observers during the camera-pan portion of the test scene took the form of low frequency, diagonal color stripes (beat pattern). Subsequently, a carefully executed test revealed that the beat pattern was always present in the image, but that it was exacerbated during the motion of the man in the scene due to eye-tracking of that motion by the observers. It was experimentally found that by shaking one's head from side-to-side (forced motion), the color beat was observed to be present all the time. It was determined that if the color beat found in some of the NTSC sets were *not* ignored but considered in the voting process of the expert observers, then the color beat was shown to be the dominant video impairment for this test equipment.

A summary of the color beat test results can be found in the original ATTC documentation (pages **I-3-18** through **I-3-20** of **Ref 7**). The color beat from the upper adjacent channel DTV signal was observed to be the dominant visual effect (CCIR-3) at all three desired NTSC signal levels. The "voted" median upper adjacent channel D/U ratio (*ignoring* the color beat impairment) for a CCIR-3 impairment of the 24 reference receivers was determined to occur at -16.91 dB at a weak (-55 dBm) desired NTSC level, -13.03 dB at a moderate (-35 dBm) desired NTSC level, and -13.00 dB at a strong (-25 dBm) desired NTSC level. Again, the ACATS group decided to use –25 dBm as the strong desired NTSC signal level in these first adjacent channel interference tests rather than the –15 dBm used in the previous rounds of testing. However, the color beat impairments on some of the 24 reference NTSC sets occurred with less interference than the "voted" CCIR-3 video impairment levels. At the –55 dBm weak desired NTSC level, the color beat was predominant on 8 receivers (2.0 to 14.2 dB less interference needed for CCIR-3 than that determined by the original vote), degrading the *median* CCIR-3 level of the 24 receivers by 1 dB. At the –35 dBm moderate desired NTSC level, the color beat was predominant on 13 receivers (9 to 26 dB less interference needed for CCIR-3 than determined by the original vote), degrading the *median* CCIR-3 level of the 24 receivers by 11.5 dB. At the –25 dBm strong desired NTSC level, the color beat was predominant on 10 receivers (7.1 to 17.9 dB less interference needed for CCIR-3 than determined by the original vote), degrading the *median* CCIR-3 level of the 24 receivers by about 4 dB. It is obvious that there is a great deal of *variability* in this upper adjacent channel interference color beat impairment (up to 11.5 dB) among the various reference NTSC receivers.

Subsequent Grand Alliance analysis of this upper adjacent DTV-into-NTSC color beat interference is documented in a later section of the ATTC test results (pages **I-15-9** to **I-15-14** in **Ref 7)**. It was noted that the fixed diagonal stripe beat pattern observed during camera-panning motion sequences in the test video were often accompanied by, depending upon the D/U ratio, a "streaky noise-like" impairment and a reduction or complete loss of color. The significant variation of performance among the 24 representative reference NTSC receivers was *generally* due to the different NTSC receiver design tradeoffs made by the set designers. The chroma channel in the NTSC receivers is a cascade of the 44 MHz IF band-pass filter (often a surface acoustic wave/SAW type), the 4.5 MHz intercarrier sound trap (usually piezoelectric type), and the chroma take-off band-pass filter or modified high-pass filter (typically LC type).

Upon examination of the cascaded response, it can be shown that some TV receivers have significant response in the adjacent channel, even peaking at the pilot frequency residing at 5.06 MHz above the desired NTSC picture carrier. This extension of the chroma response into the adjacent channel has not been a problem in the past since the FCC did not allocate terrestrial NTSC broadcast stations adjacent to each other. While cable TV systems have many analog NTSC channels adjacent to each other, the relative signal levels are well controlled and within 3 dB of each other, thus minimizing interference effects. Also, the upper adjacent channel NTSC signal as experienced on a cable system does not have significant energy much beyond (lower than) the picture carrier, which is 1.25 MHz above the lower bandedge. However, an adjacent channel DTV signal has significant energy down to the pilot frequency, which is only 309 kHz above the lower bandedge. Therefore, both the small in-phase VSB pilot plus the nearby noise-like data energy pass through the cascaded filters in some of the NTSC receivers. The VSB pilot beats with the NTSC 3.58 MHz color sub-carrier (5.06 – 3.58 = 1.48 MHz) to create a low-frequency "diagonal stripe" beat while the noise-like DTV sidebands are converted down to low-frequency noise (as viewed on the TV screen) where they are visible as color noise. The total interference energy (noise-like data plus the continuous wave pilot) affects the color circuit's automatic gain control, which measures the color burst level (after time gating). It then regulates the color difference output level of the chroma amplifier for consistent matrixing with the luminance (which is regulated by the IF and tuner AGC circuitry). The effect of the interference is noticeably reduced color amplifier gain, which then causes reduced color signal level and desaturation. In the extreme case, this causes the TV's "color-killer" circuit to shut down color demodulation and display a black and white picture. In addition to the color noise, there was also some high-frequency luminance noise observed due to the in-band DTV signal leaking through cascaded filters plus any residual adjacent channel splatter noise from the DTV transmitter and NTSC tuner intermodulation. At small D/U ratios (i.e. high level of undesired interference), the luminance noise also degrades the signal to near CCIR-3 impairment levels. Similar to the color beat, there is also a very high-frequency 5.06 MHz luminance beat (between the NTSC picture carrier and the adjacent channel DTV pilot carrier). Of course, variations in receiver design from one TV receiver to the next modify the above analysis. Trap widths and depths for IF, video, and sound filters can vary, thus causing either improved or degraded performance. This explains the wide variation in adjacent channel DTV-into-NTSC D/U ratios measured during the ATTC lab tests.

The median of the 24 reference receivers used during the ATTC lab tests was determined to occur at an upper adjacent channel D/U interference ratios of -16.91 dB at a weak (-55 dBm) desired NTSC level, -13.03 dB at a moderate (-35 dBm) desired NTSC level, and –13.00 dB at a strong (-25 dBm) desired NTSC level. At these large upper adjacent channel DTV interference levels (i.e., average DTV power between 13 dB and 17 dB *above* peak NTSC power) along with an adjacent channel NTSC receiver response, it is not surprising that there are various interference factors such as color noise, color desaturation, 1.48 MHz color beat, luminance noise, and a very high 5.06 MHz frequency luminance beat.

One other effect was observed at the initial ATTC lab testing of the Grand Alliance system in 1995. It was determined that, for all three desired NTSC levels (strong, moderate, and weak), the audio signal quality was affected ("slightly annoying" CCIR-4 rating) at larger D/U interference ratios (i.e., less interference) than for a video CCIR-3 impairment level. This means that the audio performance was the limiting factor at strong and moderate desired NTSC levels. A CCIR-4 audio impairment rating was used instead of a CCIR-3 rating at strong and moderate desired levels since audio is expected to be better than the video in most circumstances. A CCIR-3 audio rating was used only at the fringe area where the desired NTSC signals are weak. This audio interference predominance over video was a surprise since this effect was not observed in the first round of (proponent) testing in 1992 where objective audio testing (measured total harmonic distortion or decrease in stereo separation) was performed rather than *subjective* listening. During the 1995 Grand Alliance *upper* adjacent channel DTV-into-NTSC interference testing, audio impairment was deemed to be the limiting factor. An explanation of this phenomenon can be found on pages **I-4-1** to **I-4-11** as well as on pages **I-15-3** to **I-15-7** in **Ref 7**. However, this result was subsequently nullified when testing was repeated with FCC-allowed DTV splatter present (as explained later in this paper).

Similar to the color beat situation, the audio interference analysis showed that the variations in NTSC receiver design. In this case, the cascaded sound processing filtering of the SAW IF filter and the 4.5 MHz ceramic IF filter as well as "hard-limiting" variations affecting FM performance) produce a wide variation of upper adjacent channel interference performance. The median TV (with a worst case visual-to-aural carrier ratio of 13 dB) was found to have this occur at a D/U ratio of –12 dB rather than the –17 dB ratio for a CCIR-3 video impairment rating. This difference of 5 dB indicates more sensitivity in the audio channel than the video channel.

A summary of the *original* ATTC *upper* adjacent DTV-into-NTSC (without DTV splatter) lab test results of the Grand Alliance HDTV system is shown in **Table 2**. Data, which includes both video and audio interference results from the original testing, is taken from the ATTC lab test results (**Table 3-11A** on page **I-3-19,** and **Tables 4-1, 4-2,** and **4-3** on pages **I-4-1** through **I-4-9** in **Ref 7**). Since CCIR-3 impairments are being measured and no DTV splatter is present, strong interference levels are tolerated, with D/U ratios reaching near –17 dB. However, at these strong undesired DTV levels, the color beat and color noise/desaturation is worse than what would be tolerated if DTV splatter were present, thus limiting acceptable D/U values under these no-splatter conditions.

Note that the color beat increases (worsens) the *median* values of CCIR-3 video D/U ratios 1 to 11.5 dB (moderate desired NTSC levels are the worst). Likewise, median values of audio CCIR-4 D/U ratios are more restrictive (limiting) than the median values of video CCIR-3 D/U ratios. The median NTSC receiver still had good upper adjacent channel interference performance even when the color beat is taken into account (D/U ratio between –15.9 to –1.46 dB). Note that the worst-case D/U ratio for the 83rd percentile of

CCIR-3 color beat impairment rating is +11.04 dB. As a reference, 13 of the 24 reference NTSC receivers had noticeable color beats, and only 10 of these 13 had interference levels below that of the desired signal (i.e. positive D/U ratios).

The preliminary conclusion from this analysis was that upper adjacent channel spectrum allocation by the FCC would be limited by the *color beat* and the *audio* interference (note that audio data in **Table 2** has more restrictive D/U ratios than voted video D/U ratios). However, as will be shown later in this paper, this is not the case when "real world" adjacent channel splatter from DTV transmitters is taken into account since splatter limits the D/U ratios to interference levels where the color beat and audio impairments are insignificant. Despite the presence of the color beat, the worst-case *median* D/U ratio is only about -1.5 dB, which indicates that co-sited NTSC and DTV transmitters with a 10 dB power ratio would have acceptable results (i.e., NTSC *above* DTV by 10 dB). Even the 83rd percentile evaluation indicates that a +10-dB NTSC-to-DTV ratio would survive (with some sets showing a color beat at a CCIR-3 impairment level).

TABLE 2 Upper Adjacent DTV-into-NTSC Channel Interference

CCIR-3 Thresholds for Color Beat and CCIR-4 Thresholds for Audio with No DTV Splatter

Desired NTSC Level	Median CCIR-3 Voted *Video* w/o Color Beat Impairment	Median CCIR-3 Adjusted *Video* w/Color Beat Impairment	83% CCIR-3 Adjusted *Video* w/Color Beat Impairment	Median CCIR-4 *Audio* V/A = 13 dB Impairment	83% CCIR-4 *Audio* V/A = 13 dB Impairment
(S / M / W)	**D/U (dB)**	**D/U (dB)**	**D/U (dB)**	**D/U (dB)**	**D/U (dB)**
Strong -25 dBm	-13.00	-8.52	+3.12	-11.80	-9.05
Moderate: -35 dBm	-13.03	-1.46 *	+11.04	-10.78	-4.03
Weak: -55 dBm	-16.91	-15.91	-2.91	-11.85 **	-7.85 **

* This test result is a corrected version of ATTC median value of undesired level (-33.54 rather than -37.54) using raw data from **Table 4-2** on page **I-4-6** in **Ref 7**

** This test result is for CCIR-3 rating since the test plan focused only on CCIR-3 at the *weak* desired NTSC level

Upper Adjacent DTV Channel Frequency Offset Techniques

In order to mitigate the color and luminance beat problem, ATTC recommended the use of *precision* frequency offset between the desired NTSC signal and the undesired upper adjacent interfering DTV signal. This is described in the ATTC test results (pages **I-14-67** to **I-14-70** in **Ref 7**). The *nominal* frequency difference between the small DTV pilot carrier (which has its power 11.3 dB below the *total* average DTV power in 6 MHz) and the NTSC visual carrier can be determined as follows:

$$F_{PILOT} - F_{VISUAL} = F_{CHROMA} + 94.055\,556 * F_H = (455 / 2) * F_H + 94.055\,556 * F_H = 5.059\,440\,6 \text{ MHz}$$

$$F_{PILOT} - (F_{CHROMA} + F_{VISUAL}) = 94.055\,556 * F_H = 1.479\,895\,1 \text{ MHz}$$

where F_H is the NTSC horizontal scan frequency of 15.734 kHz (= 4.5 MHz / 286). It was determined that if the frequency difference between the pilot carrier frequency and the NTSC color subcarrier frequency was changed (F'_{PILOT}) to be an *odd* multiple of *half*-NTSC-line rate, the color beat would be "integrated" in the human visual system in the same manner as the 3.58 MHz color subcarrier, which is also an odd multiple of half-NTSC-line rate (455* ½). That is,

$$F'_{PILOT} - F_{VISUAL} = F_{CHROMA} + (191 / 2) * F_H = (455 / 2) * F_H + 95.5 * F_H = 5.082\,167\,8 \text{ MHz}$$

$$F'_{PILOT} - (F_{VISUAL} + F_{CHROMA}) = (191 / 2) * F_H = 1.502\,622\,4 \text{ MHz}$$

where 191 is the odd multiple of half-line rate. This is the desired frequency difference between the pilot and color subcarrier, which means that the DTV pilot carrier should be offset by:

$$F'_{OFFSET} = F_{PILOT} - F'_{PILOT} = 5.082\,167\,8 \text{ MHz} - 5.059\,440\,6 \text{ MHz} = +22.727\,2 \text{ kHz} \quad (\pm 1 \text{ kHz})$$

Note that the required tolerance is *not* critical since the offset is compared to about 7.85 kHz (i.e. half-line rate). However, while this would essentially remove the low-frequency color beat (1.48 MHz), it would not remove the remaining high-frequency luminance beat (5.09 MHz). For full-service stations, the FCC *requires* upper adjacent channel DTV signals to a have *precise*-frequency offset so that the high-frequency luminance beat will be removed by the human visual system via video frame interleaving. This requires an additional 29.97 Hz offset, which leads to the final DTV pilot frequency requirement (F''_{PILOT}):

$$F''_{PILOT} - F_{VISUAL} = (455 / 2) * F_H + 95.5 * F_H - 29.97 = 5.082\,137\,9 \text{ MHz}$$

$$F''_{OFFSET} = 5.082\,137\,9 \text{ MHz} - 5.059\,440\,6 \text{ MHz} = +22.697\,3 \text{ kHz} \quad (\pm 3 \text{ Hz})$$

However, it should be noted that precision frequency offset only removes the color beat ("diagonal stripes") and does ***not*** mitigate the color noise, color desaturation, and luminance noise effects. Only improved analog NTSC receiver design or lower D/U ratios can solve these problems. Also, the effect of the high-frequency luminance beat is not as objectionable to the human eye as the low-frequency color beat since the human visual system acts like a low-pass filter just as the TV picture tube transfer function has a roll-off response with increasing frequency. For these reasons, it may *not* be necessary to employ precision frequency offset in low-power, co-sited translator situations where D/U ratios can be kept relatively high (i.e., lower interference levels) and much better controlled. Also, only those NTSC receivers with poor adjacent channel response in their color circuitry will exhibit these problems. And finally, any other naturally occurring impairments (noise, multipath, etc.) will tend to hide any color and luminance beat artifacts.

To determine the effectiveness of the selected upper adjacent channel precision frequency DTV pilot offset to reduce or remove the color beat in some of the reference TV receivers, the ATTC laboratory conducted a supplemental color beat test on 11/27/95 (**Ref 10**). Tests were performed at the three nominal desired NTSC signal levels used in lab testing (weak @ -55 dBm, moderate @ -35 dBm, and strong @ -25 dBm). In the absence of the Grand Alliance modem equipment, a continuous wave (CW) carrier was placed in the upper adjacent channel of a desired NTSC signal at the same frequency utilized by the DTV pilot carrier. The equivalent CW pilot signal was placed 309 kHz above the lower bandedge of the adjacent channel and its level adjust to 11.6 dB below where the total average power *would* have been had the complete DTV signal been used. Three different CW interference carrier frequencies were used: nominal, worst-case offset, and best-case offset. Three expert observers viewed the 24 reference NTSC receivers to independently rate the effects of the interference caused by such a CW carrier using the 5-point CCIR impairment rating method (described in **Appendix 1**). However, this test determined the effectiveness of reducing the color & luminance beats due to the pilot *without* any color or luminance noise (from the noise-like data signal) that normally would accompany these beats and tend to hide them.

The level of the interference carrier was set at the 80^{th} percentile (best 19 of the 24 reference sets) as measured in the original ATTC testing of BTSC Audio degradation (page **I-4-1** through **I-4-9** in **Ref 7**), which also measured the color beat interference effect. The selected *equivalent* D/U ratios of the *upper* adjacent channel interference for each of the three desired NTSC signal levels were: weak (-55 dBm) had a D/U ratio of -8 dB, moderate (-35 dBm) had a D/U ratio of -8 dB, and strong (-25 dBm) had a D/U ratio of -5 dB. These D/U ratios (80^{th} percentile) are overall more conservative than the median (50^{th} percentile, adjusted for color beat impairment) values reported in the original ATTC test report.

The test results show almost one CCIR-rating point of improvement (using median values) for the optimum frequency offset case compared to the non-offset case for the weak (CCIR-3.2 to CCIR-4.1) and moderate (CCIR-3.0 to CCIR-3.8) desired NTSC signal levels. No significant improvement was observed at strong level (CCIR-3.9 to CCIR-3.8). However, it should be pointed out that since only a CW interferer (representing the DTV pilot) was used without the noise-like data modulation, any masking of the beat by the noise or color desaturation that normally occurs in the affected TV sets was absent. The lack of the random data allowed the improvement to be viewed as better than it might have been if the complete interfering DTV signal were present. For the D/U ratios tested, the CW beat was judged at 3.0 or higher with no offset, which is not a problem at weaker desired levels occurring at the fringe of coverage area where the receiver noise masks the color beat. Finally, all of these reasons plus a proposed transmitted NTSC-to-DTV ratio of +10 dB may provide even better results (less noticeable color beat interference) for the weak and strong desired NTSC levels. Therefore, no frequency offset may be needed in most co-sited, low power translator situations. Of course, only an exact re-testing of the 24 reference TV sets would give the exact answer. However, if it was determined that there was unacceptable color-beat interference in a statistically significant number of NTSC receivers in the coverage area, a lower-cost, *non*-precision frequency offset implementation (±1 kHz tolerance) can be used with acceptable results. Naturally, further lowering the DTV signal (i.e., larger D/U ratio) is also a possible solution.

Another separate DTV carrier frequency offset verification test was performed by ATTC on August 30, 1996 and documented on October 22, 1996 (**Ref 11**). This test, which was primarily performed to verify the adjacent channel DTV-into-NTSC interference with DTV splatter present, also verified the carrier frequency offset selection with a complete DTV signal (not just with a CW carrier). With the precise carrier offset implemented, no color stripe artifact was observed on any of the 24 reference NTSC sets at any of the interference threshold D/U ratios. This once again indicates that the pilot carrier offset is effective at eliminating the "color stripe" beat (but not the color noise and desaturation problem).

DTV-Into-NTSC Adjacent Channel Interference - *With* Splatter

All of the above analysis is of lab test data on the Grand Alliance system when the undesired interfering DTV signal had essentially no splatter (i.e., the splatter was at least 51 dB below the in-band power, and perhaps as great as 60 dB below). However, the *first* adjacent channel DTV-into-NTSC and DTV-into-DTV interference D/U ratios are greatly affected by the amount of allowable DTV splatter energy in the adjacent channel. This DTV splatter is primarily due to non-linearities (both 3^{rd} order and 5^{th} order) that arise in the high power amplifier (HPA) utilized at transmitter sites. The intermod products not only fall within the DTV channel but also into the upper and lower adjacent channels. The out-of-band splatter appears as *co-channel* to any *first* adjacent NTSC or other DTV signals. This splatter is present in high-power transmitters employed in full-service DTV stations as well as low-power transmitters employed in DTV translators.

The *original* FCC emission mask defined in the 5th Further NPRM (**Ref 14**) was used in the initial spectrum allocation planning. The concern in the industry was that there was little implementation margin in the FCC's planning factors, even when considering that the original emission mask was designed with an assumed DTV average ERP 12 dB below that of the adjacent channel NTSC peak sync ERP. This was an important issue since 20% of the originally allocated DTV channels were first adjacent to NTSC stations in the 6th Further NPRM (**Ref 15**). Therefore, subsequent ATTC lab tests were performed on August 30, 1996 (**Ref 11**) with the intention of determining whether there was any implementation margin in the interference D/U ratios between adjacent channel NTSC and DTV signals when using the (original) FCC emission mask, and quantifying the results. Note that the original FCC mask is identical to the "simple" rigid emission mask proposed for use in DTV translators (**Ref 5**).

The general approach to the test was to assess the DTV splatter interference into NTSC from a typical 8-VSB signal with adjacent channel splatter that just met the then-proposed original FCC emission mask (i.e., shoulders at –35 dB and progressing down to –60 dB in a quadratic manner as explained in **Ref 5**). The lab test was performed with adjacent channel DTV splatter generated by controlled amounts of non-linearities in a solid-state IF amplifier just before upconversion. This undesired signal was placed on either side of the desired channel 23 NTSC signal (upper fist adjacent channel 24 and lower first adjacent channel 22), which was at a moderate (-35 dBm) level. The same 24 reference NTSC receivers and the same NTSC program material (M14 "Texas Sign Dude") were used once again for the expert observer subjective viewing tests. TOV was determined once more by *pulsing* the interference signal on and off at a 3-second rate to differentiate the interference from the program material, which provides a conservative (worst-case) test result of at least 2 to 3 dB.

The upper and lower adjacent DTV-into-NTSC interference results, shown respectively in **Figure 1** and **Figure 2**, represent the relative power levels at which each of the NTSC receivers just start to show an impairment as judged by each expert observer, i.e. at TOV. The *lower* adjacent channel DTV interference into NTSC had a *median* D/U ratio of 11.33 dB while the *upper* adjacent channel interference had a *median* D/U ratio of 7.33 dB. Note that the spread of the lower adjacent channel interference is not as great as that of the upper adjacent channel interference.

An interesting comparison was made at the ATTC with respect to the TOV (*not* CCIR-3) interference ratios for DTV signals *with* and *without* adjacent channel splatter, as shown in **Table 3** (taken from **Table 4** on page **12** of **Ref 11**).

Table 3 Comparison of DTV-into-NTSC TOV interference levels
With and Without DTV Splatter

D-into-N Condition	Lower Adjacent Channel D = -35 dBm D/U (dB)	Upper Adjacent Channel D = -35 dBm D/U (dB)
DTV interference @ TOV *with* splatter	+11.33	+7.33
DTV interference @ TOV *without* splatter	- 0.77	-1.92 *

Corrected value from original ATTC lab test results using the accompanying raw data

NOTE: DTV splatter matching the original FCC emission mask limits

Note that the *difference* in TOV levels is about 12 dB for the *lower* adjacent channel and 9.5 dB for the *upper* adjacent channel, which is a significant amount. This means that in "real-world" applications, the DTV signal (compared to the NTSC signal) cannot be as strong as originally thought, which means that the operational limit is essentially determined by the *linear* distortion caused by the adjacent channel splatter (which acts as a *co*-channel interference) rather than the non-linear distortion caused by the adjacent channel cross-modulation interference (overload). This fact explains why the original ATTC testing without splatter showed the interference on the NTSC sets as *impulsive*-type noise (due to *non*-linear cross-modulation) and the subsequent ATTC tests with splatter showed the interference as *random*-type noise (due to linear co-channel splatter).

Note that a +10 dB NTSC-to-DTV ratio makes the median NTSC receiver TOV interference threshold for the upper adjacent channel but misses by 1.3 dB on the lower adjacent channel. However, the ATTC laboratory determination of TOV used a conservative methodology of *pulsing* the DTV interference on and off at a 3-second rate, which is at least 2-3 dB worse (visually) to an average lay viewer than if no pulsing were used. Furthermore, the number of NTSC TV sets that are affected by this TOV impairment are only in locations where the desired NTSC signal level is strong or moderate (> -45 dBm), relatively noise-free (SNR > 51 dB), and relatively impairment-free (no multipath, impulse noise, co-channel, etc.). Otherwise, any amount of white Gaussian noise (or other impairments) in the receiver would tend to hide the "just barely visible" TOV interference from the adjacent (taboo) DTV signals. Finally, if a CCIR-4.5 rating picture (≈ 45 dB SNR) were observed on a minority of rural NTSC television sets, a very satisfying viewing experience would still occur. Therefore, a +10-dB NTSC-to-DTV transmission ratio should provide satisfactory results.

During this particular splatter test where the DTV pilot and the NTSC visual carrier and chroma subcarrier were set for precision-frequency offset (following the guidelines in the previous section), not one of the 24 reference NTSC sets showed a color beat. However, it should be remembered that a *precise* frequency offset of the DTV carrier is *not* needed to remove the color beat, but rather a non-precise offset that has only about ±1 kHz tolerance. Precision offset is required to remove the remaining small 5.08 MHz luminance beat, which often is not as significant or as noticeable as the color beat. Also, the color beat is not such a strong phenomenon when the D/U ratios are large (i.e. small interfering DTV signal), which is the required situation when DTV splatter is present and is the limiting factor. For the proposed 10 dB ratio of NTSC to DTV in co-sited translator cases, this is particularly true.

Also, since the DTV splatter required this large (positive) D/U interference ratio, there was no *audio* interference observed during this specific ATTC test. This means that the DTV splatter into the adjacent channel NTSC *video* signal is the primary limit of performance and not the NTSC audio (as originally believed).

Another observation regarding the above lab test results is that the original FCC estimate of an NTSC-to-DTV ratio of 12 dB (for equivalent coverage area to an NTSC CCIR-3-rating level) did not have enough operational (implementation) margin in the FCC's channel allocations when using the *original* emission mask. This is why the FCC emission mask was subsequently made more stringent, which then changed the above DTV interference D/U ratios. This is thoroughly covered in **Ref 5**.

The resulting D/U values show that a co-sited DTV and NTSC signal can co-exist without interference if the transmitted ERP levels are carefully determined and controlled. **Figure 3** is a summary plot of the DTV-into-NTSC adjacent channel and taboo interference test results, and refers to the interference data in **Table 1** with the *first* adjacent channel splatter results from **Table 3** replacing their non-splatter counterparts. It should be noted that these types of laboratory tests are performed at moderate or strong *desired* NTSC signal levels (large S/N ratios) and with no other impairments (e.g. ghosts) or interference (e.g. co-channel). These conditions produce a very clean NTSC picture. This makes them a *worst*-case type of situation since any small amount of DTV splatter interference will be observable and not hidden by other impairments. Also, the conservative test methodology of *pulsing* the interference signal on and off at a 3-second rate minimally adds an additional couple of dB of margin. These factors make a convincing case that DTV signals that meet the proposed "simple" rigid emission mask and are transmitted 10 dB below their co-sited first adjacent NTSC neighbors produce acceptable coverage and interference results.

NTSC-into-DTV and DTV-Into-DTV Adjacent Channel Interference - *No* Splatter

Interference of NTSC into a DTV signal is an important topic during the transition period. However, interference of one DTV signal into another is not only an important topic *during* the transition but also *after* the transition ends when all the DTV channels are re-packed into the current core spectrum CH 2 – CH 51 (barring any FCC rule changes). Therefore, broadcasters and DTV receiver manufacturers are continually investigating this issue. The lab test data taken at the ATTC on the Grand Alliance prototype is the only data that was considered by the FCC when they created their planning factors for DTV reception since no other DTV receivers existed at that time. However, future independent lab tests should include current DTV receivers.

Table 4 shows the results of NTSC and DTV interference (@ TOV) into a desired DTV signal taken during the *original* ATTC testing of the Grand Alliance transmission system, all taken from the ATTC test result document (**Ref 7**). Co-channel interference data is taken from **Table 3-10B** (on page **I-3-17**), the first *upper* adjacent channel interference from **Table 3-11B** (on page **I-3-20**), the first *lower* adjacent channel interference from **Table 3-12B** (on page **I-3-21**), and the DTV taboo channel (N±2, N±3) from **Table 3-13B** (page **I-3-26**).

TABLE 4 Interference Ratios into DTV
TOV Thresholds with *No* DTV Splatter (BER Method)

	NTSC-into-DTV	DTV-into-DTV	NTSC-into-DTV	DTV-into-DTV	NTSC-into-DTV	DTV-into-DTV
DTV CH Offset	D/U @ Strong Level D = -28 dBm	D/U @ Strong Level D = -28 dBm	D/U @ Moderate Level D = -53 dBm	D/U @ Moderate Level D = -53 dBm	D/U @ Weak Level D = -68 dBm	D/U @ Weak Level D = -68 dBm
(*)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
-3	< -22.07	< -20.95	< -47.06	< -45.98	< -61.79	< -60.61
-2	< -23.19	< -21.83	< -48.23	< -46.80	-62.45	-60.52
-1	< -23.18	< -13.35 *	-44.46	< -38.23 *	-47.73	-41.98 *
0**	-----	-----	+ 1.40	+ 14.78	+ 1.81	+15.27
+1	< -23.18	< -17.58 *	-44.44	-39.32 *	-48.71	-43.17 *
+2	< -23.88	< -22.35	< -48.87	< -47.33	-59.86	-59.13
+3	< -23.10	< -21.99	< -48.08	< -46.98	< -62.49	< -61.53

* *First* adjacent channel would be affected by *lack* of DTV splatter
** Co-channel case with *no* frequency offsets as recommended by the Grand Alliance
"<" indicates the ATTC test bed was unable to produce a strong enough interfering signal to reach median TOV threshold

Not unexpectedly, the co-channel NTSC-into-DTV interference D/U ratios are very low (+1.4 dB and +1.8 dB) due to the NTSC rejection (12-symbol subtractive comb) filter employed in the Grand Alliance prototype receiver. This means that the peak sync NTSC power of a co-channel interferer can be 2 dB *below* the total average power of the desired DTV signal without causing errors. It should be noted that an NTSC rejection filter (typically activated only when co-channel NTSC is detected) comes with 3.5-dB white noise threshold degradation. However, newer DTV receiver designs have mitigate the use of a rejection filter, and thus have removed the 3.5 dB white noise threshold penalty in the presence of co-channel NTSC interference. The co-channel DTV-into-DTV interference result is essentially equal to the 15 dB white noise threshold of the 8-VSB system since the interfering co-channel DTV signal is a “noise-like” random-data interference.

The NTSC-into-DTV *first* adjacent channel interference test results could not be obtained for TOV at *strong* desired signal levels due to a signal level limitation in the test bed. However, the results for moderate and weak desired signal levels show very small D/U ratios (-44 dB to -49 dB) due to the robust nature of the Grand Alliance tuner. First adjacent channel DTV-into-DTV results are also very low (-42 dB to -43 dB), but it must be remembered that this test was administered with *no* interfering DTV splatter. Therefore, these tests produced much more severe D/U ratios than what would be useable in the “real world” of non-linear transmitter splatter. The next section deals with “real world” DTV splatter.

For the taboo channel tests (both undesired NTSC and DTV) at strong and moderate desired levels, the problem encountered again was that the test bed could not provide strong enough undesired NTSC or DTV signal levels in order to determine TOV threshold levels for N±3. Only at the N±2 weak desired level tests was TOV able to be reached. Also note that no other taboo channels were tested beyond third adjacent (N±3), presumably since it was known that the Grand Alliance prototype employed a robust double-conversion tuner (image frequencies outside the TV band) with a very good tracking band-pass filter at the front end. However, this may not be the case in all consumer DTV receivers.

The FCC used the *weak* signal results from above in their spectrum planning factors. For the Grand Alliance prototype, the taboo channel performance was so good (often immeasurable) that the FCC chose to not consider (NC) these D/U ratios in their spectrum allocation planning (see **Appendix 1**). Given that current DTV receivers often do not use double-conversion tuner methodology as the Grand Alliance prototype did, perhaps the NTSC-into-DTV and DTV-into-DTV taboo planning factors used by the FCC should be “revisited” to determine if they should remain “not considered” (NC) in the future. Again, more independent laboratory testing is needed for current DTV receivers.

It should be noted that the first adjacent channel DTV-into-DTV planning factors were subsequently changed in a revised OET Bulletin #69 (February 2004) by the FCC when the supplementary lab test results became known with interfering DTV splatter (next section). Likewise, the DTV-into-NTSC interference D/U planning factors were also changed at this time to match those values published in the FCC rules. However, the DTV-into-NTSC results *with* splatter (from a previous section of this paper) have yet to be changed in the FCC planning factors. That is, the –14 dB and –17 dB in the FCC rules and in OET Bulletin #69 for lower and upper adjacent channels, respectively, do not reflect adjacent channel DTV splatter.

DTV-Into-DTV First Adjacent Channel Interference - *With* Splatter

After the “6th Report and Order” required an emission mask to limit adjacent channel DTV splatter for the protection of *first*-adjacent analog and digital channels, there was concern in the industry regarding the FCC planning factors used to allocate a second 6 MHz channel to all TV stations in the U.S. The concern was due to the fact that the FCC planning factors were based on the Grand Alliance lab tests at the ATTC that were performed (according to the ACATS test plan) using DTV signals that had essentially *no* adjacent channel splatter emissions. Therefore, the effects of DTV splatter were not evaluated in the original ACATS testing. Just as in the DTV-into-NTSC case, subsequent laboratory tests were developed and conducted to determine if the (original) FCC RF mask provided sufficient protection to adjacent DTV channels. Therefore, subsequent ATTC lab tests were performed on July 7, 1997 (**Ref 12**) with the intention of determining whether there was any implementation margin in the interference D/U ratios for adjacent channel DTV signals when using the original FCC emission mask, and to quantify the results.

All of the tests performed during the original ACATS lab testing process were done in a controlled environment with linear amplification, and with the DTV adjacent channel splatter more than 50 dB down. A practical high power DTV transmitter, however, will create 3rd order and 5th order intermodulation products in channels adjacent to the DTV channel. Therefore, it was proposed to repeat some of the adjacent channel tests using a DTV signal with maximum permissible splatter energy as defined by the (original) FCC emission mask in the 6th Report and Order.

With significant adjacent channel splatter (as in a practical transmitter amplifier), the *total* average DTV power in the sidebands (regardless of the exact spectral shape) is the dominant interference mechanism in adjacent channel DTV operation rather than the in-band power of the undesired adjacent DTV channel. Of course, this assumes a reasonably well-designed DTV tuner with good overload performance (e.g. front-end circuitry such as tracking bandpass filter, preamplifier, mixer, and wideband AGC). This adjacent channel splatter, acting like co-channel interference to another DTV first-adjacent neighbor, is *noise*-like in nature. If the adjacent channel splatter has the exact shape of the maximum permissible (original) FCC mask, the *total* sideband splatter power (in 6 MHz) is about 39 dB below the *total* in-band average power (in 6 MHz). When compared to the 15-dB white noise threshold of the 8-VSB-transmission system, the 39 dB down splatter would theoretically allow a -24 dB D/U ratio for adjacent channel DTV operation at TOV (i.e., using up the entire noise threshold). Note that the proposed “simple” mask is equivalent to the original FCC emission mask.

The lab test was performed with adjacent channel splatter spectrum approximating the amount and shape allowed by the original FCC mask (-35 dB close-in “shelves as described in **Ref 5).** These sidebands were once again generated by controlled amounts of non-linearities in a solid-state IF amplifier, and this undesired DTV signal was upconverted to a channel on either side of the desired channel 23 DTV signal (upper and lower *first* adjacent channel). The desired DTV signal level was either at a moderate (-53 dBm) or a weak (-68 dBm) level (strong desired signal not tested). The limit of operation was again defined at the TOV threshold of the Grand Alliance 8-VSB demodulator as determined by averaging three 20-second bit-error rate measurements ($3x10^{-6}$ or less for each of the three measurement intervals). The D/U power ratio for TOV was then recorded.

The results of the test (taken from **Table 1** on page **6** of **Ref 12**) were that the *lower* adjacent channel D/U ratio (for TOV) was –23 dB while the *upper* adjacent channel D/U ratio (for TOV) was –21 dB. The asymmetry in the results between upper and lower adjacent channels was believed to be due to the slight (2 dB integrated power) difference in the amount of splatter from the undesired test signal in each sideband. The resulting D/U values were significantly different (about 20 dB *lower*, i.e., more stringent) from those found in the original ATTC lab tests that did not use DTV splatter. **Table 5** illustrates the comparison between the first adjacent D/U thresholds with and without the interfering DTV splatter. This supports the theoretical prediction that the *dominant* interference mechanism is the total sideband DTV splatter power (*linear* co-channel effect) rather than the interfering in-band DTV power (*non*-linear cross-modulation effect).

TABLE 5 DTV-into-DTV Interference Ratios

TOV Thresholds with DTV Splatter *

Test Conditions	Desired Signal Level	Lower Adjacent Channel Desired DTV Channel = N Undesired DTV Channel = N-1	Upper Adjacent Channel Desired DTV Channel = N Undesired DTV Channel = N+1
TOV with Sidebands	Moderate -53 dBm	-23.09	-21.15
TOV with Sidebands	Weak -68 dBm	-22.83	-21.15
TOV with***out*** Sidebands	Moderate -53 dBm	< -41	-37.40
TOV with***out*** Sidebands	Weak -68 dBm	-41.87	-38.23

* Splatter equal to *original* FCC Emission Mask (which is the same as the proposed "simple" translator emission mask)

Of course, these values are modified when using DTV splatter that conforms to the more stringent current FCC emission mask defined in the 6^{th} Report and Order (see **Ref 17**). The new mask has adjacent channel splatter that integrates to about 44 dB below the total in-band power, or about 5 dB *less* total splatter interference than the original mask. The current FCC planning factors for adjacent channel D/U ratios are adjusted to –28 dB and –26 dB for lower and upper adjacent channels, respectively (decreasing the previously measured D/U ratios by the theoretical 5 dB integrated splatter power difference). Of course, the assumption is that any well-designed DTV receiver would have its own *non*-linear D/U threshold limit (due to *non*-linear cross modulation) much farther away than the theoretical -29 dB linear D/U limit. This can be verified by lab measurement of the first adjacent DTV-into-DTV D/U ratios (upper and lower) with *no* splatter as a comparison check.

Note that these values are for TOV operation (the edge of the "digital cliff", where errors just begin to occur) and *not* for use at co-sited DTV translator sites. Since the adjacent channel DTV splatter is noise-like in nature, it will add to any front-end DTV receiver white noise, with the two noise components determining the minimum signal level of error-free operation. Therefore, the DTV splatter noise will essentially increase the "equivalent noise threshold" of any DTV receiver. For this reason, the D/U ratio used in any planning factors for co-sited DTV translators cannot be such that it "uses up" the entire noise margin leaving no room for receiver white noise at or near the fringe area where SNR values are lower. Therefore, a more conservative set of D/U ratios must be used (e.g. such as those suggested in **Ref 5**) so that the nearby coverage area around the co-sited translators does *not* have significantly degraded noise margins. If different values of noise threshold *degradation* need consideration, then different D/U planning factors can be determined (adjusted) with the following equation:

$$\mathbf{D/U\ (dB)} = -\left[\ \mathbf{U/S\ (dB)} + 10 * \log \left\{ 10^{(-THR(dB)/10)} - 10^{(-SNR(dB)/10)} \right\} \right]$$

where SNR is the signal-to- *white*-noise ratio, U/S is the *undesired* signal's in-band-to-integrated-splatter DTV power ratio for a signal complying with a given emission mask (e.g. U/S = 39 dB for the simple mask and U/S = 44 dB for the stringent mask), THR is the desired DTV signal's TOV threshold (≈15 dB), and D/U is the required desired-to-undesired signal ratio at the location under test. An example D/U interference ratio adjustment (de-rating) values versus receiver SNR is plotted in **Figure 4** for the two proposed translator emission masks ("simple" and "stringent"). U/S is fixed (either 39 dB or 44 dB) along with THR (the 15-dB TOV threshold), while SNR is varied. As different values of desired receiver SNR are inserted into the equation, D/U limits are calculated for the receive site.

BTSC Audio Interference

The original ACATS tests at ATTC had determined that upper adjacent channel DTV-into-NTSC interference ratios was limited by audio rather than video (**Ref 7** on page **I-3-18** and **I-4-1** through **I-4-11**). Of course, this determination has been reversed since the original ATTC lab tests did not use an interfering DTV signal with adjacent channel splatter (i.e. it was over 51 dB below the in-band DTV signal power), which resulted in D/U ratios (e.g. –17 dB) that were far too low. When "real world" splatter is taken into account, the D/U interference ratios must be increased (i.e. lower undesired signal levels), which then causes the video to be the dominant interference mechanism.

Another separate audio interference threshold test was performed by the ATTC on August 30, 1996 (**Ref 11**). This test, which was primarily performed to verify the *first* adjacent channel DTV-into-NTSC interference with DTV splatter present, also verified the video interference threshold precedes the audio interference threshold on all 24 reference NTSC sets. This result was verified at D/U ratios of +6 dB and with a *worst*-case visual-to-aural carrier ratio of 13 dB (see **Table 3** on page **11** in **Ref 11**). This, of course, is due to the fact that "real world" DTV splatter limits the D/U thresholds (primarily video interference) to levels that do not have audible interference, despite the close proximity of audio carrier to the DTV channel.

As a final verification of audio performance in the presence of undesired DTV signals, audio interference was re-evaluated during the supplemental tests for DTV taboo channel interference into NTSC under strong signal conditions performed by the ATTC and reported on October 1, 1998 (**Ref 13**). Channels N+2 and N+14 were tested, and once again it was verified that video is the dominant interference mechanism (D/U interference ratios) rather than audio, even with worst-case 13 dB NTSC visual-to-aural carrier ratios.

Multiple Interferers

During the supplemental DTV-into-NTSC taboo channel testing (**Ref 13**), a brief multiple interferer test was performed at the strong desired NTSC level (-15 dBm). An N+2 and an N-2 interfering DTV signal were *simultaneously* added to a desired strong NTSC signal. The combined effect of multiple interferers caused the NTSC receivers to fail at lower undesired signal levels than they would have individually. This result was expected, and not surprising. Therefore, two or more taboo interferers operating at equal lower power levels than an NTSC signal would cause interference greater than a single interferer. However, quantifying the exact interference level is not an easy task, thereby suggesting the need for more theoretical analysis and laboratory measurement work.

Therefore, more "official" independent lab testing using the 24 reference NTSC receivers would be required in order to accurately determine the combined effect of multiple DTV interferers from co-sited analog and digital television translators. However, it is known that digital signals (similar to VSB) have been put on cable or Multipoint Microwave Distribution Systems (MMDS) microwave channels at essentially equal signal levels and do not cause severe degradation to any desired NTSC signals or other DTV signals if appropriate D/U ratios are maintained. Therefore, if the co-sited NTSC signals were all equal to each other, and the DTV signals were all equal to each other, and the DTV signals were 10 dB below any NTSC signals at the same, there should be no mutual interference among any of the signals.

Also, note that multiple adjacent DTV channels (i.e. simultaneous upper and lower first adjacent channels) surrounding a desired analog or digital channel will have their splatter power added which increases the interference into the desired signal. This total interference power can be calculated by adding the two statistically independent splatter powers together in *linear* form (in Watts, not in dB).

Proposed Supplemental Testing

As pointed out previously, the entire overload testing of DTV receivers to date upon which the FCC planning factors were based has been performed on the original Grand Alliance prototype DTV receiver. At this point in time, there have been many different consumer DTV receivers sold on the market. Tests should be performed on these units as well, preferably by an independent laboratory, with the results made public. Tests should include the same *single* interferer tests described above, including both NTSC-into-DTV and DTV-into-DTV. One set of laboratory tests on consumer DTV receivers was performed and reported by ATTC in April 2003 (**Ref 18**). Six DTV receivers (5 set-top boxes and 1 integrated unit) were tested, among other things, for first adjacent channel NTSC-into-DTV at the usual three desired signal levels (strong at –28 dBm, moderate at –53 dBm, and weak at –68 dBm). The results are tabulated in **Table 6**. Note that none of the consumer DTV receivers met the FCC planning factors of –48 dB and –49 dB for first adjacent NTSC-into-DTV.

In addition to single interferer tests, *multiple* interferer tests can be performed. Different groupings of multiple interferers should be tested. For instance, it is known that third order intermodulation occurs when interfering signals occur in certain pairs of adjacent channels. For example, all of the following can create third order modulation products that fall within the desired DTV channel (N): N+1/N+2, N+2/N+4, N+3/N+6, N-1/N-2, N-2/N-4, N-3/N-6, etc.

These types of combinations should be evaluated as well as simultaneously loading up six or eight (or more) DTV and NTSC channels to check for overload performance of DTV receivers. However, there are an extremely large number of possible channel combinations, especially when different power levels are considered. One thing that can be done to reduce the testing to reasonable proportions is to make all the DTV signals equal to each other, all the NTSC signals equal to each other, and the DTV signal levels 10 dB *below* the NTSC signal levels. Tests should be performed at a minimum of three different desired signal levels (strong, moderate, and weak). Care must be taken when testing significant numbers of multiple interferers to minimize the effects of additive broadband noise from each of the individual transmitter outputs. These effects can be accomplished with appropriate channel filtering.

TABLE 6 NTSC-into-DTV TOV Interference Ratios for Consumer Receivers

	Lower Adjacent Channel NTSC-into-DTV			Upper Adjacent Channel NTSC-into-DTV		
DTV Rx Brand	D/U @ Strong Level D = -28 dBm	D/U @ Moderate Level D = -53 dBm	D/U @ Weak Level D = -68 dBm	D/U @ Strong Level D = -28 dBm	D/U @ Moderate Level D = -53 dBm	D/U @ Weak Level D = -68 dBm
(*)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
A	-23	-30	-30	-24	-37	-41
B	<-28	-35	-35	<-28	-32	-34
C	-27	-32	-41	-26	-32	-41
D	<-28	-30	-34	-27	-29	-34
E	<-28	-42	-41	<-28	-39	-44
F	<-28	-39	-39	<-28	-39	-37

Note: NTSC visual/aural ratio was 13 dB; no undesired signal levels above 0 dBm were used during the strong level test

Co-Sited Analog and Digital Translators / Transmitters

Appendix 2 contains a summary table of all the TOV interference D/U ratios for strong, moderate, and weak desired signal levels. This chart includes first adjacent channel test results with interferer DTV splatter present. From this chart, the worst-case D/U ratios for co-sited analog and digital transmission signals (on different channels since co-channel signals cannot exist at the same transmitter location) are those with the largest values (most positive).

For DTV-into-NTSC interference, this worst-case value shown in **Appendix 2** is 11 dB, and describes the first upper adjacent channel. All of the other taboo channels allow ratios well below the +10 dB D/U ratio (i.e. NTSC 10 dB *above* DTV) being proposed for co-sited NTSC and DTV translator signals. This means that the DTV signals will not cause interference into the NTSC signals or other DTV signals. According to this chart, the first upper adjacent channel DTV signal, in theory, should be operated at 11 dB below NTSC. However, it should be noted once again that the TOV test methodology (including pulsing) was used to obtain this number, which makes it conservative. Also, the philosophy of using a CCIR-4 (or CCIR-4.5) rating interference limit can be utilized in the spirit of "thinking outside the box" in order to use the scarce spectrum efficiently. Of course, the simple emission mask can be replaced with the stringent emission mask (see **Ref 5**) to gain an additional 10 dB of margin for DTV-into-NTSC interference or another 5 dB of margin for DTV-into-DTV interference. Lastly, in certain instances (such as first adjacent DTV to NTSC), the D/U ratio used could be set to 12 dB, and in most cases achieve the same coverage area as the existing NTSC signals.

For DTV-into-DTV interference, the worst-case value shown in **Appendix 2** is –21 dB, which describes the first upper adjacent channel interference. This indicates a significant amount of margin of the 0-dB ratios (i.e., equal DTV powers) proposed for co-sited DTV translators.

The analysis above indicates that *co-sited* analog and digital signals sharing common equipment is a good method to efficiently using spectrum. Therefore, old analog taboo channels can be utilized, just as they are in "wireless cable" (MMDS) systems that employ 31 contiguously adjacent channel NTSC signals (all at equal powers). NTSC receivers can easily receive MMDS signals (or many more signals on Cable TV systems) because all the carriers are carefully controlled to be approximately the same power, especially for first adjacent channel signals which are required to be within 3 dB of each other. This same principal can be used with analog and digital television translators that are co-sited. If all the NTSC signals are roughly the same power as each other and all the DTV signals are approximately the same power as each other and 10 dB below that of the NTSC signals, many channels can be utilized in areas where few were available before. Of course, this applies to interference among all the co-sited translator signals and not any distant city signals that may experience interference out in the fringe area.

Not all taboo channels have the same protection ratios, as determined by the above analysis from measured NTSC and DTV receivers. Some general recommendations should be considered when designing co-sited multiple analog or digital translator sites. They are listed below, in order of importance.

1) Try to co-site all the signals, using the same tower, directional coupler test points, test equipment, feedline, and broadband antenna to minimize signal propagation variations and to maintain consistent D/U ratios throughout the service area.

2) If separate antennas must be used (e.g. odd and even channels), use two identical antennas (same azimuth and elevation gain patterns) at the same height on the same tower.

3) Try to keep all analog NTSC signals at equal power, all DTV signals at equal power, and NTSC-to-DTV power ratios at 10 dB.

4) Whenever possible, space all the signals apart, such as second adjacent (to avoid first adjacent channels)

5) If using a first adjacent channel is required, put the DTV signal on the *lower* first adjacent channel of an NTSC signal

6) If DTV is on a first adjacent channel next to NTSC, determine if the DTV signal level can remain at 10 dB below the NTSC signal or if it needs to be lowered 2-3 dB (D/U ratio increased to 12-13 dB), for reduced interference, while maintaining desired coverage area.

7) If DTV is placed on a first adjacent channel next to NTSC, determine if using a stringent emission mask is required for more margin.

8) If DTV must be on the first *upper* adjacent channel to an NTSC signal, determine the need for a DTV pilot carrier frequency offset.

9) If a DTV pilot carrier offset cannot be avoided, use a *non*-precise +22.727 kHz (± 1 kHz) offset (i.e. avoid costly precision frequency offset methods).

Summary and Conclusion

This paper provides an evaluation of the previously measured interference ratios at the ATTC during and after the Grand Alliance era. The original test data plus that obtained from subsequent supplemental testing is summarized along with test methodology and data analysis. From the above analysis, which is summarized in **Appendix 2**, some conclusions can be determined and applied to *co-sited* analog NTSC and digital ATSC translator signals.

1) DTV translators often do not require large transmitter ERP values (often less than 500 Watts).

2) Transmitting a DTV signal with an average power (in 6 MHz) 10 dB below the peak-sync power of a co-sited NTSC signal on *any* of the adjacent channels will not cause visible interference on NTSC or DTV receivers.

3) Co-sited DTV signals meeting the proposed "*simple*" emission mask can be transmitted in a channel first adjacent to NTSC signals if the average DTV signal power is 10 dB below the NTSC peak sync power. Under these conditions, no significant degradation will occur to the co-sited NTSC signal (CCIR-4.5 rating or better). If more margin is needed in the service area, the proposed "*stringent*" emission mask can be employed to obtain an additional 10-dB protection.

4) Co-sited DTV signals meeting the proposed "*simple*" emission mask can be transmitted in a channel first adjacent to other DTV signals at the same average power. Under these conditions, no more than 0.1 dB of threshold degradation will occur to either of the co-sited DTV signals. If more margin is needed in the service area, the proposed "*stringent*" emission mask can be employed to obtain an additional 5 dB of protection.

5) For low power translators transmitting NTSC signals with co-sited first *upper* adjacent channel DTV signals, it is *not* be required to have precision-carrier frequency-locking of DTV signals that are 10 dB below the NTSC signals. If by some (small) chance low-frequency color beat interference is observed in a significant percentage of NTSC sets in a given coverage area, then a *non*-precise frequency offset (+22.727 kHz ±1 kHz) can be used to remove the low-frequency color beat, ignoring the insignificant high-frequency luminance beat.

6) DTV interference into an adjacent channel NTSC audio signal, even with the visual-to-aural ratio of 13 dB, is *not* a limiting factor for co-sited translator signals, but rather the interference into NTSC video.

7) Many co-sited NTSC and DTV translator signals are possible, just as used in "wireless cable" (MMDS) systems, if the transmitter ERP ratios are selected to be 10 dB for NTSC-to-DTV and 0 dB for DTV-to-DTV.

8) More independent laboratory testing needs to be performed on consumer NTSC and DTV receivers to gain further insight into impairments from multiple interfering signals, such as N-4/N-2, N-2/N-1, N+1/N+2, or N+2/N+4 that can produce undesired third-order intermodulation products within the desired signal channel. Likewise, it is recommended to test consumer NTSC and DTV receivers with 6 or more adjacent channel analog and/or digital signals.

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APPENDIX 1

Current FCC Interference Planning Factors

Planning Factor	FCC Rules 73.623(c)	OET-69 {Table 5a & 5b}	ACATS / ATTC { I-3-14 to I-3-26}	Corrections {see Note 1}
	D/U Ratio (dB)	**D/U Ratio (dB)**	**D/U Ratio (dB)**	**D/U Ratio (dB)**
Co-Channel:				
DTV-into-NTSC (CCIR-3 @ weak)	+34	+34	+33.81	
NTSC-into-DTV (TOV @ weak)	+ 2	+ 2	+ 1.81	
DTV-into-DTV (TOV @ weak)	+15	+15	+15.27	
Lower Adjacent Channel:				
DTV-into-NTSC (CCIR-3 @ weak) see **Note 2**	-14	-14	-15.96	**-6**
DTV-into-NTSC (TOV @ weak) see **Note 4**	---	**---**	+11.33	**+10**
NTSC-into-DTV (TOV @ weak)	-48	-48	-47.73	
DTV-into-DTV (TOV @ weak) see **Note 3**	-28	-28	-41.98	
Upper Adjacent Channel:				
DTV-into-NTSC (CCIR-3 @ weak) see **Note 2**	-17	-17	-16.91	**-10**
DTV-into-NTSC (TOV @ weak) see **Note 4**	---	**---**	+7.33	**+10**
NTSC-into-DTV (TOV @ weak)	-49	-49	-48.71	
DTV-into-DTV (TOV @ weak) see **Note 3**	-26	-26	-43.17	
UHF Taboo Channels: DTV-into-NTSC				
N-2 (TOV @ weak)	-24	-24	-23.73	
N+2 (TOV @ weak)	-28	-28	-27.93	
N-3 (TOV @ weak)	-30	-30	-29.73	
N+3 (TOV @ weak)	-34	-34	-34.13	
N-4 (TOV @ weak) see **Note 6**	-34	-34	**------**	
N+4 (TOV @ weak)	-25	-25	-24.96	
N-7 (TOV @ weak) see **Note 6**	-35	-35	**------**	
N+7 (TOV @ weak) see **Note 5, 6**	**-43**	**-34**	**------**	**-34**
N-8 (TOV @ weak)	-32	-32	-31.62	
N+8 (TOV @ weak)	-43	-43	-43.22	
N+14 (CCIR-3 @ weak)	-33	-33	-33.38	
N+15 (CCIR-3 @ weak)	-31	-31	-30.58	
UHF Taboo Channels: NTSC-into-DTV				
N-2 (TOV @ weak)	NC	NC	-62.45	
N+2 (TOV @ weak)	NC	NC	-59.86	
N-3 (TOV @ weak)	NC	NC	< -61.79	
N+3 (TOV @ weak)	NC	NC	< -62.49	
N-4 (TOV @ weak)	NC	NC	-----	
N+4 (TOV @ weak)	NC	NC	-----	
N-7 (TOV @ weak)	NC	NC	-----	
N+7 (TOV @ weak)	NC	NC	-----	
N-8 (TOV @ weak)	NC	NC	-----	
N+8 (TOV @ weak)	NC	NC	-----	
N+14 (CCIR-3 @ weak)	NC	NC	-----	
N+15 (CCIR-3 @ weak)	NC	NC	-----	
UHF Taboo Channels: DTV-into-DTV				
N-2 (TOV @ weak)	NC	NC	-60.52	
N+2 (TOV @ weak)	NC	NC	-59.13	
N-3 (TOV @ weak)	NC	NC	< -60.61	
N+3 (TOV @ weak)	NC	NC	< -61.53	
N-4 (TOV @ weak)	NC	NC	-----	
N+4 (TOV @ weak)	NC	NC	-----	
N-7 (TOV @ weak)	NC	NC	-----	
N+7 (TOV @ weak)	NC	NC	-----	
N-8 (TOV @ weak)	NC	NC	-----	
N+8 (TOV @ weak)	NC	NC	-----	
N+14 (CCIR-3 @ weak)	NC	NC	-----	
N+15 (CCIR-3 @ weak)	NC	NC	-----	

Note 1:. A TOV *subjective* impairment is defined as threshold of visibility, and is the level of interference that is" just barely visible" (for DTV, this corresponds to a MEG packet-error rate of 2.5 packets/second). A CCIR-3 *subjective* impairment rating describes a level of interference that is statistically described by the "average" viewer as "slightly annoying". CCIR-3 interference is much more noticeable to the typical viewer than TOV.

The *subjective* CCIR impairment scale is graded on a scale of 1 to 5, and is often used in 0.5 steps. It is defined as follows:

CCIR-5	Imperceptible
CCIR-4	Perceptible, but not annoying
CCIR-3	Slightly annoying
CCIR-2	Annoying
CCIR-1	Very Annoying

The correction values in this column represent an attempt to conservatively take into consideration DTV splatter (meeting the *original* FCC mask or the proposed "*simple*" translator mask) from the interfering DTV signal that causes either TOV or CCIR-3 subjective impairment to the NTSC video signal.

Note 2: These CCIR-3 test results are with *no* DTV adjacent channel splatter, and therefore need to be modified in the future.

At all three of the desired NTSC signal levels (strong/-25 dBm, moderate/-35 dBm, and weak/-55 dBm) during ATTC *upper* first adjacent channel testing, a "diagonal stripes" ("color beat") problem occurred during the camera-pan in the "Texas Sign Dude" sequence. During the camera-pan, equivalent CCIR-3 interference levels (due to the beats) were observed at a lower level of interference than the final impairment level voted on by the expert observers (for the entire sequence). Subsequently, it was confirmed by experiment that the beat pattern was constant, but that it became noticeable during motion of the image due to eye tracking of the motion by the expert observers. This interfering beat was due to the small DTV pilot carrier "leaking into" the chroma demodulation circuitry of *some* of the analog TV sets and creating a *low*-frequency visible color beat (1.48 MHz, which is the difference between the desired NTSC chroma subcarrier and the undesired adjacent channel DTV pilot carrier). For those affected analog sets that exhibited this color beat interference, it was the dominant *video* impairment. In addition to the beat, color *noise* and color *desaturation* effects were observed. Also, at these CCIR-3 D/U ratios and discounting the color beat interference, it was found that *audio* impairments were the predominant limiting factor.

For **strong** desired NTSC signal levels (-25 dBm), this *CCIR-3* color beat interference occurred in 10 of the 24 reference sets (e.g. D/U = +3 dB for 9 analog TV sets and D/U = +4 dB for 1 analog TV set). For **weak** desired NTSC signal levels (-55 dBm), 8 of the 24 sets exhibited this color beat interference (e.g. D/U = - 2.9 dB *worst* case).

At **weak** NTSC levels, only 4 of the 24 reference analog TV sets exhibited worse than the *TOV* interference from a DTV signal at D/U ≈ +10 dB. (Remember that TOV is a very sensitive test, and is determined by *pulsing* the interference signal on & off).

However, when adjacent channel DTV splatter is taken into account and the precision DTV frequency offset is used to remove the low-frequency color beat and high-frequency luminance beat, video (rather than audio) is then the predominant limiting factor.

The **DTV** carrier frequency offset *mandated* by the FCC for *upper* DTV-into-NTSC situations require the DTV pilot carrier to be above the NTSC chroma subcarrier by an *odd* multiple of half NTSC horizontal line rate ($90.5*F_H$). This causes the (1.48 MHz) pilot beat to alternate from one NTSC video line to the next, thus being integrated in the observer's eye, which reduces this beat to insignificance. The additional 29.97 Hz *precision* frequency offset required by the FCC is to reduce the 5.08 MHz *luminance* beat (between NTSC visual and DTV pilot carriers), which is less noticeable than the color beat. However, the color *noise* and *desaturation* problems remain.

Note 3: These initial ATTC tests were performed per the ACATS test plan with *flat* adjacent channel DTV splatter more than 51 dB (perhaps as much as 60 dB) below the nearly flat in-band spectrum. Therefore, the DTV-into-DTV adjacent channel interference tests did not take into account real-world DTV adjacent channel splatter from typical high-power amplifiers (HPA), which will be the limiting factor in practice. The new values of planning factors were obtained from subsequent ATTC testing that used DTV adjacent channel splatter equal to the *original* FCC emission mask, and then corrected *mathematically* for the 5 dB integrated splatter improvement that the *current* FCC mask offers.

Note 4: These results are for testing done with adjacent channel splatter equal to the *original* FCC rigid emission mask. DTV-into-NTSC TOV interference was measured as +7 dB and +11 dB for upper and lower first adjacent channel interference, respectively.

Note 5: A **typographical** error in the OET Bulletin #69 (*perhaps* transposing the 3 and the 4 to get 34 dB instead of 43 dB) in the original version (July 1997) has been corrected in the revised version (February 2004).

Note 6: ACATS did not authorize tests involving DTV-into-NTSC for N-4, N-7, and N+7 taboo interference, so there is no ATTC laboratory test data known on which to base these D/U ratios.

APPENDIX 2

Summary of ATTC Laboratory Interference Performance Tests

With DTV Splatter Equal to *Original* FCC Emission Mask

Channel Offset from desired	**DTV-into-NTSC Median *TOV* D/U Ratios**			**NTSC-into-DTV Median *TOV* D/U Ratios**			**DTV-into-DTV Median *TOV* D/U Ratios**		
(±)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
	Strong D=-15 dBm	Moderate D=-35 dBm	Weak D=-55 dBm	Strong D=-28 dBm	Moderate D=-53 dBm	Weak D=-68 dBm	Strong D=-28 dBm	Moderate D=-53dBm	Weak D=-68 dBm
-8	- 6.90	-16.11	-31.62	-----	-----	-----	-----	-----	-----
-3	- 1.73	-18.28	-29.73	< -22.07	< - 47.06	< - 61.79	< - 20.95	< - 45.98	< -60.61
-2	- 1.43	-15.00	-23.74	< -23.09	< - 48.23	- 62.45	< - 21.83	< - 46.80	- 60.52
-1	**-----**	**+ 11.33**	**-----**	< - 23.18	- 44.46	- 47.73	-----	- 23.09	- 22.83
0	-----	+ 51.27	+47.74	-----	+ 1.40	+ 1.81	-----	+ 14.78	+ 15.27
+1	**-----**	**+ 7.33**	**-----**	< - 23.18	- 44.44	- 48.71	-----	- 21.15	- 21.15
+2	- 3.80	- 17.47	-27.94	< -23.88	< - 48.87	-59.86	< - 22.35	< - 47.33	- 59.13
+3	- 5.55	- 19.79	-34.13	< -23.10	< - 48.08	< - 62.49	< - 21.99	< - 46.98	< - 61.53
+4	- 5.60	- 18.22	-24.96	-----	-----	-----	-----	-----	-----
+8	- 9.77	- 22.97	-43.22	-----	-----	-----	-----	-----	-----
+14	- 8.40	- 22.24	-29.55	-----	-----	-----	-----	-----	-----
+15	+1.29	- 14.54	-17.58	-----	-----	-----	-----	-----	-----

General Comments:

An entry with dashed lines (-----) indicates that no ATTC laboratory tests were performed according to the ACATS test plan.

An entry with a “<” indicates that the ATTC test bed could not produce an undesired signal large enough to reach the TOV threshold for the median NTSC receiver or the Grand Alliance DTV prototype receiver. The true D/U ratio result is, in effect, smaller (i.e., a larger interfering signal could have been handled had the ATTC test bed possessed a larger dynamic range).

TOV (threshold of visibility) is the most sensitive impairment level. For both analog and digital reception, it is the point where interference is “just barely visible” to expert observers looking at repeating video clips. For DTV reception, this corresponds to an MPEG packet-error rate of 2.5 packets/second (or a bit error rate of $3x10^{-6}$).

All DTV-into-NTSC laboratory tests for TOV were performed by *pulsing* the undesired DTV signal on and off at a 3-second rate, which provides repeatability and possibly a few dB of implementation margin to the average viewer experiencing a *constant* interference (i.e., *non*-pulsing).

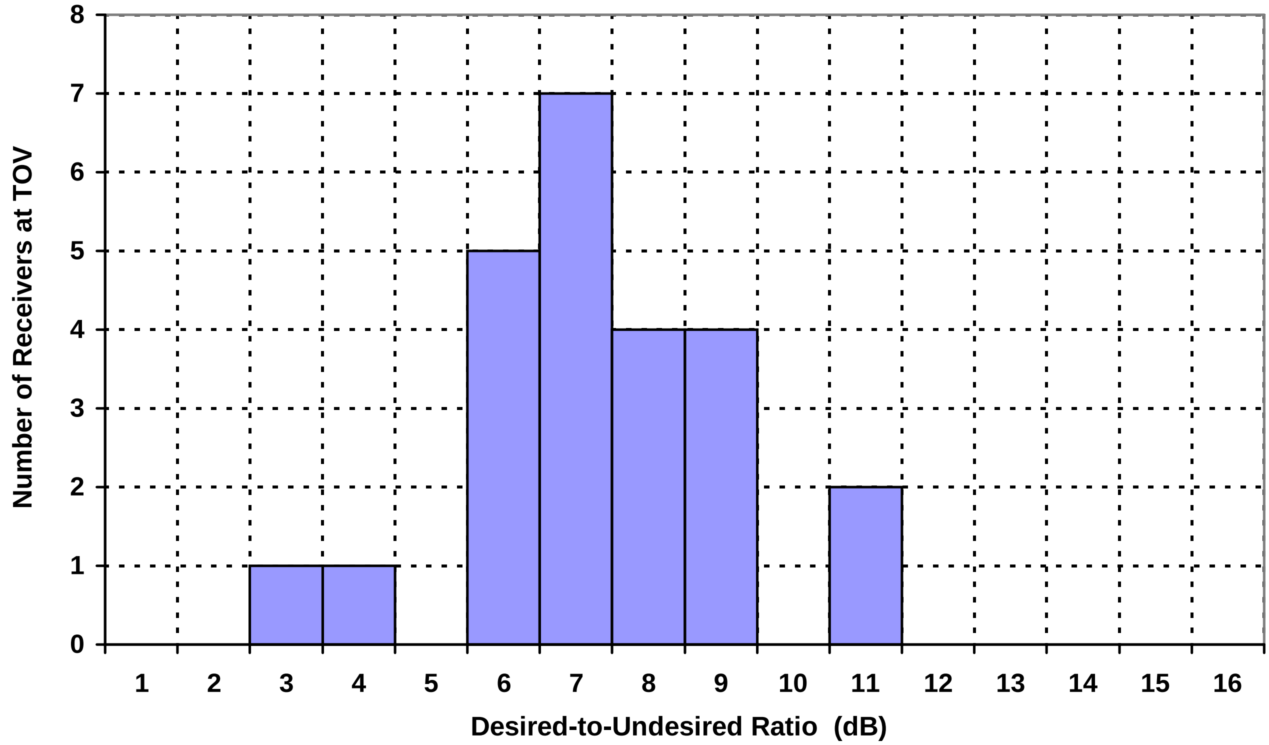

Figure 1 *Upper* Adjacent Channel DTV-into-NTSC with DTV splatter present (equivalent to *original* FCC mask)

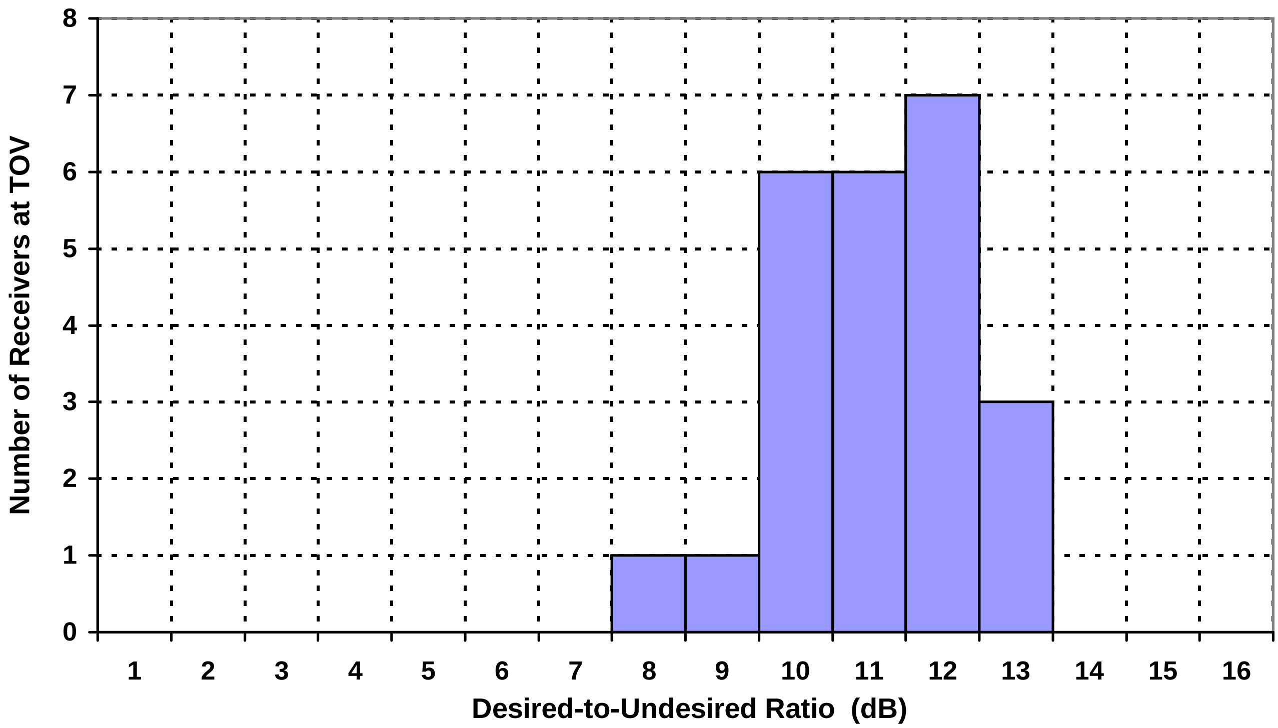

Figure 2 *Lower* Adjacent Channel DTV-into-NTSC with DTV splatter present (equivalent to *original* FCC mask)

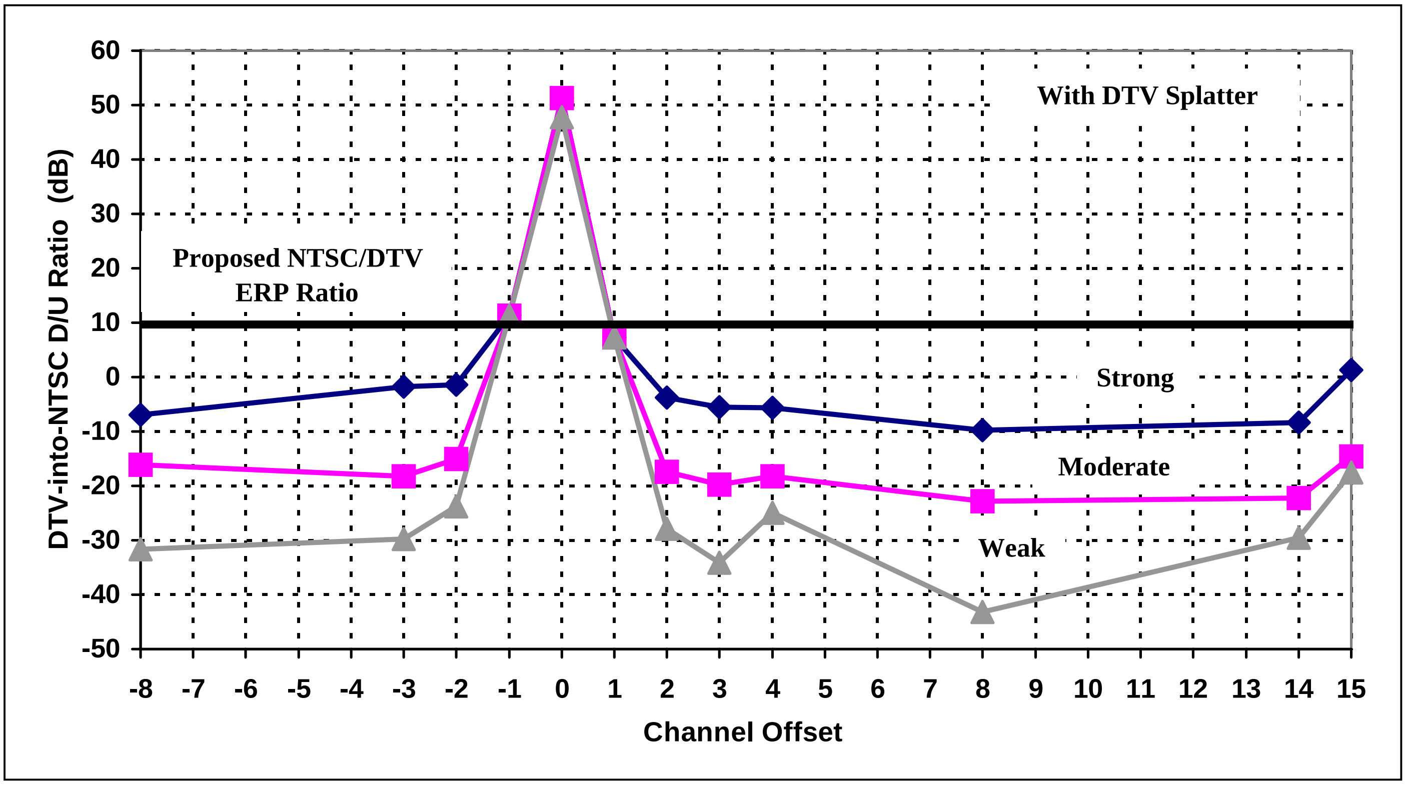

Figure 3 *Median* TOV D/U ratios for DTV-into-NTSC Interference for strong, moderate, and weak desired levels.

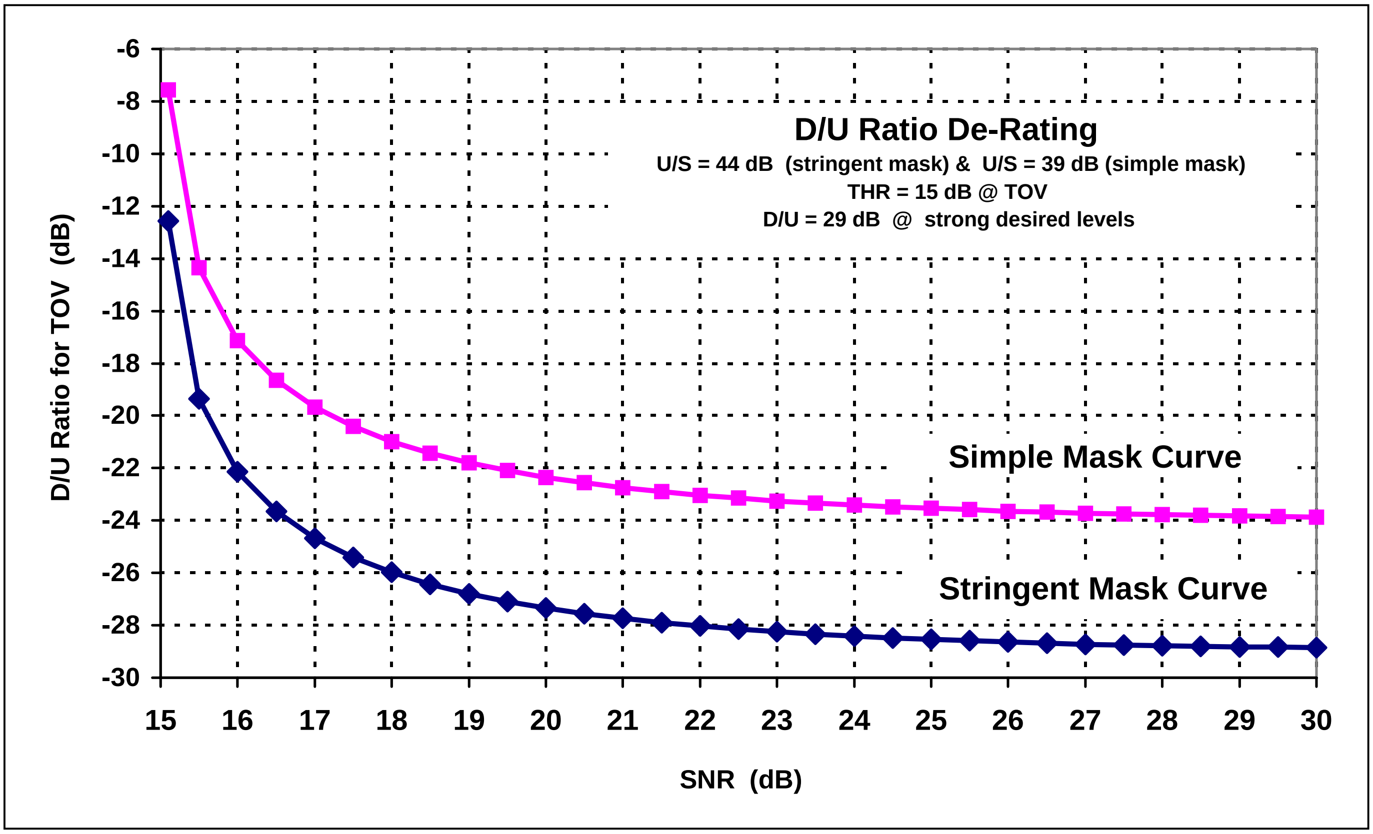

Figure 4 DTV-into-DTV adjacent channel (upper or lower) interference plus white noise *adjustment* chart