Planning Factors for Fixed and Portable DTTV Reception

Oded Bendov, Yiyan Wu, Charles W. Rhodes and John F.X. Browne

Abstract-- **The transition plan from the analog (NTSC) to digital terrestrial television (DTTV) in the USA was based on a simplified version of the Longley-Rice service prediction algorithm, and a link budget that mimicked the traditional planning factors for NTSC. It is now clear that the service prediction and the link budget both have serious shortfalls. This paper provides the formalism required for the development of realistic link budget and service grades for fixed and portable DTTV reception.**

Index Terms—**DTTV, planning factors, link budget, interference, man-made noise, sky noise, field strength, fixed reception, portable reception, service grades.**

I. INTRODUCTION

The transition plan from the analog (NTSC) to digital terrestrial television (DTTV) in the USA was based on a simplified version of the Longley-Rice service prediction algorithm, and a link budget that mimicked the traditional planning factors for NTSC. It is now clear that the service prediction and the link budget both have serious shortfalls. The shortfalls related to service prediction have been discussed in earlier papers[1,2] showing that DTTV service prediction in some bands unrealistically exceeds the radio horizon by as much as 40 km.

Recent field tests[3,4] also showed that the actual incident "field strength" (see Section IX) required at the receiver for robust reception is 10-20 dB higher than that called for in the Planning Factors adopted by the Federal Communications Commission (FCC). In this paper, we address the shortfall in the DTTV link budget.

The link budget for NTSC did not include the Signal-Noise ratio (SNR) degradations incurred in real-world transmission channels, probably because those degradations were graceful and did not cause total loss of video or audio. Sky and man-made noises were also ignored, as were the added losses due to impedance mismatches at the transmitter and at the receiver.

The link budget for analog TV did not include the effective noise figure due to the impedance mismatch between the antenna and the tuner, nor the sideband splatter from adjacent channels into the desired channel. In short, the many sources of degradation critical to DTTV service prediction have heretofore been ignored simply because they were ignored in the era of analog TV.

Thus a DTTV link budget based on idealized assumptions and an inadequately formulated Longley-Rice propagation prediction algorithm underestimated the minimum signal required and overlooked the importance of the receiver front-end design in service prediction[5].

The approach to calculating the "field strength" from the total received power by imputing a non-existent carrier frequency will be analyzed and corrected, and the limits to the validity of the calculation will be clarified. We will show that the received power is a more appropriate metric than "field strength" for coverage and interference specification and measurement of digital television.

II. LINK BUDGET FOR IDEAL TRANSMISSION AND RECEPTION

Table I shows the FCC's link budget for DTTV. For a channel that is thermal-noise-limited and free of multipath and interference with a theoretical threshold SNR of 15.2 dB, a minimum power of –80 dBm at the antenna (approximately -84 dBm at the tuner) is required to decode the 6 MHz wide, 8-VSB digital modulation. With a directional rooftop antenna, that received power has been translated into an incident "field strength" of 41 dBu.

By combining the link budget with the channel allocation table, the FCC has set some de facto minimum performance requirements on the receiver. For example, the maximum allowable radiated power is 1,000 kW for UHF channels. That power, if radiated from a 1,000' tower by the antenna described in FCC Bulletin OET-69, would correspond to –15 dBm into a tuner located within 5 miles from the tower. Therefore, the implied receiver would have to have a dynamic linear range of at least –84 dBm to –15 dBM with a noise figure not in excess of 7 dB even with the receive antenna connected. In contrast, during the tests leading to the establishment of the 8-VSB standard, the power levels varied from "weak" –68 dBm to "strong" –28 dBm.

While the DTTV link budget of Table I may have been useful to devise a channel allocation table, its usefulness for service prediction is rather limited. Losses of gain and SNR due to multipath at the transmitter, at the receiver and in the

Manuscript received
O. Bendov is with TV Transmission Antenna Group, Inc,
Cherry Hill,NJ USA. (Odedbendov@comcast.net)
Y. Wu is with the Communications Research Centre Canada, Ottawa, Ontario, Canada. (yiyan.wu@crc.ca)
C.W. Rhodes is an independent consultant, Upper Marlboro, MD USA (charleswrhodes@worldnet.att.net)
John F.X. Browne is with John F.X. Browne & Associates, Bloomfield Hills, MI USA (jbrowne.jfxb@comcast.net)

propagation channel are unaccounted for. Also, sky and man-made noises that severely limit reception for some VHF channels were not considered. At the receiver, the ideal channel's threshold SNR of 15.2 dB no longer holds as noise is added due to the transmitter's own SNR and through the receiver's equalizer processing of multipath. The receiver's true noise figure is a function of the antenna and tuner's impedance rather than that specified by the manufacturer. As the transition from analog to digital TV progresses and the population of TV stations transmitting at full power becomes significant, inter-modulation products (IM) and cross-modulation (XM) products will become additional sources of interference, heretofore ignored in the link budget.

III. TRANSMISSION SYSTEM ISSUES

There are four distinct degradations at the transmitter. One degradation arises from the in-band linear distortion generated by the exciter, by the power amplifier (PA) and by the mask filter. Linear distortion can be significantly reduced with adaptive pre-correction in which a sample of the PA signal is processed through an inverse of the transfer function and then fed back into the exciter.

An undesirable byproduct of adaptive pre-correction is an increase in the peak-average ratio of the desired signal. Unless there is enough headroom to accommodate that increase, the operating dynamic range of the PA must be reduced to avoid an increase of the in-band noise and to maintain the desired SNR. Such adjustment would result in some reduction of the radiated power.

Another degradation is the non-linear distortion, generated mainly in the PA, which may be reduced by adding circuitry that provides enhanced linear operation of the PA.

The third and fourth degradations are due to the load presented to the PA by the passive system of the feed line and antenna as shown in Figure 1. A practical passive system fails to present a perfect impedance match across a single TV channel to the PA, let alone across the wide band which typifies a system designed for mutiplexing several TV channels on one antenna. The residual impedance mismatch is a two-edged sword. It causes a reduction in the transmitted signal's SNR and it lowers the power delivered to the antenna.

An improvement in the performance of the antenna/PA system can be realized by configuring the transmitter with two balanced PAs in quadrature. Such configuration would have two advantages compared with a single-ended PA transmitter:

- Higher SNR due to absorption of the echoes from the antenna system.
- Higher power transfer efficiency from the PA to the antenna.

The importance of the linear distortion level and the non-linear distortion level relative to the SNR of the transmitter is an open issue. The residual SNR degradation due to non-linear distortion cannot be corrected at the receiver, whereas the residual SNR degradation due to linear distortion can, in principle, be corrected for at the receiver. The tradeoff is that correction at the receiver increases the threshold SNR due to the noise introduced by the equalizer. If the propagation channel is already plagued with heavy multipath, the added linear distortion by the transmitter may cause reception failure. The magnitudes of the linear and non-linear SNR degradations can be separated by switching the linear pre-correction on and off.

Although transmitter manufacturers may have claimed that the SNR degradation due to typical impedance mismatches can be eliminated via adaptive equalization, the same manufacturers would not guarantee that same SNR into the antenna be that obtained into a matched load. Unless the SNR can be restored to that available when the PA operates into a matched load, it is clear that impedance mismatches, at least those attributable to the feed line and the antenna, should be regarded as causing uncorrectable loss of SNR.

When the PA is operating at the rated power and full data rate, and is terminated with a matched load, the SNR of the transmitted signal may be as high as 34 dB. The SNR may drop to 27 dB, the minimum recommended for 8VSB modulation, or lower, when the matched load is replaced with a well-designed filter/transmission line/antenna system. Figure 2 shows a theoretical analysis of the degradation in SNR due to combined impedance mismatches of the antenna and feed line as seen by the transmitter. The antenna system's mismatches are represented as the mean Voltage Standing Wave Ratio (<VSWR>) across the channel. The Transmitter's SNR is:

$$SNR_T\,(dB) = -10Log\left(10^{-A/10} + 10^{-B/10}\right) \qquad (III-1)$$

$$where \;\; A(dB) = -20Log\left(\frac{<VSWR>-1}{<VSWR>+1}\right)$$

$$B(dB) = SNR\ with\ matched\ load$$

For example, if a transmitter with SNR=33 dB when terminated with a matched load (VSWR=1.00) is switched into antenna system's load of <VSWR>=1.08, its SNR would drop to 27 dB. For the same transmitter with system's load of <VSWR>=1.16, SNR would drop to 22.2 dB.

The results shown in Figure 2 are consistent with measurements[*]T using various feed line lengths terminated with a range of impedance mismatches. A third-order polynomial fit of the measured SNR vs. the <VSWR> at the input to the feed line is shown in Figure 3. There is a difference of approximately 1 dB between the theoretical and the experimental data and that

---

[*] Data provided by Thales Multimedia

difference may be attributable to the reflection due to the mismatch being absorbed during measurement after one pass.

The effective power penalty on the threshold SNR due to the <VSWR> is given by:

$$Power\ Penalty = P(dB)$$
$$= 15.2 + 10Log\left(10^{-15.2/10} + 10^{-SNR_T/10}\right) \quad (III-2)$$

where 15.2 is the theoretical SNR threshold value in dB.

Figure 4 shows the magnitude of the penalty as a function of mean system (antenna and line) <VSWR>. For the examples discussed above, the power penalty on the threshold SNR is .3dB for a system <VSWR>=1.08 and .8 dB for a system <VSWR>=1.16.

Some prefer the Error Vector Magnitude (EVM) as a degradation metric instead of SNR. They are related to each other and Figure 3 shows the relationship between the two. An explicit relationship between SNR to EVM for 8-VSB modulation is provided in Appendix A.

When the antenna complex and the transmitter are impedance mismatched to each other, the added loss in power transfer efficiency due to the mismatches is given by:

$$Loss\ (dB) = -10Log\frac{Power\ delivered\ to\ load}{Power\ input\ to\ network} \quad (III-3)$$
$$= -10Log\frac{e^{-2\alpha L}\left(1-|\Gamma_a|^2\right)}{1+|\Gamma_a|^2\left(|\Gamma_{Tx}|^2 - e^{-2\alpha L}\right) - 2\,\mathrm{Re}(\Gamma_a \Gamma_{Tx})}$$

Where

Γ_a is the complex reflection coefficient looking into the antenna input.

Γ_{Tx} is the complex reflection coefficient looking from the antenna toward the PA output.

L is the length of the feed line from the transmitter to the antenna.

α is the real part of the complex propagation constant in the feed line connecting the transmitter and antenna.

The parameters in (III-3) are usually frequency-dependent, and an exact evaluation of the loss requires integration over the channel. For relatively low loss, it would be reasonable to assume the mean values for the parameters. For a single-ended PA transmitter, $<\Gamma_{Tx}> \approx -1$, and for a parallel PA transmitter $<\Gamma_{Tx}> \approx 0$. Equation (III-3) shows that single-ended PA transmitter would exhibit higher added loss in power transfer to the antenna, over and above the one-way loss of the feed line, compared with the added loss for a parallel PA transmitter. Additionally, for a parallel PA transmitter the uncorrected loss of SNR would be smaller than that expected from a single-ended PA transmitter because the residual reflections from the antenna and feed line would be absorbed in a reject load.

As an example, consider a UHF antenna with <VSWR>=1.15 at the end of 1200 feet of a 6”-75Ω feed line. The added loss of power transfer from the transmitter to the antenna over and above the loss in an impedance-matched antenna system (Γ_A=0) would be:

Channels	Parallel PA	Single-ended PA
2-6	0.002 dB	0.434 dB
7-13	0.004 dB	0.435 dB
14-69	0.006 dB	0.437 dB

Thus it appears reasonable to assume that a well-designed transmission system may introduce a threshold SNR penalty of .8 dB and reduce the power transfer efficiency by as much as .4 dB.

IV. MAN-MADE AND SKY NOISE

Man-made noise encompasses radiation from electrical machinery, electronic equipment, power transmission lines and internal combustion engine ignition. Man-made noise levels in business, residential and rural areas have been documented[6]. Following the cited International Telecommunication Union (ITU) document with certain modifications[*], the median noise power in dB over thermal noise (kBT_0 = -106.2 dBm for B=6 MHz channel at $T_0=290^0$K and $k=1.38*10^{-23}$ joules/^{0}K) is:

$$F(dB/kBT_0) = c - dLogf$$
$$f \leq 200MHz \qquad (IV-1)$$
$$F(dB/kBT_0) = b - 12.3Logf$$
$$200Mhz < f < 900MHz \qquad (IV-2)$$

Where f is in MHz.

Category	**c**	**d**	**b**
Business	75.6	27.7	40.0
Residential	71.3	27.7	35.9
Rural	66.0	27.7	30.5

The decile deviations of the noise are:

Category	Decile	Time Variation (dB)	Location Variation (dB)
Business	Upper Lower	11.0 6.7	8.4 8.4
Residential	Upper Lower	10.6 5.3	5.8 5.8
Rural	Upper Lower	9.2 4.6	6.8 6.8

---

[*] Equation (IV-2) was modified to fit with (IV-1) at 200 Mhz and to include a correction factor of –1.25 dB to account for the reduced US channel bandwidth was applied.

The equivalent temperature of the man-made noise is:

$$T_{MM} = T_0 10^{F/10} \qquad (IV-3)$$

For example, using equation (IV-1) at f=57 MHz with c=71.3 and d=35.9 yields F=22.7 (dB/-106.2 dBm). Thus, the median residential noise power at channel 2 would be –83.5 dBm over thermal noise, corresponding to an equivalent noise temperature of 53,333^{0}K.

The minimum and maximum sky temperature, T_S in ^{0}K, over the VHF and UHF in the US was measured and reported[7] to the FCC. To allow for easy computations, the measurement data has been fitted into the following equation:

$$Log(T_S / a) = b - cLogf \qquad (IV-4)$$

Where f is in MHz and T_S is the sky temperature in ^{0}K.

The parameters of equation (IV-4) are:

Category	a	b	c
Maximum T_S	800	5.7	2.35
Average T_S	300	5.8	2.48

The total noise power due to sky and man-made noises will depend on the antenna pattern as shown in Figures 6 and 7. For a rooftop antenna it would be reasonable to assume that sky noise is received above the horizontal and man-made noise below the horizontal. For set-top antennas near ground level, it is assumed that sky noise is not received and that man-made noise is received indoors and outdoors from below and from above the horizontal. Be the set-top antenna indoors or outdoors, no additional attenuation is assumed between man-made noise sources and the antenna. Thus, the equivalent antenna temperatures are:

$$T_R = .5T_S + .5(T_G + T_{MM}) \qquad (IV-5)$$

$$\textit{for rooftop antennas and}$$

$$T_I = T_G + T_{MM} \qquad (IV-6)$$

$$\textit{for set-top antennas}$$

The antenna temperature includes ambient building and ground temperature T_G, usually estimated at 290^{0}K. Figure 5 shows the combined average man-made and residential sky noise power available at the receive antenna. From Figure 5 it is concluded that expected noise levels could be higher than originally estimated by more than 20 dB at VHF frequencies, and by 2-5 dB at UHF frequencies.

V. RECEIVER SYSTEM ISSUES

In addition to the transmitter, sky and man-made noises, additional degradations generated at the receiver are increased noise figure, and signal loss due to impedance mismatches and equalizer-added noise. In some locations, sideband splatter from adjacent channels may further limit reception and this subject will be covered in the next section. Quantifying other potential interference such as IM and XM products and front-end overload is outside the scope of this paper.

In earlier work[1], we have shown that impedance mismatch between the antenna and the input of the tuner (or the LNA's if included) theoretically results in additional loss of signal power and an increase in the noise figure. There is no upper limit to these degradations. The higher the <VSWR>, the greater the degradations. For an antenna with <VSWR> ≤3.00, the mean added loss would be approximately 2.5 dB and the mean increase in noise figure approximately 5 dB.

Recent experiments have provided preliminary data from which the estimated increase in noise figure due to impedance mismatch between the antenna and the front-end of the receiver was be extracted. The experiment was conducted on channels 20, 63 and 67 using double bow tie and silver-sensor antennas. Figure 8 shows the experimental setup. The SNR was measured with the equalizer on and off and, in each case, with the double stub tuner in or out. With the double stub tuner in, the stubs were adjusted for maximum SNR, presumably the point of impedance match between the antenna and the tuner.

The results of the experiments at the CRC show a penalty of 0-4.8 dB to the noise figure and 0-1.7 dB to the threshold SNR (15.2 dB), depending on channel and antenna. The experiments also showed that when the double-stub was adjusted to sufficiently increase the impedance mismatch, the increased noise figure resulted in reception failure.

What should be the effective noise figure for service planning? The FCC has recommended 7 dB for the UHF band and 10 dB for the VHF band. These values do not include the effect of the impedance mismatch between the antenna and the front-end of the receiver. Given our previous analysis and current experiments, we believe that effective noise figure for single-conversion receivers, including the VSWR effect of practical antennas, be raised from 7 dB to 12 dB for all bands.

The added loss and effective noise figure were combined with the man-made and sky noises to yield the increase in total noise power over thermal noise (dB/kT_0B) at the antenna terminals. The governing equations are given in Appendix B. Evaluation of the total noise power was applied to three receive antennas: rooftop antenna with and without LNA as shown in Figure 6 and a set-top antenna as shown in Figure 7. The noise power at the antenna terminals of each of the three models is shown in Figure 9. When compared with the FCC model for rooftop antenna, our model shows an increased noise power at the antenna terminals from 7.5 dB at 615 MHz to 8.7 dB at 69 MHz. Our model also shows that the addition of LNA to rooftop antennas holds promise of improved service except for channels 2-6, provided the LNA has adequate linear dynamic range.

The equalizer added noise level is highly dependent on the equalizer design and the type of multipath. Some designs perform better with static rather than with dynamic ghosts. Other designs have too narrow a window of acceptable delay, especially for pre-ghosts. A “rule of thumb” is that for slow moving and static moderate multipath of between –5 and –10 dB, a margin of 0-3 dB should be added to the threshold SNR.

VI. INTERFERENCE ISSUES: TRANSMITTER SIDEBAND SPLATTER

The assignment of adjacent channels in the Table of Allotment for DTTV service has been a cause of concern. From a regulatory perspective, collocation is not required as long as certain Desired/Undesired (D/U) ratios are met at the receiver within the protected contour. Prior to the introduction of DTTV, adjacent NTSC channels were not permitted in the same market and “taboo” channels were permitted only if the separation distance exceeded a certain minimum. Some rudimentary laboratory tests to determine the D/U ratios were conducted prior to the introduction of the 8-VSB standard, but those tests did not include non-linear effects such as sideband splatter into adjacent channels. Whereas degradations related to IM products and XM products may be controlled by the design of the receiver, sideband power splattered by the undesired adjacent channel into the desired channel is permitted as long as it does not exceed the FCC’s prescribed mask filter. The splattered power appears to the desired channel as added co-channel noise. A broader discussion of interference due to adjacent and taboo channels is provided in the Annex. A comprehensive paper that covers all issues related to first adjacent channel interference will be published separately.

A. DTTV into DTTV

By integrating the area under the FCC mask for DTTV transmitters, the estimated power in the adjacent channel was shown[8] to be –44.1 dB relative to the power within the channel. Later it was agreed[9] that including the effect of receiver’s IF filter the corrected number would be –46.5 dB. Thus the relationship between the Interference (I) power and the maximum permissible power of the undesired channel is:

$$I(dBm) = U_{N\pm1}(dBm) - 46.5dB \qquad \text{(VI-1)}$$

At the same time, the FCC established the following ratios for safe operation of adjacent DTTV channels:

$$\frac{D}{U_{N-1}} = -28dB \;\; \frac{D}{U_{N+1}} = -26dB \quad \text{(VI-2)}$$

where D_{min} is the minimum power of the Desired channel and $U_{N\pm1}$ is power of the upper or lower adjacent channel.

We shall assume a single ratio, D/U=-27 dB as a reasonable average for either adjacent channel. With the splattered power added to the noise power N_A (see Figure 9) at the receive antenna terminals, the threshold SNR is:

$$SNR_T(dB) = 10Log\frac{D_{\min}}{N_A + I} \qquad \text{(VI-3)}$$

$$D_{\min}(dBm) =$$

$$N_A(dBm) - 10Log\left[10^{-SNR_T/10} - (1+K)10^{-(\frac{D}{U}+46.5)/10}\right] \quad \text{(VI-4)}$$

$$0 \le K \le 1$$

Combining equations (V-1) and (V-3) and solving for D_{min} in terms of the D/U at the receiver, we get:

where K is power ratio of the two undesired adjacent channels. For a single undesired adjacent channel, K=0.

The additional margin required (power penalty imposed) in the desired channel due to the interference from the splattered power is:

$$M(dB) = D_{\min}(dBm) - D_{I=0}(dBm) \quad \text{(VI-5)}$$

where $D_{I=0}$ is the desired level in the absence of sideband splatter.

Figure 10 shows the margin and the minimum desired level for a single adjacent channel with D/U ratios from 1dB to –30 dB. The graphs are based on antenna noise of -88 dBm and threshold SNR of 16 dB (15.2 dB theoretical +.8 dB Tx margin). The antenna noise and threshold SNR are those pertinent to a rooftop antenna at UHF as shown in Table II. Figure 10 shows that at the allowable D/U=-27 dB, the minimum desired level has increased by almost 3 dB. In fact, if the D/U were to decrease to –31 dB, decoding would not be possible. It would appear that the allowable D/U=-27 dB is too close to the “cliff edge” except perhaps for the case of all adjacent channels multiplexed on the desired channel’s antenna. If separate antennas are contemplated for the adjacent channels, even if they are installed on the same tower as the desired channel’s, the chance of breaching D/U=-27 dB is high. For the proposed “Distributed Transmission” system, the distributed undesired adjacent channels may have to be terrain-shielded from the desired channel.

B. NTSC into DTTV

The several FCC rules governing the maximum permissible sideband splatter of NTSC channels are not as clear as the single rule governing the splatter of DTTV channels, but a clear interpretation of rules governing the allowable NTSC splatter is available[10]. Basically, the allowable splatter level in the first ± 3 MHz next to the NTSC channel must be at least 20 dB below the level of the visual carrier ±200 kHz. For the next 3 MHz, the level must be at least 60 dB below peak of sync. Integration yields the maximum permissible sideband power as –41 dB relative to peak of sync.

Following the analysis of the previous section,

$$D_{\min}(dBm) =$$

$$N_A(dBm) - 10Log\left[10^{-SNR_T/10} - (1+K)10^{-(\frac{D}{U}+41)/10}\right] \quad (V - 6)$$

$$0 \le K \le 1$$

The actual sideband splatter of modern NTSC transmitters is far less than that permissible by the FCC. Figure 11 shows the minimum desired signal for various levels of splatter, from –45 dB to –65 dB. What Figure 11 shows is that if the desired channel is DTTV and the undesired adjacent channel is NTSC, then the NTSC splatter must be below –65 dB to maintain the FCC D/U=-49 dB planning factor for NTSC interference into DTV.

VII. LINK BUDGETS FOR NON-IDEAL TRANSMISSION AND RECEPTION

With the noise level at the antenna, given by Figure 9, the construction of the link budgets for the three receiver models is straightforward. The proposed link budgets and the assumptions underlying those budgets are shown in Table II. Table III provides a direct comparison of our results with the FCC planning factors. If we characterize the FCC factors as “idealistic,” our results could be characterized as “optimistic.” Certain margins due to interference, propagation fading, uncorrectable multipath and added equalizer noise are not included in Table II. Further, the noise level in Figure 9 is based on residential rather than business’ man-made noise, and the sky noise is average rather than maximum.

Table III: Threshold Signal Levels for Rooftop Antenna

Channels:	2-6	7-13	14-51
FCC:	-80 dBm	-79 dBm	-80 dBm
Table II*:	-70.5 dBm	-73.4 dBm	-71.7 dBm
Shortfall:	9.5 dB	5.6 dB	8.3 dB
* Margins for interference, multipath and fading not included			

The BBC has measured the relationship between the signal level at a rooftop antenna 10 meters above ground and set-top antenna indoors 1.5 meters above ground[11]. The data, measured at UHF on the ground level floor, shows a combined height and penetration loss from 34 dB for 50% of rooms/90% of locations within room, to 41 dB for all rooms/50% of locations within room. We suggest a mean value of 37 dB for both UHF and VHF bands. The BBC results are consistent with the reported range of building penetration loss of 10-25 dB[17] and of height loss of 9-19 dB[18]. In VHF the loss due to height differential is smaller than in UHF but a higher window penetration loss should be expected. From Table II, indoor reception on the ground floor requires a “field strength” of 90-93 dBu at 30 feet above ground. Therefore, reliable DTTV service to indoor antennas will be limited to about 15 miles radius from an omnidirectional antenna radiating 1MW from a height of 1,000 feet.

VIII. DTTV SERVICE GRADES

NTSC grades of service are based on picture quality. For example, NTSC grade-A with SNR=30 dB is deemed “acceptable”[12]. In the case of DTTV, grades of service cannot be based on picture quality. Rather, DTTV service can be defined in terms of reception reliability statistics or outage. In the U.S., DTTV service is now defined by a single grade. That grade is characterized by a threshold signal available at the best 50% of the locations at least 90% of time or (L,T)=(50,90).

Clearly, a DTTV service with time availability of 90% (or outage of 10%) is not acceptable. The European Telecommunications Standards Institute (ETSI) has proposed[13] two grades of DTTV service, “acceptable” with (L,T)=(75,99) and “good” with (L,T)=(95,99).

Increasing the location and time availability percentages requires additional signal margin. The margin increase for 99% time availability has been recently measured[14]. The results show that a mean margin of 2.37 dB would account for 99% availability and that the distribution statistics are skewed rather than normal. Recent experiments at the CRC show similar result as shown in Figure 12.

Lacking other credible data, we assume that normal distribution holds for location variation. Using the US[15] standard deviation for location variation and assuming normal distribution, the proposed margins over the minimum signal level given in Table II are given in Table IV.

Table IV: Service Margins (dB)

Service Grade	(L,T) statistics	69 MHz	194 MHz	615 MHz
Reference	(50,90)	0	0	0
Acceptable	(75,99)	7.3	8.7	10.3
Good	(95,99)	14.3	17.8	21.7

Naturally, adequate signal level is necessary but not sufficient condition for reliable service. Multipath, interference and receiver performance specifications all play a major role in providing reliable reception.

IX. “FIELD STRENGTH” VS. RECEIVED POWER AS A COVERAGE AND INTERFERENCE METRIC FOR BROADBAND AND CARRIERLESS CHANNELS

In devising communication link budgets it is sometimes desirable to convert the received power in *Watts* to power flux density in *Watts/m*^{2} or field strength in *V/m* that is incident on the receive antenna. The formula that has been used heretofore is known as Friis’ transmission formula[16]:

$$P_R = \left[\frac{E^2}{120\pi}\right]\left[\frac{1.64 G_R c^2}{4\pi f_0^2}\right] \quad (IX-1)$$

where P_R is the received power, E is the incident RMS (Root Mean Squared) field strength, G_R is the antenna gain relative to half-wave dipole, c is the speed of light and f_0 is the carrier frequency. The first term inside the square brackets represents the incident power flux density. The second term inside the square brackets represents the maximum absorption area of any antenna.

Friis' formula is explicitly limited to plane wave propagation in free space at a single frequency. As such, it is applicable to microwave point-to-point links. For example, it does not apply to Gaussian laser beam, it assumes a multipath-free channel and it assumes a single, identifiable carrier. From (IX-1), the power at the terminals of a half-wave dipole is:

$$P_R(W) = 31.1\frac{E^2(V/m)}{f_0^2(Mhz)} \qquad (IX-2)$$

$$P_R(dBm) = \\ -75.073 + E(dBu) - 20Log(f_0) \quad (IX-3)$$

where dBm=dB over 1 mW and dBu=dB over 1 microvolt.

For 1 mW (P_R = 0 dBm), equation (IX-3) is known as the "dipole factor." At f_0=615 MHz, the dipole factor is 130.85 dBu/1mW.

Equation (IX-2) has been widely applied to new broadband systems without much attention to the underlying assumptions and the limits imposed by those assumptions. Examples of such new systems are spread spectrum, digital television and nanosecond pulse transmissions. In applying equation (IX-2) to broadband systems, an arbitrary carrier frequency, f_0, must be imputed even for suppressed-carrier channels. Typically, f_0 has been chosen to be the center frequency of the channel. Because f_0 is arbitrary, there cannot be a single value for the field strength resulting from a single valued radiated power. Thus, for broadband and carrier-less systems, the "field strength" based on equation (IX-2) is multi-valued and its associated error unknown.

For broadband systems, the received power, desired signal with noise, averaged over the channel's bandwidth is:

$$P_{AVG} = \\ \frac{1}{BW}\int\left[\frac{|E(f)|^2}{120\pi}\right]\left[\frac{1.64 G_R(f) c^2}{4\pi f^2}\right]df \quad (IX-4)$$

In general, the incident field strength is a function of frequency, especially with multipath present. The antenna's gain is also frequency-dependent. Therefore, in general, the field strength cannot be calculated from the measurable received power.

It is clear that the field strength calculated from equation (IX-1), regardless of f_0, is not the same as that calculated using equation (IX-4). For the special case of a channel free of multipath and assuming an antenna with constant gain over the channel bandwidth, the error in using (IX-1) to compute the field strength of broadband and distortionless channels is (see Appendix C):

$$E_{BROADBAND} = \\ E_{NARROWBAND}\sqrt{1-\left(\frac{BW}{2f_c}\right)^2}\,\frac{f_c}{f_0} \quad (IX-5)$$

Figure 13 shows the error incurred by applying the traditional formula (equation IX-1) to calculating the "field strength" of broadband and multipath-free channels. The larger the bandwidth, the greater the error. The correction given by (IX-5) applies to point-to-point communication systems free of multipath. It should not be applied to DTTV where multipath is generally evident.

For several decades, the field strength of NTSC signals has been measured by a process originally described in the TASO[7] report and later codified in the FCC Rules & Regulations at 47 CFR 73.686. The rules specify the use of an RF voltmeter "capable of indicating accurately the peak amplitude of the synchronizing signal." The measured voltage across a defined load impedance is then converted to field strength by adjusting the observed values for the antenna system's gain / losses and the "dipole factor" defined in (IX-3).

In the context of the transition to a terrestrial digital broadcast service, it is instructive to understand what is being measured in the analog case and what constitutes service. The field strength meter, which has a bandwidth of only several hundred kilohertz, measures the peak voltage of the well-defined visual carrier. The presence of sufficient NTSC signal level is a good predictor of whether a signal will be viewable except in rare cases of extreme multipath propagation.

In the DTTV realm, the NTSC measurement technique specified by the FCC cannot be applied to broadband and carrier-less DTTV. The carrier-less, broadband signal cannot be assigned a field strength at some frequency within the channel (e.g., center frequency) based on a measurement of the total power within the channel. Furthermore, the total received power is not the only requirement for service, i.e., receivability of a DTTV signal. Since the reliable decoding of a DTTV signal is dependent on factors such as multipath and distortion (and the ability to correct these anomalies), it is possible to present the receiver with a very strong but non-decodable signal. This then begs the question of how DTTV signal "coverage" or “service” can be measured and evaluated in the field. Clearly, the total signal power within the bandwidth must be measured as a precursor of service. Making the traditional 100 ft. runs where data is continuously recorded seems to be of little value as multipath effects will not be properly noted in the total power summation (integration). Perhaps, combining power data samples with BER and/or receiver equalizer tap energy values along such a run could be used to develop a "figure of merit" to define the quality of service. It is suggested that this figure of merit would include a margin component for both signal level and degree of required equalizer correction. Furthermore, taking measurements at 30 feet may be apropos for rooftop antenna reception but not in predicting performance at heights below 10 feet for portable and indoor reception; thus, new measurement protocols may also require that data be collected at multiple antenna heights to accurately characterize DTTV “coverage.” Further study is clearly required to develop meaningful ways of measuring DTTV signals (including factors beyond mere integrated signal power) and, most importantly, ways of interpreting and expressing the data in terms of coverage and service.

We have shown that for broadband channels, field strength is not directly measurable and it can be explicitly defined only in a multipath-free channel with a constant-gain antenna at a predetermined “carrier” frequency by using the correction factor given by (IX-5). These restrictions exclude real-world DTTV channels. Thus, the adoption of the incident “field strength” as a metric for DTTV analysis is grounded in tradition more than in good engineering practice.

X. CONCLUSIONS AND RECOMMENDATIONS

The transition plan to DTTV was intended to provide coverage and service “comparable” to that provided by the analog NTSC. While the DTTV planning factors now in use in the US may have been adequate for establishing the starting point for the channel allocation table, they are inadequate for service planning. This paper offers a framework for reliable service planning.

We find that unaccounted for noise levels, generated internally and externally at the receiver, and uncorrectable dynamic multipath will result in DTTV service that falls short of that originally suggested. Our analysis indicates a shortfall of at least 8 dB of signal power in the UHF range and 10 dB in the low VHF range.

By adopting the test results obtained at the Advanced Television Test Center (ATTC) together with the channel allocation table and a distortion-free link budget, the FCC has set de facto minimum performance requirements on the receiver. In the UHF band, these requirements amount to minimum IF selectivity of 60 dB, maximum noise-figure of 7 dB in the UHF band (10 dB in the VHF band) with the antenna connected to the receiver, and a linear dynamic range of at least –84 dBm to –15 dBm at the front-end. These specifications are not met with consumer-grade receivers connected to consumer-grade antennas.

DTV reception will depend significantly on the receiver’s specifications and design. It is now clear that reception will be limited by too low a signal in the thermal-noise-limited fringe area and by adjacent channel interference and possibly front-end overload in the city of license.

We recommend that heretofore ignored interference issues related to adjacent channel splatter, and IM and XM products due to overload and “taboo” channels are thoroughly investigated.

For reliable reception beyond NTSC’s grade-A contour, an outdoor antenna equipped with LNA is recommended. However, due to the high level of sky and man-made noise, the LNA usefulness is be limited to the UHF and High VHF bands. The LNA must exhibit adequate linear dynamic range and low level of IM products. The addition of LNA to a rooftop antenna could significantly enhance the distribution of the signal to multiple devices without incurring additional loss of signal. Significant improvement to reliable reception availability is possible with smart and active antennas capable of having automatically adjusted space and polarization diversity.

The authors recommend updating the DTTV planning factors using the framework established in this paper and that minimum receiver performance standards be adopted.

Field strength cannot be explicitly calculated for broadband channels with multipath. Hence the incident “field strength” should not be adopted as metric for DTTV analysis and measurement. The authors recommend that received power in dBm be adopted instead as a metric for service and interference analysis.

We also recommend that the transmitter power amplifier be configured as balance parallel amplifiers in quadrature in order to improve its SNR and to maximize the power transferred to the antenna.

MATHEMATICAL APPENDICES

A. SNR/EVM Equations

The Error Vector Magnitude (EVM) of N symbols is defined by:

$$EVM_{RMS} = \sqrt{\frac{\frac{1}{N}\sum_{j=1}^{N}\left(\Delta I_j^2 + \Delta Q_j^2\right)}{S_{MAX}^2}} * 100\%$$

where S_{MAX} is the magnitude of the vector to the outermost symbol in the constellation and ΔI_j and ΔQ_j are respectively the in-phase and quadrature errors of the received symbols.

In the case of 8-VSB modulation, $S_{MAX} = \pm 7$ and $\Delta I_j \approx \Delta Q_j$. Therefore,

$$EVM_{RMS} = \sqrt{\frac{\frac{2}{N}\sum_{j=1}^{N}\left(\Delta I_j^2\right)}{7^2}} * 100\%$$

For 8-VSB modulation, the Signal to Noise Ratio (SNR) is defined by:

$$SNR = 10 Log \frac{S_{RMS}}{\frac{1}{N}\sum_{j=1}^{N}\Delta I_j^2}$$

Where $S_{RMS}=1^2+3^2+5^2+7^2=21$ is the vector magnitude to root mean square of all the symbols. The relationship between the EVM and the SNR is given by:

$$SNR = 39.33 - 20 Log(EVM_{RMS})$$

B. Receiver Noise Equations

For *n* receivers connected through a cable and a loss-less splitter to an antenna with LNA at its terminals, the noise figure at the antenna terminals is:

$$NF = \frac{F_{LNA}}{\eta_A} + n\frac{F_R - \eta_D / n}{\eta_D G_{LNA}}$$

where η_D = downlead cable efficiency, η_A = antenna to LNA cable efficiency, G_{LNA} = gain of the LNA, F_R = receiver noise figure and F_{LNA} = noise figure of the LNA.
The noise figures and the cable efficiencies include the effect of all impedance mismatches.

For a single receiver without LNA, the noise figure at the antenna terminals is:

$$NF = \frac{F_R}{\eta_D \eta_A}$$

The total noise power available at the antenna terminals is:

$$N = kB[T_{R,I} + (NF - 1)T_0]$$

where T_0 is the ambient temperature of the LNA/downlead (typically 290^0K) and $T_{R,I}$ is the rooftop or set-top antenna temperature derived from equations (IV-5) and (IV-6).

The added noise level due to the antenna temperature $T_{R,I}$ is:

$$\Delta N(dB / kBT_0) = 10 Log \frac{\frac{T_{R,I}}{T_0} + NF - 1}{NF}$$

The added loss between the antenna and the tuner or the LNA due to impedance mismatches is:

$$\Delta L(dB) = 10 Log \frac{\left(1 - |\Gamma_A|^2\right)\left(1 - |\Gamma_R|^2\right)}{\left|1 - e^{-2\gamma L}\Gamma_A \Gamma_R\right|^2}$$

Where Γ_A and Γ_R are, respectively, the reflection coefficients of the antenna and the receiver, and $\gamma=\alpha+j\beta$ is the propagation constant of the cable connecting the antenna to the receiver and L is the length of that cable.

C. Derivation of Equation (IX-5)

For the special case of a channel free of multipath and constant antenna gain over the channel bandwidth, the RMS field strength can be related to the averaged received power by:

$$P_{AVG} = \frac{1}{BW}\left[\frac{E^2}{120\pi}\right]\frac{1.64 G_R c^2}{4\pi}\int\left[\frac{1}{f^2}\right]df$$

The channel over which the integration is to be performed can be defined in terms of its bandwidth BW and the center frequency f_c as:

$$Channel = f_c - \frac{BW}{2} \text{ to } f_c + \frac{BW}{2}$$

And since

$$\int_{f_c - \frac{BW}{2}}^{f_c + \frac{BW}{2}} \frac{df}{f^2} = \frac{BW}{f_c^2 - \left(\frac{BW}{2}\right)^2}$$

$$\text{where } f_c - \frac{BW}{2} > 0$$

For multipath-free channel and with constant gain antenna, an explicit relation between P_{AVG} and E can be written as:
Thus, the error in using (VIII-1) to compute the field strength of broadband and distortionless channels is:

$$E_{BROADBAND} = E_{NARROWBAND}\sqrt{1 - \left(\frac{BW}{2 f_c}\right)^2}\frac{f_c}{f_0}$$

$$P_{AVG} = \left[\frac{E^2}{120\pi}\right]\left[\frac{1.64 G_R c^2}{4\pi f_c^2}\right]\left[\frac{1}{1 - \left(\frac{BW}{2 f_c}\right)^2}\right]$$

References

[1] O. Bendov, J. F. X. Browne, C. W. Rhodes, Y. Wu and P. Bouchard, “DTV Coverage and Service Prediction,

Measurement and Performance Indices," IEEE Trans. on Broadcasting, Vol. 47, no. 3, Sept. 2001
[2] O. Bendov, "On the Validity of the Longley-Rice (50,90/10) Propagation Model for HDTV Coverage and Interference Analysis," Proceedings of the Broadcast Engineering Conference, 1999 NAB, Las Vegas, NV.
[3] 8VSB/COFDM Comparison Report, Association for Maximum Service Television (MSTV), Wash. DC, December 2000
[4] VSB Enhancement Testing Consortium (VETC) reports on field tests in Washington D.C (2002) and New Haven, CT (2003).
[5] The Federal Communications Commission has on March 13, 2003 adopted a Notice of Inquiry into minimum receiver performance standards. The issues related DTTV service prediction and planning remain open.
[6] International Telecommunication Union, Recommendation ITU-R P.372-8, Radio Noise, 2003
[7] "Engineering Aspects of Television Allocations," Television Allocations Study Organization (TASO), report to FCC, March 18, 1959.
[8] G. Sgrignoli, "DTV Repeater Mask Analysis," IEEE Trans. on Broadcasting, Vol. 49, no. 1, March 2003
[9] Private communication between G. Sgrignoli and C.W. Rohdes
[10] Dane E. Ericksen, "Measuring TV Sidebands & Spurious Emissions," Broadcast Engineering, May 1982.
[11] I. R. Pullen, "DTV Coverage-Prediction and Measurement," BBC R&D, IEE Colloquium, 16 March 1999, Savoy Place, London.
[12] R.A. O'Connor, "Understanding Television Grade A and Grade B Contours," IEEE Trans. on Broadcasting, Vol. 47, no. 3, Sept. 2001
[13] ETSI, Implementation guidelines for DVB terrestrial services; Transmission aspects, Technical Report TR 101 190 V1.1.1 (1997-12).
[14] Pablo Angueria et al., DTV (COFDM) SFN Signal Variation Field Tests in Urban Environments for Portable Outdoor Reception," IEEE Trans. on Broadcasting, Vol. 49, no. 1, March 2003
[15] K. Blair Benson, *Television Engineering Handbook*, McGraw-Hill Book Company, 1986.
[16] Harald T. Friis, "A Note on a Simple Transmission Formula," Proc. IRE, pp.254-256, May 1946.
[17] Y. Wu, E. Pliszka, B. Caron, P. Bouchard, and G. Chouinard, "Comparison of Terrestrial DTV Transmission Systems: The ATSC 8-VSB, the DVB-T COFDM and the ISDB-T BST-OFDM," IEEE Trans. on Broadcasting, vol. 46, no. 2, June 2000.
[18] International Telecommunication Union, Recommendation ITU-R P.370-7, 1995.

ANNEX: INTERFERENCE TO DTTV RECEPTION FROM SIGNALS IN ADJACENT AND UHF TABOO CHANNELS

a. Background

DTTV reception is limited by the threshold Signal-to-Noise ratio and by interference from NTSC signals and other DTTV signals on the same or adjacent channels, and by interference from TV signals on UHF Taboo channels. Because of spectrum congestion, many DTTV channel allotments are on adjacent channels to those presently in use in the same community. Use of first adjacent channels in the same or even nearby communities has not been possible with analog transmission techniques for radio or TV. Interference to DTTV reception is related to the Signal to Interference + Noise ratio which must exceed 15.2 dB for the North American DTTV Standard. It is the sideband splatter in the channel of the Desired signal, which is primarily responsible for adjacent channel interference, not the limited IF selectivity as was once thought.

Adjacent channel interference had historically been due to the finite selectivity of consumer receivers, be they AM, FM or TV. The unique characteristics of the DTTV signal are such that the prototype tested in 1995 for the Federal Communications Commission had selectivity approaching 60 dB down at both channel edges. It is expected that consumer receivers will also provide this selectivity. When tested, the RF Test Bed had a noise floor some 60 dB below the DTTV or NTSC Undesired signal involved in testing. This extremely low noise floor was readily obtained in a laboratory environment in which the RF power was on the order of 0 dBm.

Practical DTTV transmitters generate 3rd and 5th order Intermodulation products whose FCC permissible spectrum may project significant power into the first lower and the first upper adjacent channels and beyond. This spectrum of IM products look like noise to receivers tuned to the adjacent channels.

Across the first adjacent channels, the permissible spectral power density must decrease as a function of frequency as measured from the DTTV channel edges. The interference power into adjacent channels has been calculated and reported[8]. The maximum power in an adjacent channel is 44.5 dB below that radiated within the allocated channel. Some additional interference suppression is provided by the IF selectivity of the receiver tuned to one of the adjacent channels resulting in the effective interfering noise power being 46.5 dB below the radiated DTTV signal. Note that the noise floor in these adjacent channels is 14.5 dB higher than it was in the DTTV testing upon which the Desired-to-Undesired Ratios were devised by the FCC in 1996-7.

b. DTTV-DTTV Adjacent Channel Interference

The US adjacent channel allotments were based D/U not lower than –42 dB for lower undesired adjacent channel and –43 dB for upper undesired adjacent channel. In 1998 those limits were modified to –28 dB and –26 dB, respectively. The new limits were codified in section 73.623 of the FCC rules but OET Bulletin 69 (FCC 1997) which governs the evaluation of interference is based on the original D/U ratios. Thus it appears that the latest D/U ratios apply only to new stations, new allotments and modification to existing stations but do not impact the original allotments. The inevitable conclusion is that some channels are permitted more interference into their neighboring channels. As Figure 10 shows, even the new D/U ratios may at best be marginal if a single interfering station radiates what is permissible into the adjacent channel. The D/U ratio cannot exceed -31.3 dB (-46.5 dB 15.2 dB) for a single adjacent channel.

c. NTSC into DTTV Adjacent Channel Interference

NTSC transmitters can suffer IM distortion between their powerful visual carrier and the upper sideband video signal. This results in spurious signals (noise) appearing in the lower adjacent channel. The out-of-channel emissions from NTSC transmitters into adjacent channels have not been a problem, as those channels were not used locally until now.

The FCC Rules for NTSC may be interpreted to limit spectral power density within the first 3 MHz of the NTSC channel to be at least 38 dB below peak visual power, and 60 dB below the peak visual power in the outer 3 MHz of the adjacent channel. If this interpretation is correct, then the integrated sideband splatter in the lower adjacent channel can be no greater than 41 dB below peak visual power. This is 5 dB higher than for a DTTV transmitter so in effect, the D/U ratio for NTSC into DTTV is -41 dB. Many modern NTSC transmitters generate much lower IM distortion than this. It is likely than the sideband splatter in the Upper adjacent channel is substantially less.

d. DTTV Interference from TV signals on UHF Taboo Channels

A further potential problem depends on whether consumer DTTV receivers will have the same immunity to interference as that measured by the ATTC in 1995 using the prototype DTTV receiver. That receiver had a double conversion tuner designed to prove that the UHF Taboo channels could be used for DTTV. The economics of tuner design make single conversion tuners favored, and that is what is being used for DTTV receivers. We have no knowledge of the interference rejection capabilities of tuners in consumer DTTV products. Such information is generally considered as trade secrets.

e. Interference Due to Tuner Overloading

IM products can be generated in the tuner of TV receivers when the total RF voltage at the mixer exceeds a certain level. These IM products may fall in the desired channel. For example, the visual carriers of two signals on any of these channel pairs will produce IM in the desired channel (n):

2(n–3) -(n–6) = n	**2(n-2) - (n-4) = n**	**2(n–1) - (n–2) = n**
2(n+3) -(n+6) = n	**2(n+2) - (n–4) = n**	**2(n+1) - (n+2) = n**

IM products generated by the sidebands of one DTTV signal on either adjacent channel fall within channel n.

With multiple Undesired signals on frequencies close to the Desired signal frequency, it is the *peak envelope power* of all significant signals of concern. No tests with multiple undesired signals have been conducted to date.

f. Conclusions

Adjacent channel interference to DTTV reception is primarily due to sideband splatter into the Desired channel from TV signals on adjacent channels. This splatter may be radiated, or, in strong signal areas, generated in the affected receiver tuner or Master Antenna System feeding the receiver.

Efforts to reduce the effective noise figure of DTTV tuners are important for the success of terrestrial DTTV broadcasting for reasons outlined in the main text. However, receiver design should also strive to improve the signal overload level of DTTV receivers to avoid interference between strong TV signals. In some cases a design trade-off exists between a low noise figure and a high overload level. Both are important. The interference rejection capabilities of single conversion tuners should be compared with the FCC assumptions concerning UHF Taboo channel interference immunity. Interference from an NTSC transmitter on the Upper Adjacent channel may cause interference to DTTV reception although the NTSC transmitter is operating in accord with FCC Rules.

The authors suspect that the present DTTV Planning Factors for adjacent channel interference may permit unexpected interference to NTSC and DTTV reception when all DTTV transmitters commence full power operation.

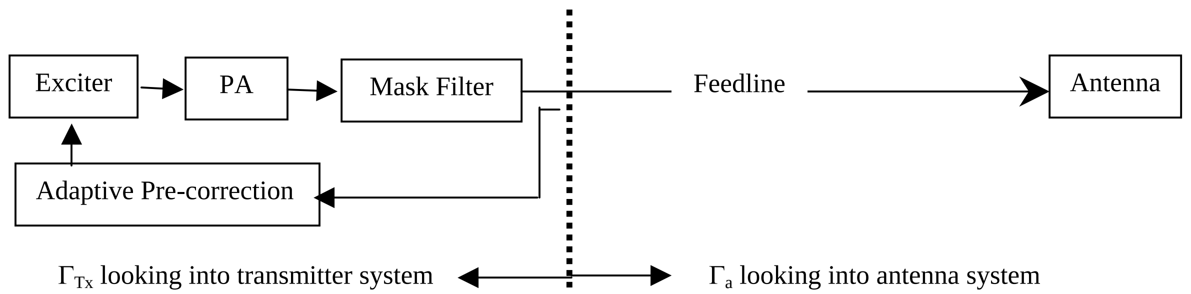

Figure 1: Defining the Antenna and Transmitter Systems

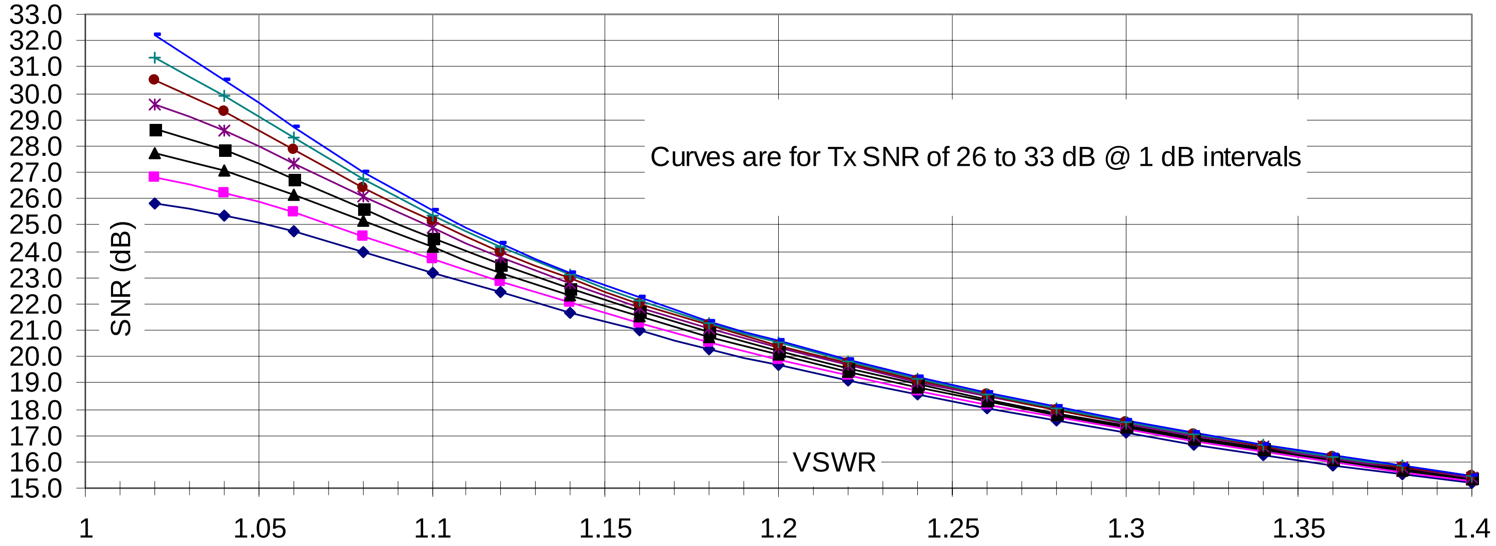

Figure 2: Theoretical Uncorrected Tx SNR vs. Antenna VSWR

THALES
BROADCAST & MULTIMEDIA

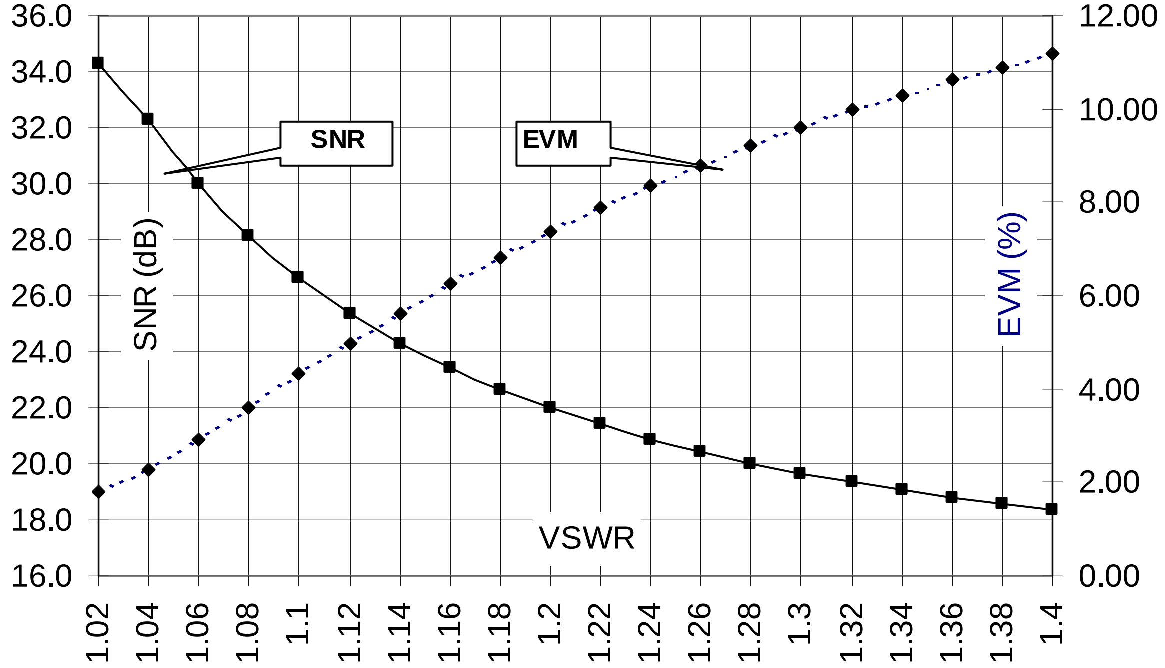

Figure 3: Measured Uncorrected Tx SNR/EVM vs. Antenna's VSWR Polynomial fit

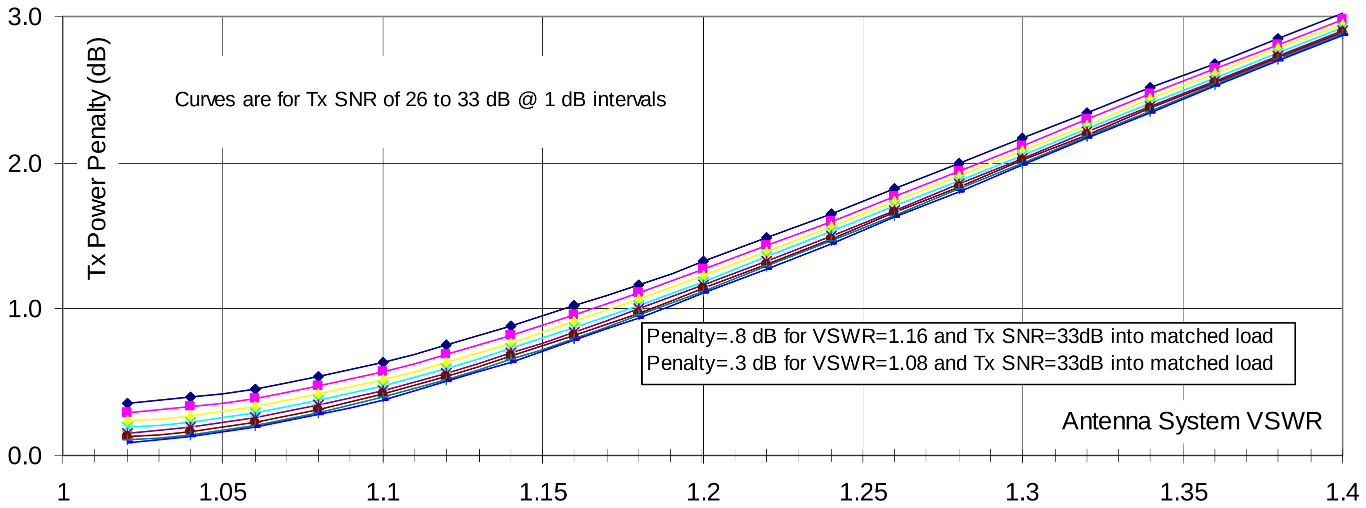

Figure 4: Theoretical Uncorrected Tx Power Penalty vs. Antenna VSWR

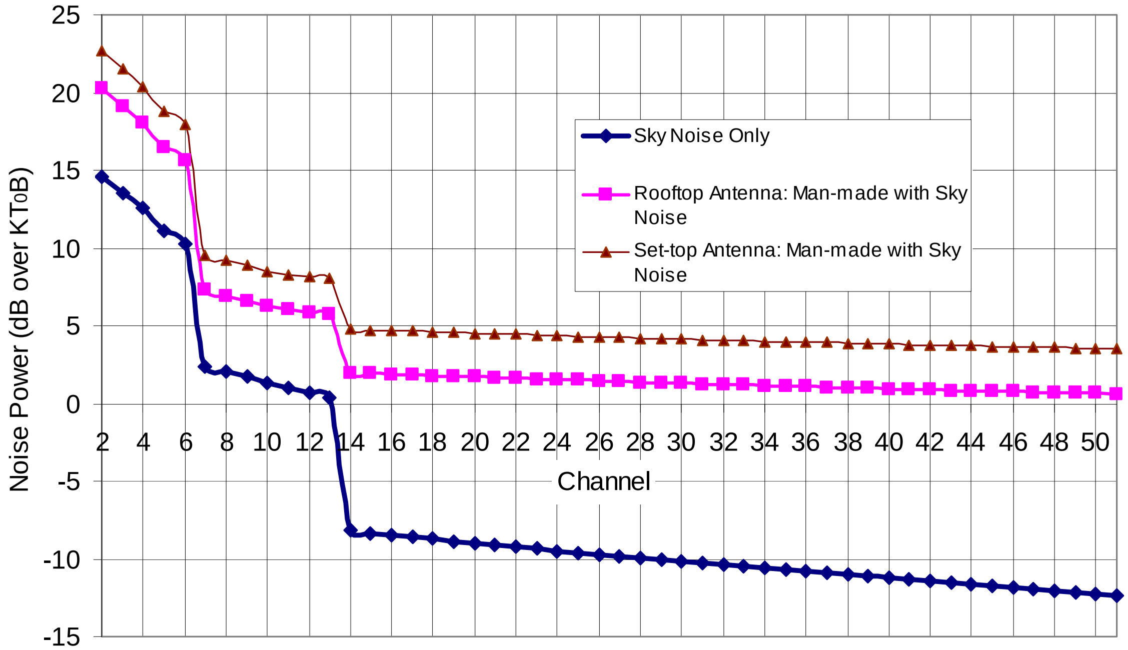

Figure 5: Median Residential Man-made and Sky Noise at the Terminals of an Outdoor Receive Antenna

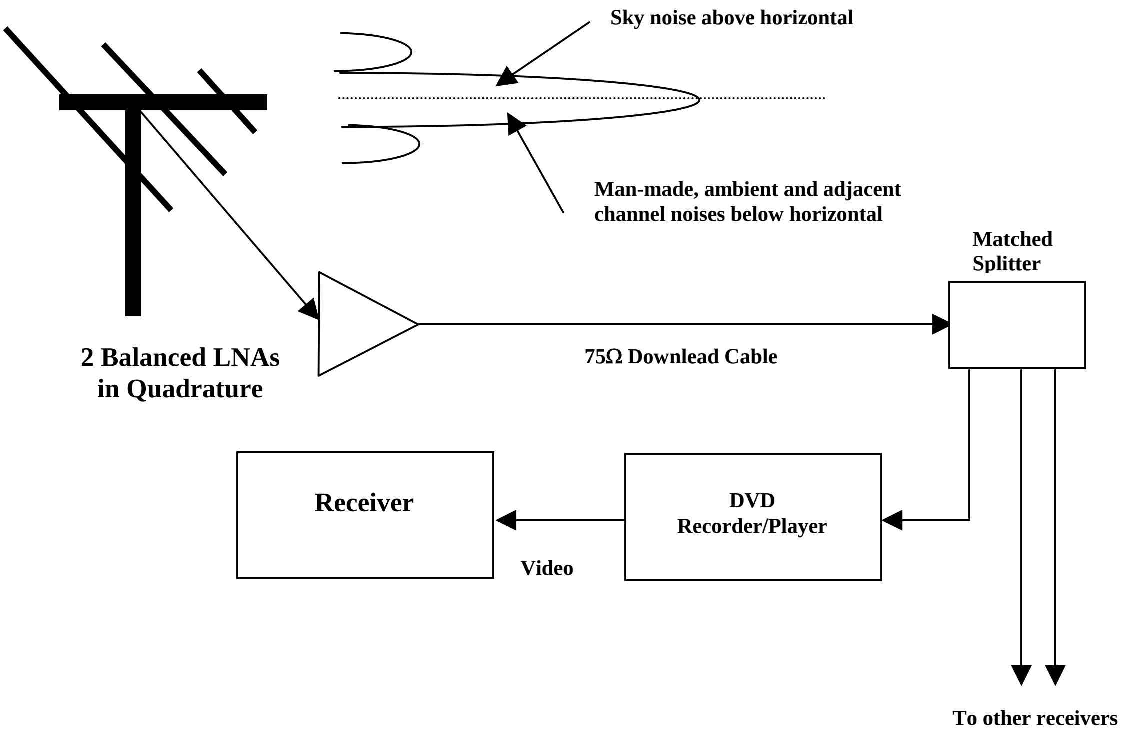

Figure 6: Reception with Directional Rooftop Antenna

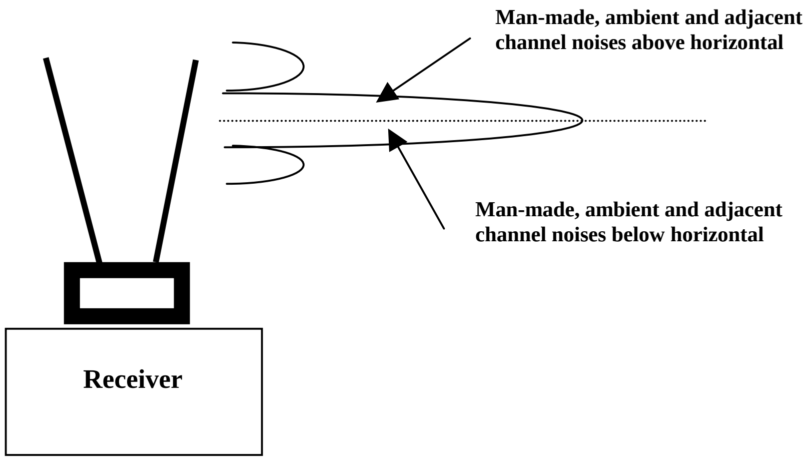

Figure 7: Reception with Set-top Antenna

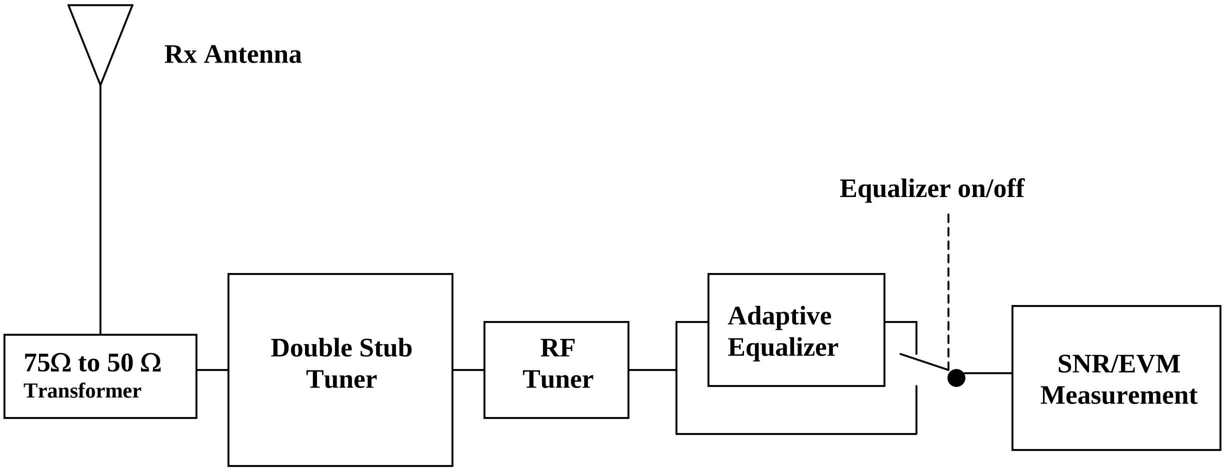

Figure 8: Degradation due to Receiving Antenna and RF Tuner Impedance Mismatch Measurement

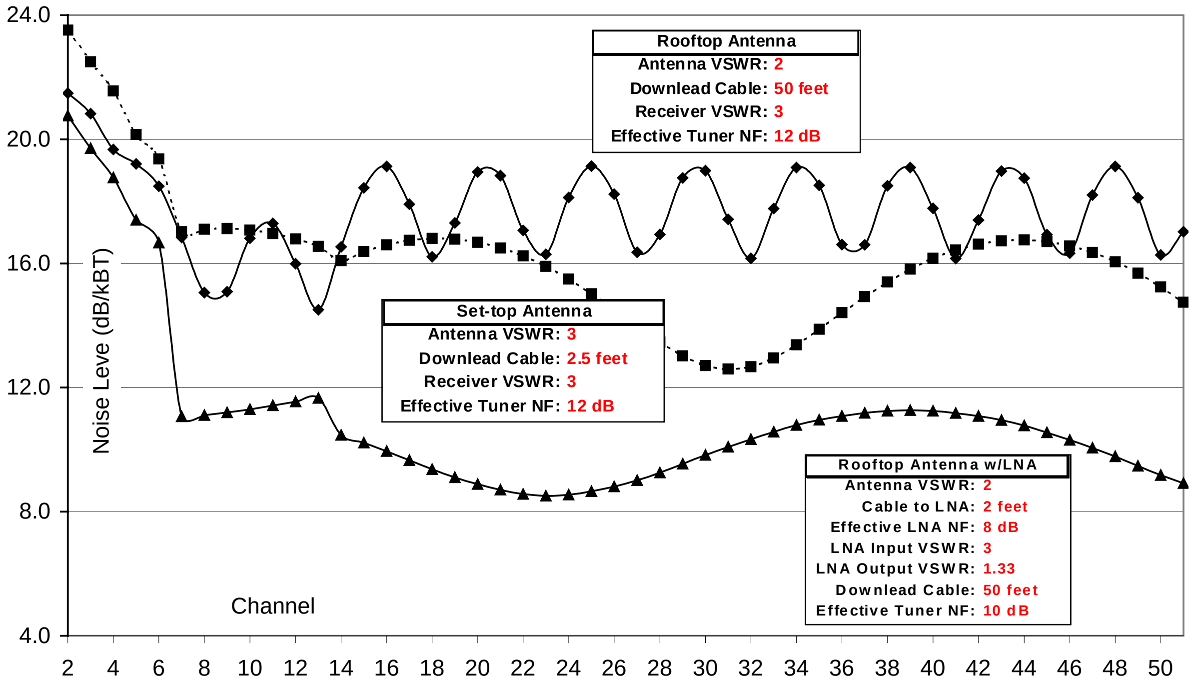

Figure 9: Noise Level at the Antenna Terminals
Added Loss due to Impedance Mismatches, Sky & Man-made Noise Included

Figure 10: Minimum Desired and Margin Levels
to Accommodate Single Adjacent DTV Channel Sideband Splatter

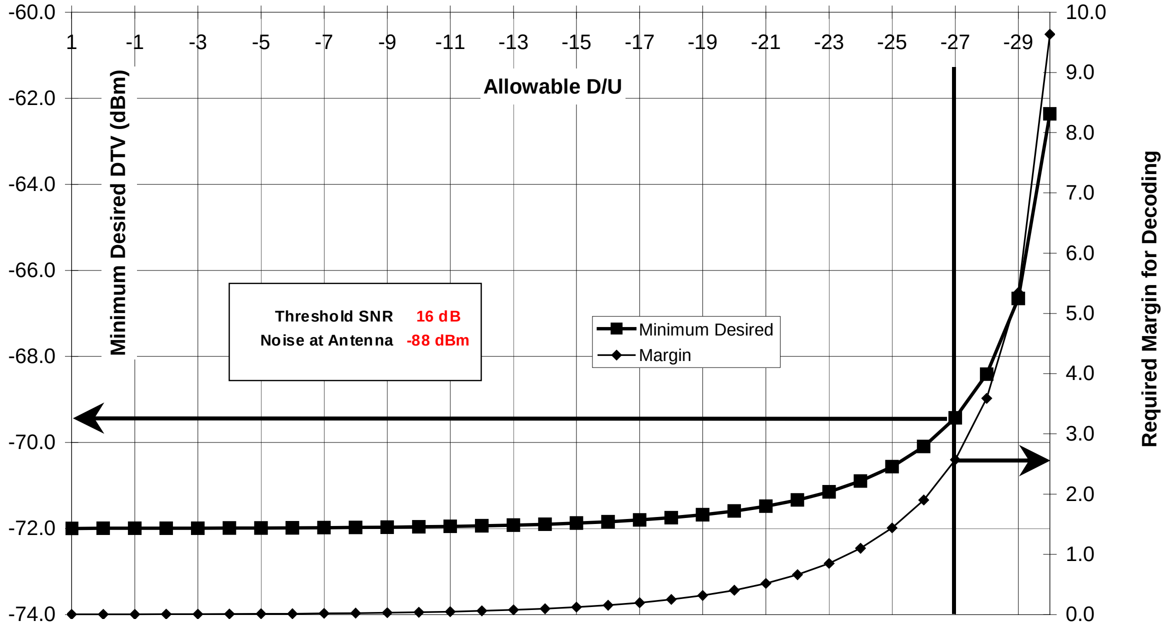

Figure 11: Minimum Desired DTV to Accommodate Single Adjacent NTSC Channel Sideband Splatter

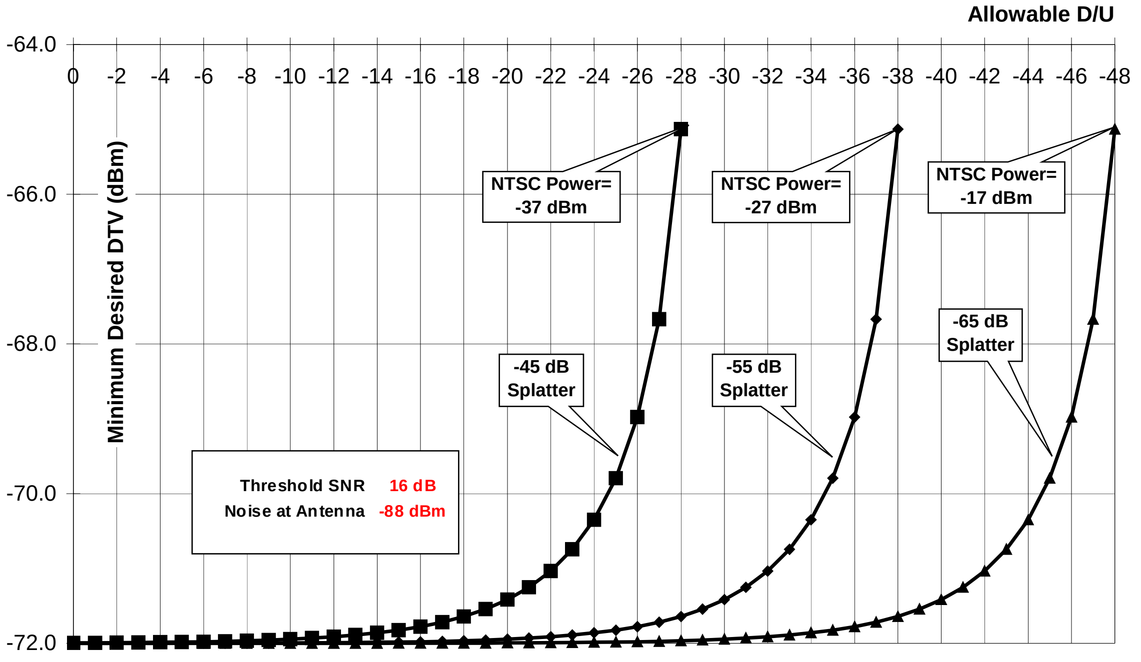

Figure 12: Received Signal Power over a 3-day Period¶
Signal power measured over 6MHz with directional antenna 30 km from the transmitter. Line of sight path.¶

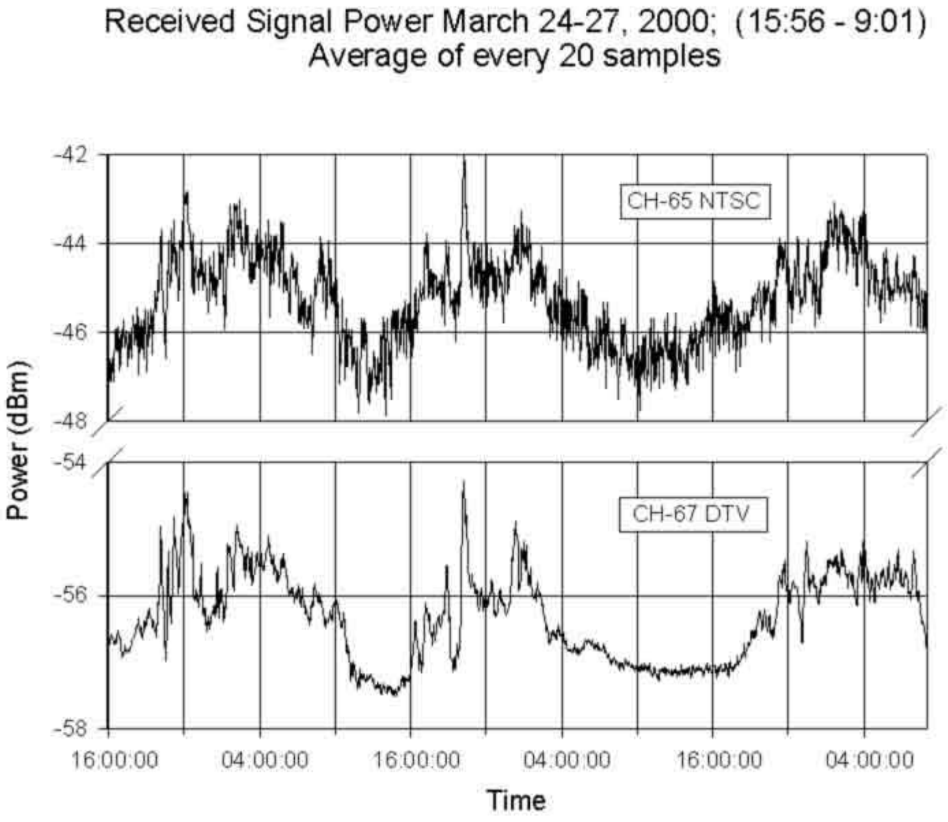

Figure 13: Error in Calculating "Field Strength" of Broadband Channels Free of Multipath and with Constant-gain Receive Antenna Using Narrow Bandwidth Formulation

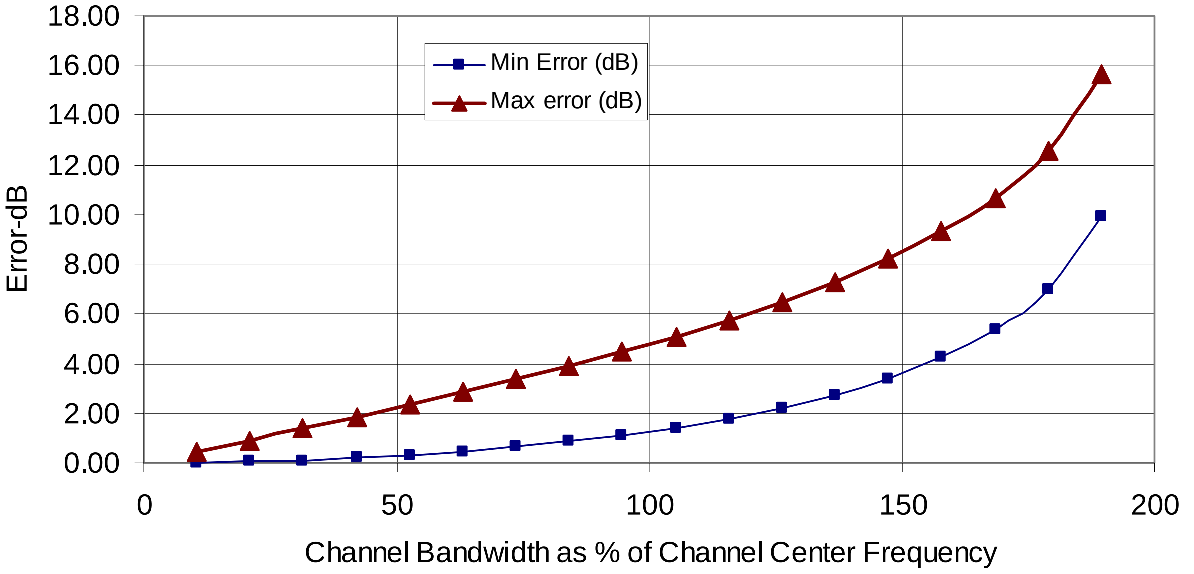

Table I: FCC's DTTV Link Budget for Ideal Channels

A. Threshold Received Power Required for Decoding

	Receiver Noise Bandwidth	6	MHz	
	Ambient Temperature	290	^{0}K	
A	Thermal Noise	-106.2	dBm m=mW	
B	Noise Figure @ Antenna Terminals	11	dB	
C=A+B	Noise Power@ Antenna Terminals	-95.2	dBm	
D	Threshold Signal-Noise Ratio	15.2	dB	
=C+D	**Threshold Power @ Antenna Terminals**	-80.0	dBm	**What is measurable**

B. Incident "Field Strength" on a Rooftop Antenna at 615 MHz

	Imputed Carrier Frequency to Power @ Antenna Terminals	615	MHz	
A	Incident "Field Strength"/1 mW of received power @ Imputed Carrier Frequency	130.8	dBu/mW u=microvolts/m	**Traditional formula is wrong for wideband digital channles**
B	Threshold Power @ Antenna Terminals	-80.0	dBm	
C	Antenna Gain Relative to 1/2 wave dipole	10	dB	
=A+B-C	**Threshold "Field Strength" @ Imputed Carrier Frequency**	40.8	dBu u=microvolts/m	**Calculated from measured received power using wrong formula**

Table II: Preliminary DTTV Link Budgets

	Rooftop Directional Antenna[1]			
	69 MHz	**194 Mhz**	**615 MHz**	
Thermal noise (kT_0B)	-106.2	-106.2	-106.2	dBm
Noise level at antenna (see Figure 9)	19.7	16.8	18.5	dB/kT_0B
Threshold SNR	16	16	16	dB
Minimum Power required for decoding exclusive of margins	**-70.5**	**-73.4**	**-71.7**	**dBm**
Antenna gain	4	6	10	dB
Equivalent minimum "field strength"	**37**	**41**	**49**	**dBu**
Equalizer Added Noise Margin for Light to Medium Multipath	0-3	0-3	0-3	dB

	Rooftop Directional Antenna with LNA[2]			
	69 MHz	**194 Mhz**	**615 MHz**	
Thermal noise (kT_0B)	-106.2	-106.2	-106.2	dBm
Noise level at antenna (see Figure 9)	18.8	11.3	11.2	dB/kT_0B
Threshold SNR	16	16	16	dB
Minimum Power required for decoding exclusive of margins	**-71.4**	**-78.9**	**-79**	**dBm**
Antenna gain	4	6	10	dB
Equivalent minimum "field strength"	**36**	**36**	**42**	**dBu**
Equalizer Added Noise Margin for Light to Medium Multipath	0-3	0-3	0-3	dB

	Set-top Non-directional Antenna[3]			
	69 MHz	**194 Mhz**	**615 MHz**	
Thermal noise (kT_0B)	-106.2	-106.2	-106.2	dBm
Noise level at antenna (see Figure 9)	21.6	17.1	15.4	dB/kT_0B
Threshold SNR	16	16	16	dB
Minimum Power required for decoding exclusive of margins	-68.6	-73.1	-74.8	dBm; Outdoor
Antenna gain**	-10	-5	0	dB
Equivalent minimum "field strength"	53	53	56	dBu; Outdoor
Combined height and ground floor penetration loss for signal and noise	37	37	37	dB
Equivalent minimum "field strength" at 10 m above ground for indoor reception	**90**	**90**	**93**	**dBu**
Equalizer Added Noise Margin for Light to Medium Multipath	0-3	0-3	0-3	dB

1
Threshold SNR includes .8dB penalty due to Tx's degradation.
Single receiver. Add 3.5 dB loss for second receiver
Median residential Man-made noise level
Median sky temperature
*Estimated for VHF
Antenna VSWR=2
Front-end VSWR=3
Antenna to front-end cable=50'
Noise Figure with matched antenna=10

2
Threshold SNR includes .8dB penalty due to Tx's degradation.
Multiple receivers
Median residential Man-made noise level
Median sky temperature
*Estimated for VHF
Antenna VSWR=2
LNA input VSWR=3
LNA Noise Figure=3 dB (matched source)
LNA output VSWR=1.33
Antenna to LNA cable=2'
LNA output VSWR=1.00
LNA to front-end cable=50'
Noise Figure with matched antenna=10

3
Threshold SNR includes .8dB penalty due to Tx's degradation.
Single receiver. Add 3.5 dB loss for second receiver
Median residential Man-made noise level
Median sky temperature
*Estimated for VHF
Antenna VSWR=3
Front-end VSWR=3
Antenna to front-end cable=3'
Noise Figure with matched antenna=10
**Estimate based on wavelength ratio
Antenna 1.5 meters above ground