Communications Research Centre Canada
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Digital Television Tests Results

Phase I

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SOMMAIRE

Dans le but d'évaluer la performance des récepteurs 8-VSB se conformant au nouveau standard (ATSC) de transmission par voie terrestre de la télévision numérique, des tests en laboratoire et des essais sur le terrain ont été exécutés par le Centre de Recherches sur les Communications (CRC). Cette évaluation fut faite en collaboration avec la direction générale de la réglementation des radiocommunications et de la radiodiffusion d'Industrie Canada et l'organisme Télévision numérique du Canada (CDTV Inc.).

Les tests en laboratoire ont permis de caractériser différentes générations de récepteurs 8-VSB provenant de plusieurs manufacturiers. Ces tests nous ont permis d'évaluer l'évolution des performances des récepteurs 8-VSB survenue entre la première génération et la génération actuelle. Les résultats démontrent que les récepteurs de la première génération (juin 1999) sont très sensibles à la phase des échos. Par contre, ceux de la dernière génération (août 2000) sont beaucoup moins sensibles à la phase des échos et présentent une plage d'égalisation plus étendue (de -2 à 40 μsecondes). Il faut toutefois noter qu'une amélioration des performances de l'égalisateur face aux pré-échos (< -2 μsecondes) est souhaitable.

Les essais sur le terrain ont démontré que le système 8-VSB fonctionne très bien avec une antenne extérieure à une hauteur de 10 mètres. Le signal de télévision numérique n'a pas pu être décodé qu'à quatre (4) reprises sur les 46 sites visités: dans le cas de ces quatre sites, le signal était la plupart du temps trop faible.

La réception du signal DTV à l'intérieur de maisons ou d'appartements a été possible à environ 50% des 43 sites visités durant les essais sur le terrain en utilisant une antenne intérieure active ou passive. La réception du signal DTV n'a pas été possible avec l'une ou l'autre de ces antennes dans 28% des cas, principalement à cause de la faiblesse du signal numérique et d'une forte proportion d'échos (affaiblissement multivoies). Dans le cas des dix autres sites visités, divers types de problèmes furent rencontrés: par exemple, la réception du signal DTV était possible soit avec l'antenne active mais pas avec l'antenne passive, etc. D'après les résultats obtenus, la réception du signal DTV à l'intérieur est dépendante de l'emplacement de l'antenne et de son orientation quelle que soit sa directivité.

D'autres tests sont en préparation pour trouver comment d'améliorer la réception du signal DTV aux sites où la réception est marginale. Parmi les approches envisagées, citons l'utilisation d'un répéteur opérant à la même fréquence, l'amélioration des récepteurs ou encore des antennes de réception.

EXECUTIVE SUMMARY

The Communications Research Center Canada (CRC) carried out laboratory and field tests to evaluate the performance of Advanced Television Systems Committee (ATSC) 8-VSB receivers. These tests were performed in collaboration with Industry Canada Broadcast Planning and Policy Directorate and the Canadian Digital Television Inc. (CDTV Inc.).

Prior to the field tests, laboratory tests have been performed to characterize 8-VSB receivers from different manufacturers and from different generations. The tests, also, provided a way to quantify improvements made in the design of 8-VSB receivers. The laboratory tests results showed that the earliest receivers tested (June 1999) were very sensitive to the phase of the echoes. However, the latest ones tested (August 2000) were significantly less sensitive to the phase of the ghosts and had a wider (-2 to 40 μseconds) equalizer window. On the other hand, the robustness to pre-ghosts still needs improvement.

The field tests results showed that the 8-VSB system performed as expected when received with an outdoor 10 meter high antenna: DTV could not be received at only 4 of the 46 sites visited, mainly due to low field strength.

Reliable indoor DTV reception could be achieved using simple set-top antennas (active and passive) at about 50% of the 43 sites visited. Indoor reception of DTV failed with either a passive or an active antenna at 28% of these sites mainly due to a combination of multipath and low field strength. For the ten (10) remaining sites, various combinations of DTV reception were observed: for example, reliable DTV reception with the active antenna, and no DTV reception with the passive one, etc. Based on the available data, reliable indoor DTV reception also appears to be strongly dependent upon the antenna orientation and location, regardless of its directivity.

Further tests are now under preparation to investigate how reception could be improved in difficult sites using, on-frequency repeaters, improved receivers, better antennas, etc.

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1 INTRODUCTION

Industry Canada has prepared a DTTB transition spectrum assignment and allocation plan for the implementation of Digital Terrestrial Television Broadcasting in Canada. This work was based on results from the laboratory and field test data that was collected during the evaluation of the **Grand Alliance** digital HDTV prototype system in the USA and Canada. Coverage prediction tools were also being used to establish service requirements. This system led to the ATSC A/53 digital television standard (www.ATSC.org), which was adopted by the FCC on December 24, 1996 and published in the Gazette by Industry Canada on November 8, 1997 as the standard for off-air broadcasting (www.strategis.ic.gc.ca/SSG/sf01731e.html) in the USA and Canada respectively.

A number of the assumptions made in the development of this plan need to be verified through additional laboratory and field tests since the results were based on rather limited data, especially, the measured field data. The planning methodology for Over-The-Air (OTA) DTV and, in some cases, the planning parameters used in Canada are also different than the ones used in United States due to differences in Canadian requirements and objectives.

Therefore, it is necessary to verify and compare the coverage for NTSC and DTV throughout the nominal service area (NTSC grade B). Concentrating resources on the most populous areas and on areas likely to exhibit difficult receiving conditions, such as indoor, dense urban areas, and in rough and hilly terrain. The results of these tests will help to identify the need and extent to which mitigation techniques may be needed to overcome possible OTA DTV reception difficulties. Moreover, some results from recent field tests done in the United States have already identified some problems with the indoor reception of OTA DTV, some related to the fact that digital systems do not degrade gracefully, but rather become undecodable (i.e. non-viewable) rather abruptly due to the so-called cliff-effect.

Prior to the field tests, laboratory tests have been performed to characterize 8-VSB receivers from different manufacturers. The tests, also, provide a way to quantify improvements made in the design of 8-VSB receivers.

The Communications Research Centre (CRC) Canada carried out all these tests in collaboration with Industry Canada Broadcast Planning and Policy Directorate and the Canadian Digital Television Inc. (CDTV Inc.).

2 LABORATORY TESTS OF 8-VSB RECEIVERS

In preparation for the DTTB field tests, the Communications Research Center Canada (CRC) carried out laboratory tests to evaluate the performance of Advanced Television Systems Committee (ATSC) 8-VSB receivers against channel impairments such as noise, multipath and other distortions. This section presents the results of laboratory measurements and a comparison of the performance of receivers from various manufacturers.

A number of receivers were tested in the laboratory. Among them, were consumer models available on the market, prototypes, and professional models. The results for the receivers C, E, F, H, L and N are presented in this document. Manufacturers were not identifying by name to protect the commercial value of some of the results. The oldest one is receiver C which was tested in June 1999. Receiver N is the newest one and was tested in August 2000. Note that the results are valid only for the particular unit used for the tests. No attempt was made to establish if similar results would be obtained with another receiver of the same model.

All receivers were tested against random noise, and random noise in the presence of static multipath ensembles. As a simplified version of the multipath test, a single echo test was also done to verify the delay range of the receivers' equalizers, and to observe the sensitivity of the receivers to the phase of an echo.

2.1 Setup and Methodology

The laboratory setup for the evaluation of the receivers is shown in Figure 1. The 19.39 Mbps high definition video signal (SMPTE 310M standard) was generated by an MPEG-2 Transport Stream Spooler, and fed into a modulator/exciter where it was modulated and up-converted to channel 54 (710 to 716 MHz).

For the random noise test, the DTV signal (at the output of the variable attenuator #1) was directly connected to the combiner where noise was added. For the static multipath and single echo tests, the signal passed through the channel simulator before reaching the combiner.

The average powers of the DTV signal and of the random noise were measured at the output of the combiner using a spectrum analyzer. The output signal from the combiner was connected to the 8-VSB receiver. Finally, the output of the 8-VSB receiver was connected to a video monitor, which was used to find the threshold of visibility (TOV). Some receivers did not have an integrated MPEG video decoder and were tested using an external one.

The threshold of visibility (TOV) was determined by increasing the impairment level until a number of errors appeared in the picture; then the impairment level was decreased gradually until TOV was reached. The TOV level recorded was the last impairment level that caused an error to occur in the picture over a period of 1 minute.

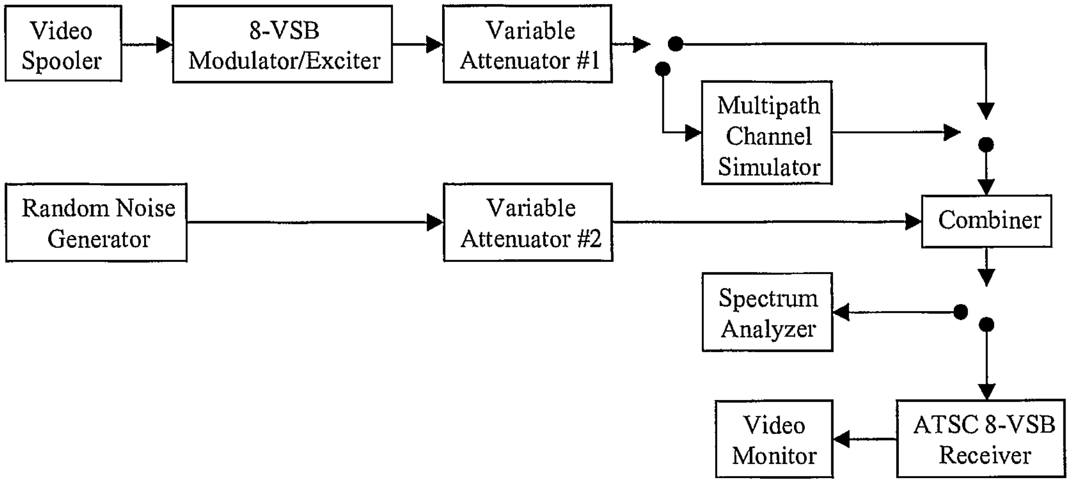


Figure 1. Laboratory setup for the evaluation of the receivers

2.2 Results of the Laboratory Tests

The following procedures were intended to measure the performance of the 8-VSB receivers. These tests included measurements of the robustness of the unit against:

-Random noise
-Multipath
-Single echo

2.2.1 Random noise impairment

The purpose of the first test was to determine the robustness of 8-VSB receivers to random noise impairment.

The DTV desired signal was adjusted at three different RF power levels: Strong (-28 dBm), moderate (-53 dBm) and weak (-68 dBm). For each power level of the DTV signal, the level of random noise was increased until TOV was reached. The ratio between the average power of the DTV signal and the random noise (C/N) was measured and the results for the receivers tested are presented in Table 1. The value measured by the Advanced Television Test Center (ATTC) for the Grand Alliance [1] prototype (Zenith Blue-rack) is also included in the table for comparison purposes.

Desired Signal Level	C/N (dB) at TOV for these receivers						
	C	E	F	H	L	N	Blue-rack
Strong (-28 dBm)	16.8 dB	15.3 dB	15.4 dB	16.0 dB	15.4 dB	15.1 dB	15.28 dB
Moderate (-53 dBm)	17.2 dB	15.3 dB	15.3 dB	16.0 dB	15.5 dB	15.2 dB	N/A
Weak (-68 dBm)	17.8 dB	15.3 dB	15.8 dB	16.7 dB	15.4 dB	15.3 dB	N/A

Table 1. Susceptibility to random noise test result

The difference between the performance of the worst and the best receivers (C and N respectively) is 2 dB at the moderate signal level as seen in Table 1. The results obtained by the receivers E, F, L and N are very close to the one obtained with the Zenith Blue-rack receiver.

2.2.2 Multipath impairment

The purpose of multipath testing was to determine how robust are the 8-VSB receivers in the presence of multipaths with random noise.

The ability of the receivers to receive the DTV signal for all the combinations of multipath representative of various reception environments was tested. The noise margin for TOV was measured for each combination of multipath presented in the Table 2.

Normally, the main (or desired) signal would be adjusted to the strong signal level (-28 dBm), but because of the insertion loss of the channel simulator, the main or desired signal level was adjusted between -43 dBm and –53 dBm.

The reference carrier-to-noise ratio (C/N) of the receiver under test in the setup with the channel simulator with no ghost was measured by increasing the level of the random noise until TOV was reached. The degradation in C/N was then measured the same way for each multipath ensemble. The phase of each echo was selected arbitrarily for each ensemble and the same values were used for each receiver tested. The results are presented in Table 3.

The receiver C could not work without error for any of the combinations of multipath. The receivers E, F and H obtained a C/N degradation comparable to the one of the Zenith Blue-rack. The newest receivers L and N outperformed the Zenith Blue-rack by up to 2.8 dB.

Ensemble		Path 1	Path 2	Path 3	Path 4	Path 5	Path 6
A	Delay (usec)	0	-1.80	+0.15	+1.80	+5.70	+18.0
	Amplitude (dB)	0	-20	-20	-10	-14	-18
	Phase (degree)	0	125	80	45	157	90
B	Delay (usec)	0	-1.75	+0.20	+1.80	+5.75	+17.95
	Amplitude (dB)	0	-20	-20	-10	-14	-18
	Phase (degree)	0	45	167	25	66	225
C	Delay (usec)	0	-1.80	+0.15	+1.80	+5.70	+18.0
	Amplitude (dB)	0	-18	-20	-20	-10	-14
	Phase (degree)	0	0	0	25	0	90
D	Delay (usec)	0	-1.80	+0.15	+1.80	+5.70	+18.0
	Amplitude (dB)	0	-20	-20	-18	-14	-10
	Phase (degree)	0	90	55	25	80	90
E	Delay (usec)	0	-1.80	+0.15	+1.80	+5.70	+18.0
	Amplitude (dB)	0	-20	-14	-10	-20	-18
	Phase (degree)	0	90	80	45	157	90
F	Delay (usec)	0	+0.20	+1.90	+3.90	+8.20	+15.0
	Amplitude (dB)	0	-10	-14	-18	-20	-20
	Phase (degree)	0	90	78	45	145	90
G	Delay (usec)	0	-0.20	+0.10	+0.15	+0.30	+0.60
	Amplitude (dB)	0	-19	-22	-17	-22	-19
	Phase (degree)	0	30	60	145	160	60

Table 2. Combinations of Multipath used by ATTC/ACATS

Static Multipath Ensemble	**Degradation Relative to No Ghost at TOV (dB) for the following receiver**						
	C	**E**	**F**	**H**	**L**	**N**	**Blue-rack**
No Ghost	17.8	16.0	15.6	16.6	15.7	15.2	15.16
A	Fail	Δ1.8	Δ1.5	Δ2.3	Δ0.9	Δ0.7	Δ3.28
B	Fail	Δ2.2	Δ1.8	Δ3.5	Δ1.0	Δ0.8	Δ2.40
C	Fail	Δ1.3	Δ1.1	Δ2.5	Δ0.2	Δ0.1	Δ2.18
D	Fail	Δ1.9	Δ1.6	Δ4.7	Δ0.9	Δ0.4	Δ2.89
E	Fail	Δ2.0	Δ1.8	Δ2.6	Δ1.8	Δ0.8	Δ3.64
F	Fail	Δ1.2	Δ1.2	Δ2.5	Δ1.5	Δ0.6	Δ1.20
G	Fail	Δ0.1	Δ0.2	Δ0.1	Δ0.1	Δ0.0	Δ1.68

Table 3. Susceptibility to random noise in presence of static multipath test results

2.2.3 Single echo impairment

A single echo test was done. This test verified the robustness of the receiver over the range of operation of the receiver's equalizer. The phase of the echo was varied from 0 degree to 360 degrees at a rotation speed of 0.1 Hz (Doppler). The goal of this test was to quickly find how the phase of the echo is critical for a given receiver and to determine the degradation caused by the worst phase value. With a phase variation limited to 0.1 Hz, the receivers were not sensitive to the Doppler effect and were affected only by the instant phase of the echo.

All the single echo tests were done with the DTV signal RF level adjusted to –53 dBm (moderate level). At this level the carrier-to-noise ratio of the signal was 32 dB.

A single echo was added to the main signal. The range of operation of all the equalizers under test was covered with an echo delay range of -10 to 44 µsec. The step size was 1 and 5 µsec depending of the results obtained. For every delay, the relative attenuation of the echo (D/U) was adjusted until TOV was reached. The results are presented in Figure 2.

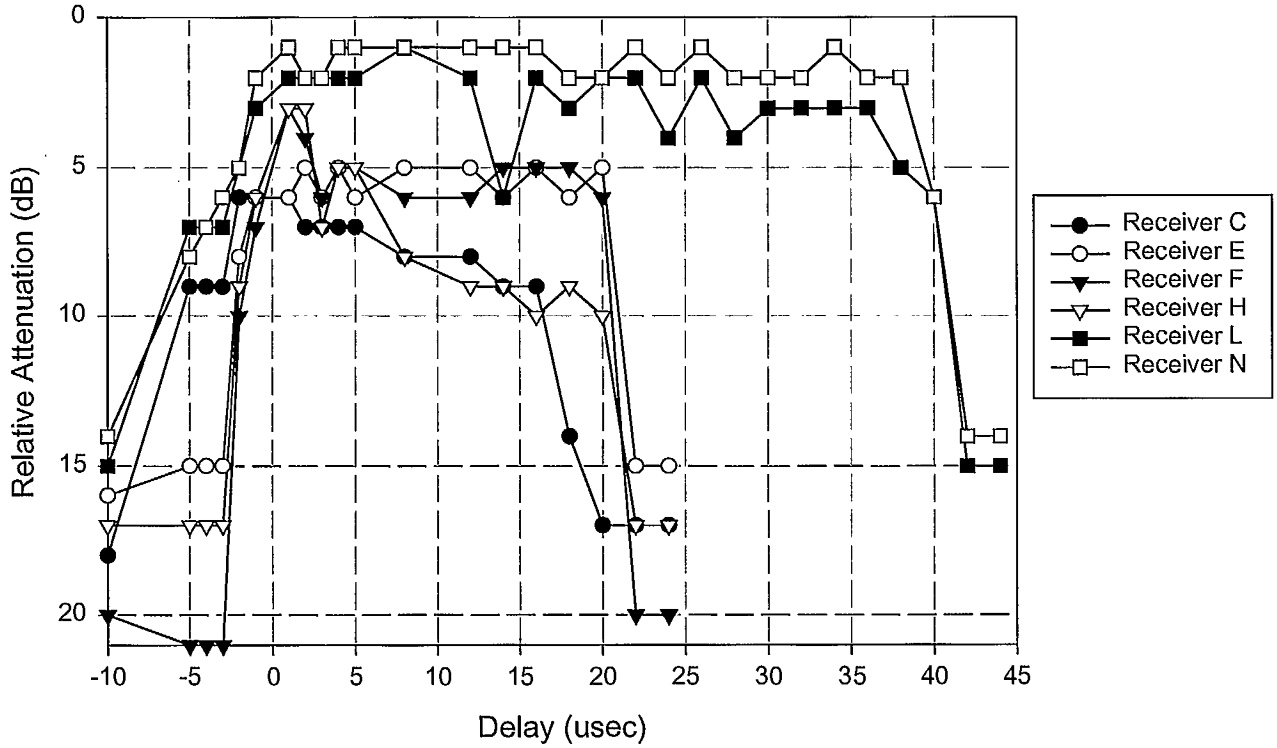


Figure 2. Single echo test with a phase variation of 0.1 Hz (C/N = 32 dB).

The performance of the receivers in this test is similar to the one for the combination of multipath. The receiver C did work for a single echo with a D/U greater than 7 dB. The receivers E and F did work for a D/U greater than 5 dB. The newest receivers obtained a better result for the D/U and also for the range of operation which increase close to 40 μsec compared to 20 μsec for the older receivers. The receiver L also shown a good improvement for the sensitivity to the phase of the echo with a D/U less than 2 dB for most of the delay range. However, even if the performance against pre-echoes have improved in the newer receiver there is still need for improvement.

3 FIELD TESTS

The purpose of the field tests was to evaluate:

The validity of the coverage prediction.
The coverage at the fringe and in difficult receiving condition.
The quality of DTV reception in the urban and most populous areas where reception with an indoor antenna is prevalent.

In view of the limited number of test sites included in this study, the results may not, by themselves, be statistically valid as the basis for coverage prediction. They, however, allow a spot-check of those sites of significance to coverage evaluation.

It is clear from the results of the laboratory tests presented before that the 8-VSB DTV receivers available for field tests were not fully mature and that rapid advance in technology is still taking place. This has to be taken into consideration in the evaluation of the results of the tests.

3.1 Transmitter

The transmission site is at the Rogers Broadcasting tower in Manotick (N45°13'01", W75°33'51"), about 35 kilometers south of Ottawa. The height of the tower is 209 m and the EHAAT of the antenna is 215.4 m.

The video server provided a short 19.39 Mbps video sequence that is short in length and can be looped, for as long as required. The video sequence from the transport steam generator can be changed remotely via a modem. The output of a HDTV server is modulated by a Zenith 8-VSB modulator with the parameters listed in Table 4, and up-converted to channel 67 (788-794 MHz). The signal is amplified by a 2.5 kW average power Larcan transmitter. The amplified signal is fed to a combiner with the existing NTSC channel 65 signal before feeding the antenna at the top of the 215.4 meter tower. The average ERP is 30.0 kW. The panel antenna is horizontally polarized with a 16.0 dBi gain.

SYSTEM PARAMETERS	
Modulation	8-VSB
Channel Bandwidth	6.00 MHz
Excess Bandwidth	11.5 %
Symbol rate	10.762 Msps
Bandwidth Efficiency	3 Bits/Symbol
Trellis Coding Rate	2/3
Reed-Solomon (FEC)	t=10 (207,187)
Payload Data Rate	19.39 Mbps
C/N Threshold of Visibility	15.3 dB (Receiver F)/16.0 dB (Receiver H)
TRANSMITTER PARAMETERS	
Antenna Height EHAAT	215.4 m
ERP (average)	30.0 kW

Table 4. Parameters of the 8-VSB transmitter used for the field tests.

For the NTSC transmitter on channel 65 (776-782 MHz), the power was measured as the peak power of the visual carrier. The licensed power was the transmitter power minus the feedline loss, times the power gain. The average visual power in NTSC was about 60 % of its peak value. Its varies with the picture content and acts as a varying load on both the AC power line and the internal components of the transmitter. To this one must added the aural carrier power, which is usually 10 % of the peak visual power.

The DTV signal was very different. Specifically, it was operated at a constant average power, at a level that was about 12 dB below the peak power of NTSC, for equivalent coverage. The coverage predicted for DTV and NTSC using CRC-COVLAB is illustrated in Figure 3.

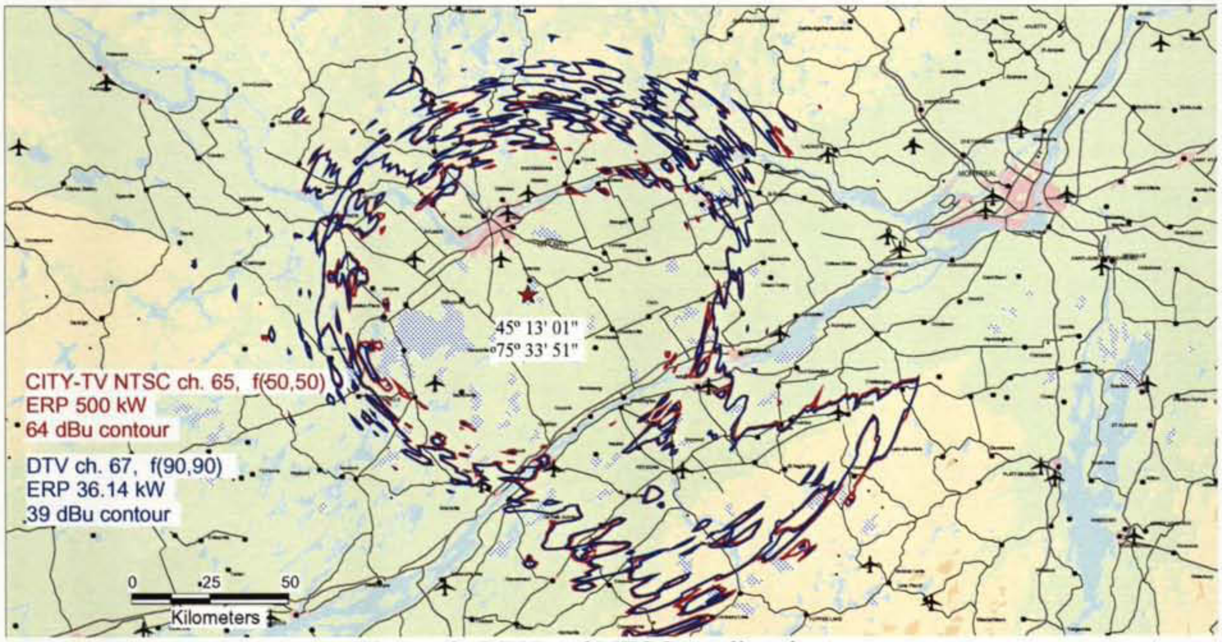


Figure 3. DTV and NTSC predicted coverage

The DTV transmitter is monitored at the transmitter site using a Davicom Remote control system as presented in Figure 4. The average power was measured continuously and a report of the status of the transmitter was faxed one time a day to CRC.

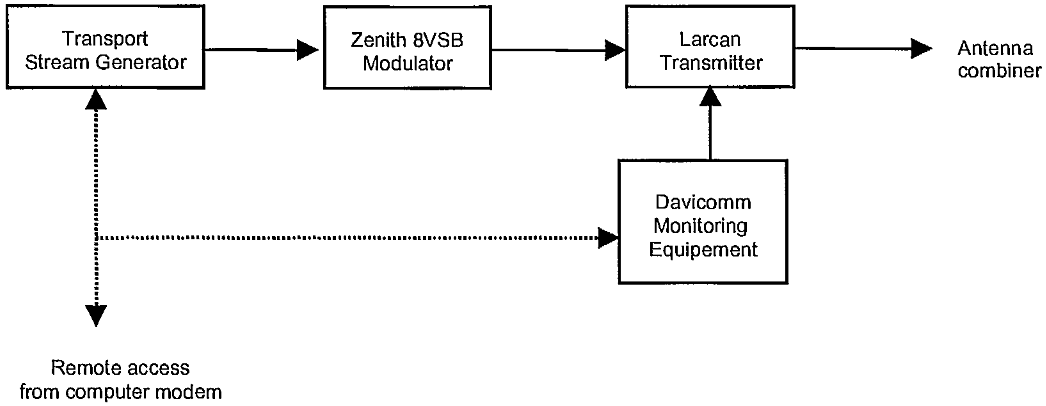


Figure 4. Setup at the transmitter site

3.1.1 Performance

The Canadian mask filter for the DTV emission is presented in Figure 5. The RF spectrum of the transmitter output is shown in Figure 6. It meets the relaxed RF spectrum mask specified for DTV transmission in Canada.

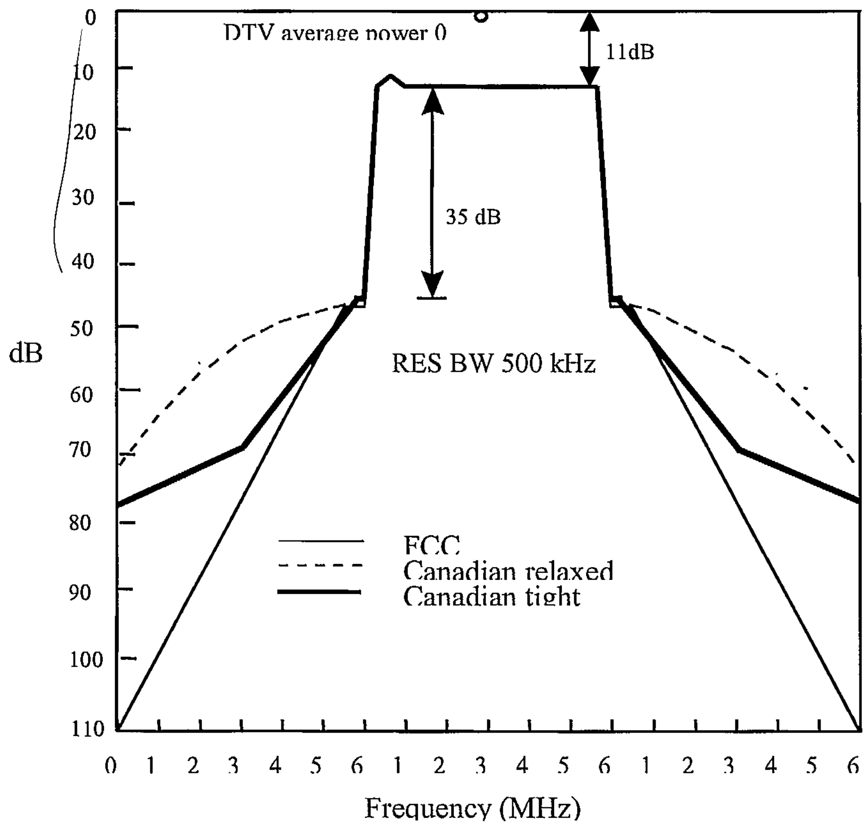


Figure 5. Digital Television Emission Mask (6 MHz)

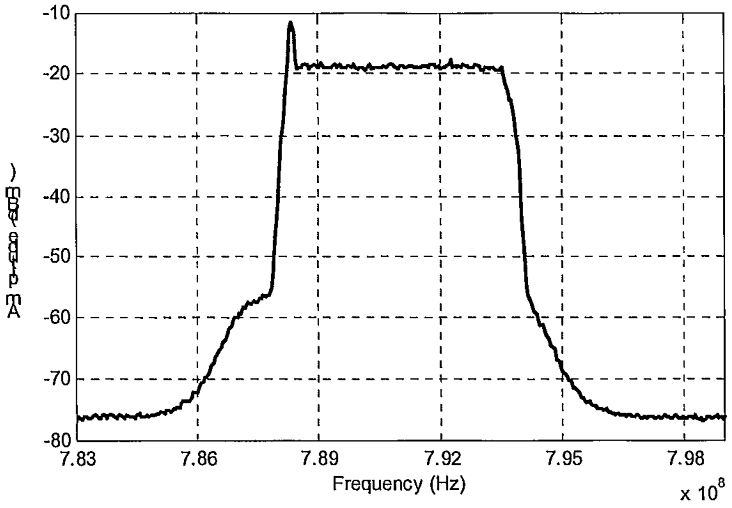


Figure 6. RF spectrum at the Manotick transmitter output

The measurement done at the calibration site showed no or little degradation in the C/N at TOV in comparison with the laboratory results for the two 8-VSB receivers which were used as presented in Table 5. This measurement confirmed that no significant phase noise degradation is created at the transmitter.

C/N at TOV with random noise injection			
Receiver F		Receiver H	
Laboratory	Calibration site	Laboratory	Calibration site
15.3 dB	15.3 dB	16.0 dB	16.3 dB

Table 5. Measurement of C/N at TOV

The difference between the NTSC peak power and DTV average power was monitored at CRC, which is 30 km from the transmitter and almost line of sight. The power difference varied between 12 and 14 dB. One example of this monitoring is presented in Figure 7 for a 72 hours period. This measurement confirmed the 12 dB difference in power between the transmission of the DTV and NTSC signals. It also shows that the power variation, creates by the propagation path, was about ±1.5 dB over that particular period of time.

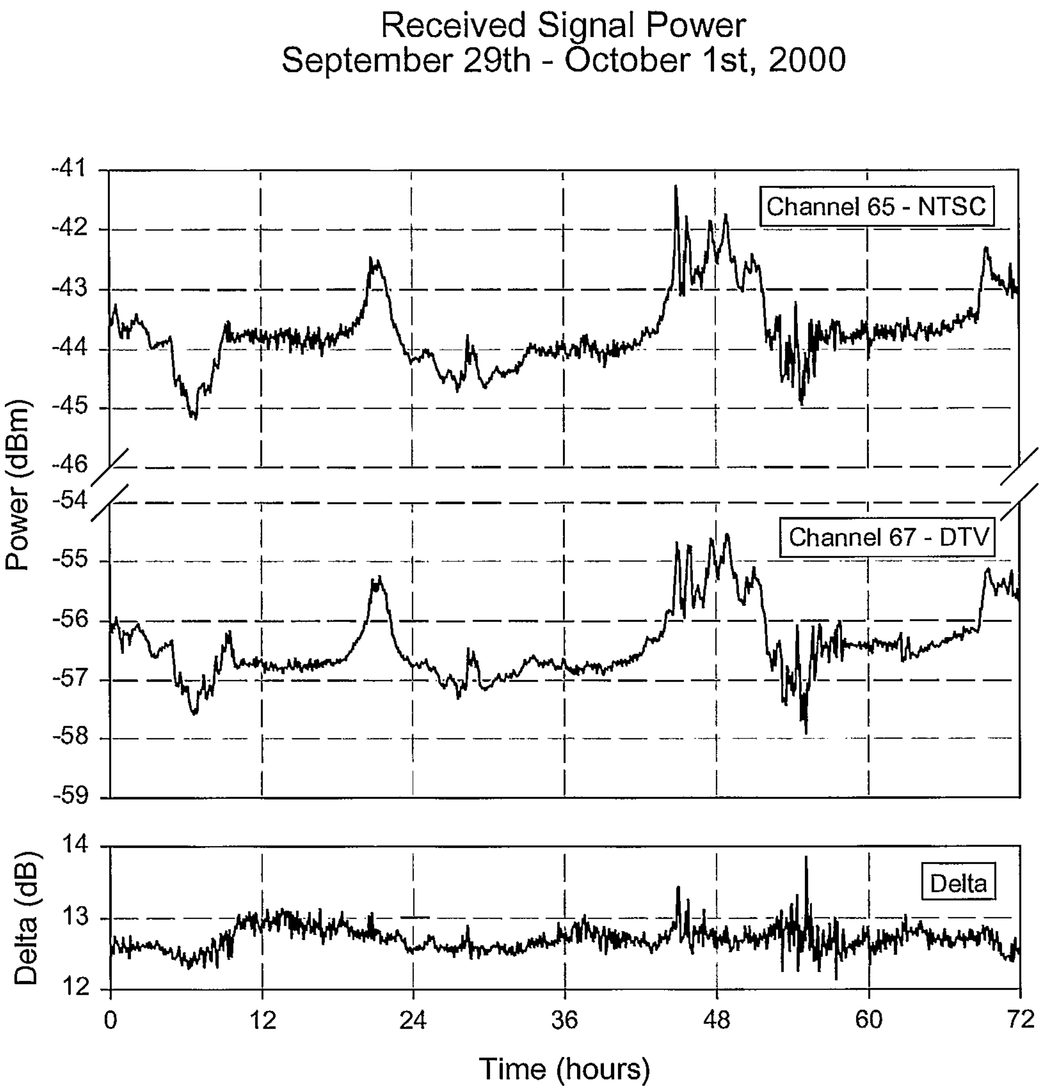


Figure 7. NTSC peak power and DTV average power variation over a period of 72 hours.

3.2 Outdoor Tests

Tests were done using a test van with a 10 meter mast, to estimate the DTV coverage and to measure the performance of the system when used with an outdoor receiver antenna. The receivers F and H were selected for these tests. Receiver F was the best professional receiver available at the beginning of the tests in February 2000. Receiver H was selected as a representative consumer type receiver.

3.2.1 Setup and methodology

In the test van, the signal was received by an 8.5 dBi gain log-periodic antenna (6.35 dB over dipole) and fed to both a DTV and an NTSC sets of test equipment as illustrated in Figure 8 with all the test point (TP).

The DTV measurements were performed on channel 67. Table 6 presents the 3 different setups for DTV measurements depending on the measured DTV average power at TP-1. Each setup used a different number of LNA to obtain a signal with the desired level at the receiver input. The HP attenuator, between TP-6 and the combiner input, is adjusted to obtain the desired gain from the antenna output to the receiver input. The spectrum analyzer was used for average power measurements, for C/N measurements and for determining the noise margin. The DTV receiver and monitor were used for subjective evaluation of the video signal. A noise generator was used to inject noise to find the noise margin at each test site. Equalizer tap energy measurements were performed using the DTV receiver F.

DTV AVERAGE POWER	**SETUP #1**	**SETUP #2**	**SETUP #3**
TP-0 (antenna output)	-10 to –20 dBm	-20 to –50 dBm	-50 to –70 dBm
TP-1 (splitter input)	**-18 to –28 dBm**	**-28 to –58 dBm**	**-58 to –78 dBm**
TP-2 (bandpass filter out)	-24 to –34 dBm	-34 to –64 dBm	-64 to –84 dBm
TP-3 (LNA#1 output)	-3 to –13 dBm	-13 to –43 dBm	-43 to –63 dBm
TP-4 (LNA#2 input)	(TP-3)	-16 to –46 dBm	-46 to –76 dBm
TP-5 (LNA#2 output)	(TP-3)	+5 to –25 dBm	-25 to –55 dBm
TP-6 (LNA#3 output)	(TP-3)	(TP-5)	-8 to –38 dBm
TP-7 (combiner output)	-7 to –17 dBm	-6 to –36 dBm	-36 to –56 dBm
TP-8 (RX input)	-21 to –31 dBm	-20 to –50 dBm	-50 to –70 dBm
Number of LNA	1	2	3
HP attenuator	0 dB	7 dB	24 dB
System Gain (TP-0 to TP-8)	-11 dB	0 dB	0 dB

Table 6. Characterization of three different setup for DTV field-tests measurement.

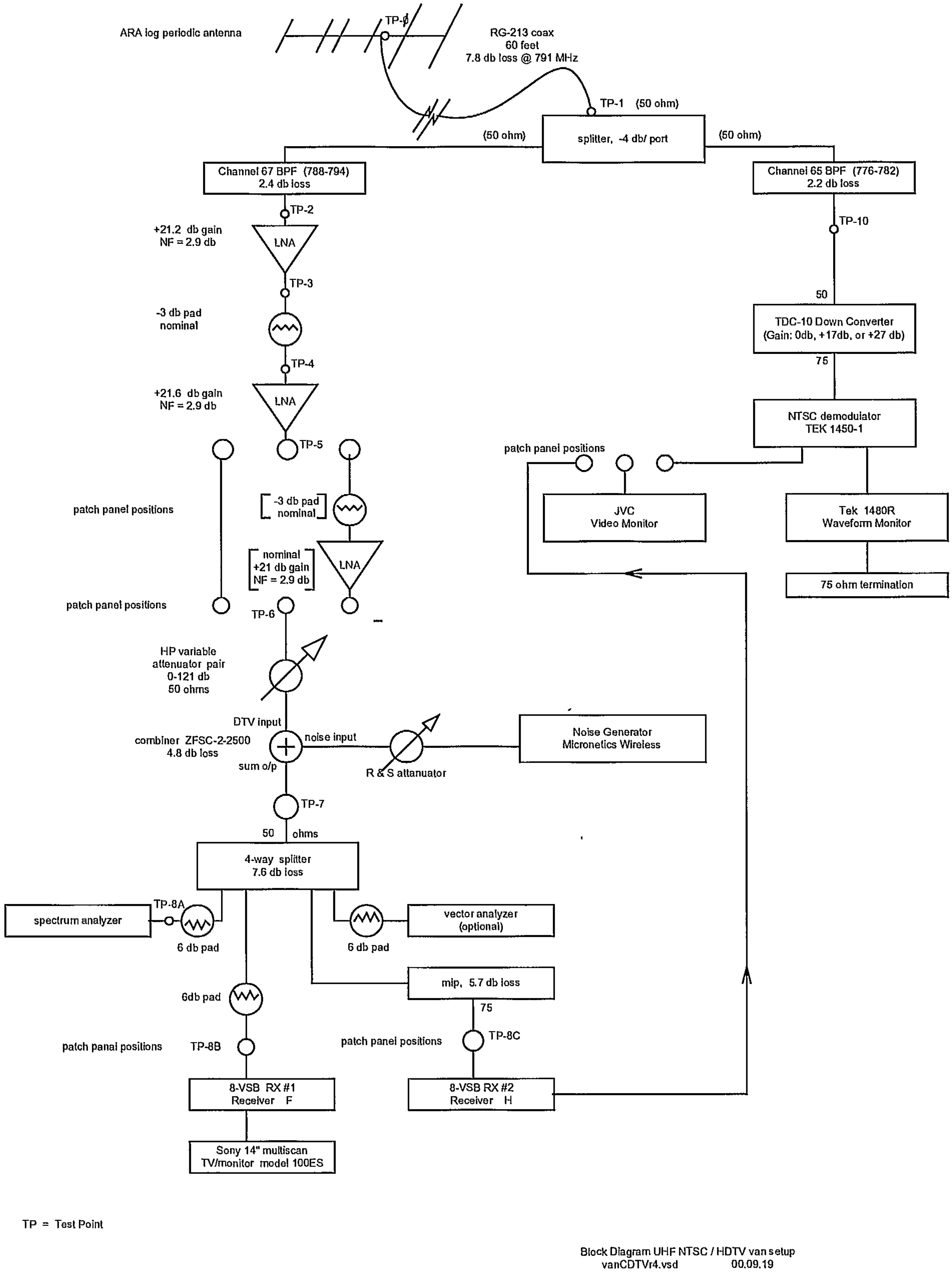


Figure 8. Setup in the receiver van

The NTSC measurements were performed on channel 65. The signal was demodulated by a professional demodulator and fed to a video monitor for subjective evaluation and to the VM-100 video analyzer for objective measurements. The NTSC power measurement was done with the professional demodulator.

A calibration site located in the CRC parking lot was visited on a regular basis to confirm the proper operation of the transmitter and receiver equipment. The signal received at this location was strong with a flat spectrum.

Receiver calibration was also performed in the laboratory once a week to verify the robustness to random noise and to the degradation due to a multipath ensemble.

3.2.2 Measurement

At each site the operators raised the antenna to 10 meters, oriented it in the direction of the transmitter, peaked the antenna using the spectrum analyzer for maximum received power and performed the measurements described below. If the DTV noise margin was found to be less than 5dB, the test was repeated with the antenna in the direction of minimum multipath. (This situation did not occur in practice).

For each site visited, the following information was also recorded:

- Date and time
- Weather conditions
- Description of the area surrounding the test vehicle.
- Global Positioning System (GPS) readings
- Compass readings of the receiving antenna

Please, refer to Figure 8 and Table 6 while reading the next sections:

3.2.2.1 DTV measurements

For the DTV measurements, the operators:

- Selected the number of LNA required following the power measured at TP-1 and make the appropriate connections.
- Adjusted the HP attenuator for the desired system gain (normally, G = 0 dB).
- Recorded the average power level over the 6 MHz DTV channel (788-794 MHz) at TP-8 (RX input)
- Recorded the carrier-to-noise (C/N) ratio, first by measuring the average power level at TP-6, turning off the DTV transmitter via the remote control system and measuring the noise level for the DTV channel. (It is also possible to measure the noise level in the upper adjacent channel if it is not possible to turn off the DTV transmitter). Calculated and recorded the C/N ratio.

- Measured the noise margin by increasing the noise level until the TOV was reached. Measured the average power and the noise level at TP-7. Calculated and recorded the C/N ratio.
- Recorded tap values from the reference receiver without noise injection.
- Logged the subjective evaluation of the DTV picture.

In order to compare our results with those of other organizations, the following two measurements were also done on selected sites.

- Recorded 20 MHz wide spectrum at 10 dB/div for adjacent channel interference measurement at TP-6.
- Recorded 10 MHz wide spectrum at 1 dB/div for in-band tilt observation at TP-6.

3.2.2.2 NTSC measurements

For the NTSC measurements, the operators:

- Adjusted the gain of the TDC-10 down converter for the desired system gain:
  If G = +17 dB; then the system gain = +3 dB
  If G = +27 dB; then the system gain = +13 dB
- Measured the received power for NTSC channel 65 with the professional NTSC receiver.
- Performed the NTSC objective measurement with the VM-100 video analyzer.
- Logged the subjective evaluation of the NTSC picture.
- Recorded the NTSC signal with the industrial VHS VCR (if required).

3.2.3 Results

46 sites were visited during the first phase of the field tests. The summary of the results is presented in the Tables 8 to11.

There was a direct relationship between the NTSC ITU subjective grade and the DTV noise margin for all sites not affected by very strong multipaths. The ITU grade scale for the NTSC subjective evaluation is presented in Table 7. There was only one site, in italic in Table 8, where the NTSC ITU grade and the DTV noise margin were not in direct relationship. At this location, the antenna was pointing over a highway and over a one storey flat roof building. An annoying strong multipath with a delay of approximately 10 µsec was observed on the NTSC video monitor. Some dynamic multipaths due to moving vehicles were also observed.

ITU GRADE SCALE
5: Imperceptible
4: Perceptible but not annoying
3: Slightly annoying
2: Annoying
1: Very annoying

Table 7. ITU scale for subjective evaluation.

Number of Sites	NTSC ITU	DTV Noise Margin
22	4 – 4.5	> 15 dB
9	3 – 3.5	> 9 dB
10	2 – 2.5	< 9dB
1	*2.5*	*16 dB*
4	1 – 1.5	No picture

Table 8. Comparison between the NTSC ITU grades and the DTV noise margin.

The results in Table 9 are for the 4 sites where no DTV reception was possible. The C/N at 3 of the 4 sites was below the required C/N level (15.3 to 16.3 dB), making DTV reception impossible. There was no LOS and the received signal was attenuated by building, houses or trees. DTV reception at site #10 was not possible due to strong multipaths. The NTSC picture was rated ITU grade 1 at this location.

Site #	Carrier to noise (C/N)	Multipath	Comments
10	17.3 dB	Very strong	Building and houses
17	15.0 dB	Very strong	Through trees
29	9.6 dB	None	Low signal (90 km)
39	9.1 dB	Strong (dynamic)	Near trees

Table 9. Receiving sites where no DTV reception was possible.

These results could also be presented in term of service availability and system performance. The DTV reception was possible for 42 of the 46 sites for an "Outdoor Service Availability of 91% (42/46). The DTV reception was possible for 42 of the 43 sites were the minimum C/N (15.3 dB for Receiver F and 16.0 dB for Receiver H) was available for an "Outdoor System Performance" of 98% (42/43).

The C/N degradation due to multipath created in the laboratory and those present in the field for each receiver is compared in Table 10. The ensemble B and D were the ones for which the receivers F and H respectively obtained the worst C/N degradation at TOV. However, theses results were not necessarily the worst case because the laboratory results showed also that the receiver F and H were sensitive to the phase of the echo. It is difficult at this point to make a conclusion from the results in Table 10 due to the fact that the combinations of multipath used in laboratory may not be similar to the multipath conditions encountered in the real-world.

C/N degradation due to multipath			
Receiver F		Receiver H	
Laboratory Ensemble B	Field Tests Worst Case	Laboratory Ensemble D	Field Tests Worst Case
1.8 dB	2.7 dB	4.7 dB	2.9 dB

Table 10. Comparison of the C/N degradation due to multipath in laboratory and in the field.

The observations made at site #12 over a period of time is presented in Table 11. This site was selected for its downtown location close to high rise buildings and with a street parallel to the signal path. The DTV reception was affected by strong multipath due to the high rise buildings and by dynamic multipath due to the traffic. The results showed that an additional 1 dB noise margin was necessary to handle the dynamic multipath created when there was moving traffic.

C/N degradation due to multipath (site #12)		
Receiver F	Receiver H	Comments
1.5 dB	2.5 dB	Strong multipath when no traffic
2.5 dB	3.5 dB	Dynamic multipath due to traffic

Table 11. C/N degradation for static and dynamic multipath.

The comparison between the DTV power measured at TP-0 (antenna output) and the predicted value using CRC COVLAB (http://www.drb.crc.ca/crc-covlab) is presented in Figure 9. Both curves were behaving similarly.

The comparison between the NTSC power measured at TP-0 (antenna output) and the predicted value using CRC COVLAB is presented in Figure 10. Both curves were behaving similarly again.

The delta is less than 10 dB for 80 % of the sites for the comparison between the measured and the predicted received power for both NTSC and DTV signals. The exceptions are now under investigation but it appears that for 13 % of the sites, the differences are due to the presence of obstacles (buildings, trees, etc.) not contained in the topographical database. For the remaining 7% of the sites, the differences are believed to be due to the imprecision of that database.

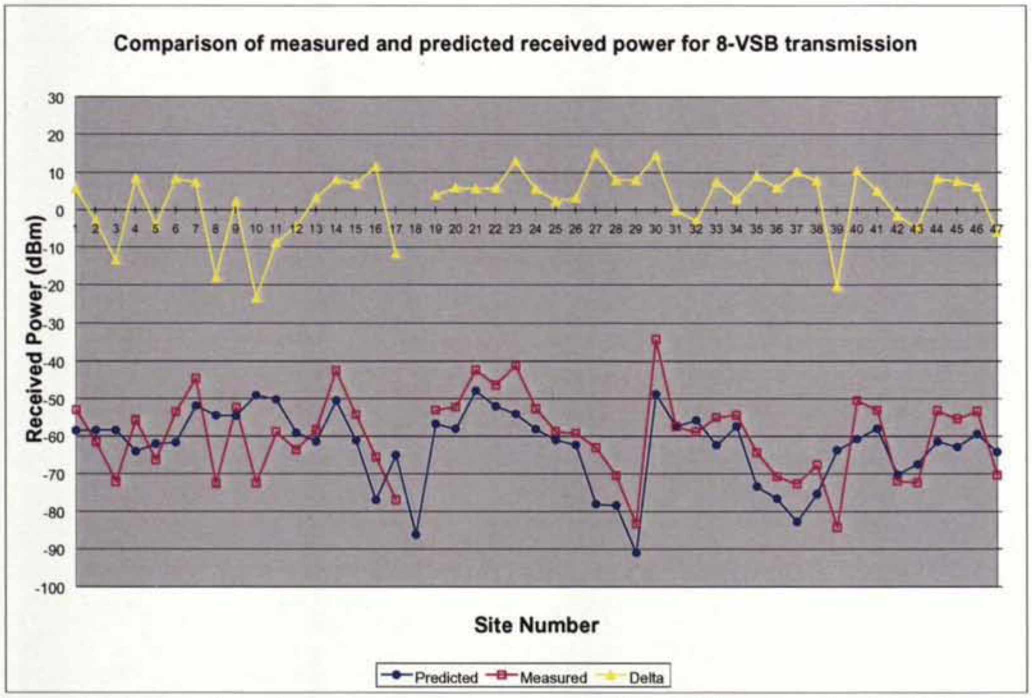


Figure 9. Comparison between the measured and the predicted received DTV power for the 46 visited sites.

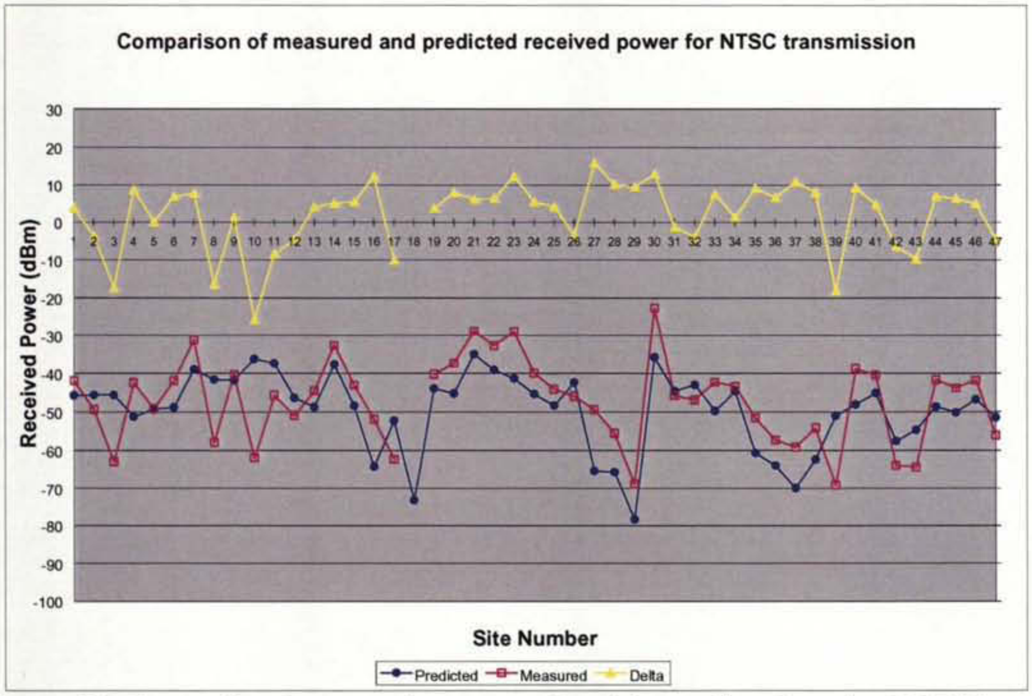


Figure 10. Comparison between the measured and the predicted received NTSC power for the 46 visited sites.

3.3 Indoor Tests

A series of tests was done to assess the quality of indoor DTV reception. This measurement campaign was set up to gain a better understanding of the following issues:

- What is the location availability of DTV using simple off-the-shelf indoor antennas ?
- What kinds of antennas (active or passive) are needed for indoor DTV reception ?
- Are DTV indoor reception problems caused by low field strength and/or multipath ?
- Are the antenna type and its orientation critical for reliable DTV reception ?

3.3.1 Equipment setup

As was the case for the outdoor reception tests, the NTSC signal on Channel 65 and the DTV signal on Channel 67 were studied. Moreover, an assessment of the picture quality of NTSC on Channels 24, 40, and 43 was made.

Two different types of indoor antennas were used at each site:

- an active loop antenna, RCA model *CANT 200* with a gain of 32 dB in the UHF band (Fig. 11);
- a log-periodic antenna manufactured by Antiference, model *Silver Sensor,* with a gain of 5 to 7.5 dBd (above dipole) across the UHF band (Fig. 12).

Before the purchase of the RCA antenna, some earlier tests were performed using the *Silver Sensor* and the Recoton "Power Wave" model *TV 800* active antenna with a gain of up to 30 dB in the UHF band (Fig. 13).

Each antenna was put on a tripod, about five feet above the floor, close to a window, since studies have shown that building penetration losses increase rapidly when the antenna is moved away from the window and farther inside the room[1]. The aerials were then oriented for maximum Carrier-to-Noise ratio (C/N) on Channel 67.

During the first month of the field tests, two different DTV receivers (E and C) were used at each site. These receivers were selected for several reasons:

- Portability: these receivers were set-top boxes (STB) with built-in MPEG-2 decoders;
- Receiver C has already been used in other field tests elsewhere;
- We wanted to know the impact of a better receiver (E) on the field test results;

[1] For example, Horikoshi et al. [2] performed indoor measurements at 1.2 GHz in a reinforced concrete building using a 1-W outdoor transmitter. All the furniture in the room was removed. They found that the median signal level close to the window was 5 to 6 dB higher than at the back of the room. Nulls between 20 dB and 30 dB were also observed when the receiving antenna was moved through small distances (a few cm). A good review of radio propagation into and within buildings can be found in [3].

- Receivers with even better performance were either unavailable at the time or considerably more difficult to use in the field (e.g. a PC board under laptop control or STB without an integrated MPEG-2 decoder).

After that period, we used receiver E exclusively since it consistently outperformed receiver C (see Section 3.3.3.1).

When DTV reception was good, a precision attenuator was used to estimate the signal margins for reliable and completely unreliable reception (defined in Section 3.3.2). This method was selected because the better technique of injecting white noise in the receiver used during the *outdoor* tests was impractical for these indoor tests.

Finally, a spectrum analyzer controlled by a laptop computer was used to observe and record the effects of multipath on the DTV spectrum. The subjective evaluation of the quality of NTSC signals was made with a consumer-grade JVC 13-inch receiver.

To reduce cable losses, the complete setup was operated *inside* the buildings, as opposed to positioning the indoor antenna inside the home and leading a long cable to the test truck containing all the measurement equipment. For increased portability, most of the equipment was pre-wired and carried inside in a rugged shipping container, as shown in Fig. 14. This allows flexibility to expand testing DTV signals inside high rise apartment and office buildings, for example.

At each location, whether or not there was DTV reception, the C/N and the Carrier-to-Noise plus Interference (C/(N+I)) ratio were measured using a bandpass filter, an amplifier, and the above-mentioned laptop-controlled spectrum analyzer, as illustrated in Fig. 15.

Figure 11. The RCA *CANT 200* active loop antenna.

Figure 12. The Antiference *Silver Sensor* passive antenna.

Figure 13. The Recoton Power Wave Model *TV 800* active antenna.

Figure 14. Complete setup used for DTV indoor reception tests. Left monitor (LCD): DTV reception; right monitor: NTSC receiver.

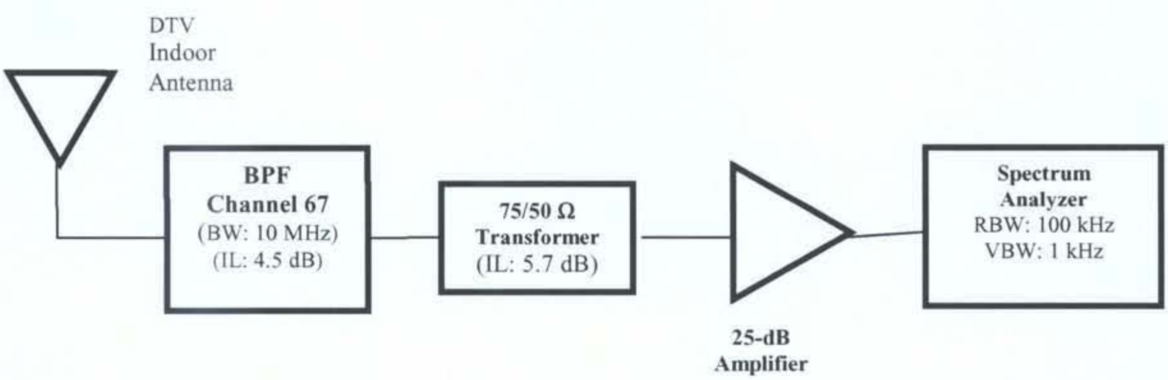


Figure 15. Setup used for the measurement of the C/(N+I) and C/N ratios during indoor reception tests.

3.3.2 Test procedure

Inside each residence, the setup was installed at a few locations where TV sets are typically found: living room, bedroom, and kitchen. Usually *reliable* DTV reception is possible only in a limited number of rooms in a given building. A site was rated as *unsuccessful* only when the receiver could not decode the signal in all the rooms that were tested: if, for example reliable DTV reception was found in the bedroom upstairs whereas DTV reception was unsuccessful in the living room, then this site was rated as being *successful.*

At each residential location, we followed the procedure given below:

1. Record the following general information on the evaluation sheet (see Appendix):

- Weather conditions (temperature, the presence of wind, and the presence of rain or snow);
- Global Positioning system (GPS) readings and magnetic bearing;
- Radial distance from the transmitter;
- The type of building (single – family dwelling, apartment, office, etc.);
- The type of house construction (wood, aluminum-sided, brick, etc.);
- The presence of tinted glass;
- The type of room (living room, kitchen, bedroom, etc.);

2. Select a suitable as well as practical location in a room facing the transmitter (*not* in the middle of the room);

3. Put the RCA antenna on the tripod, at about 5 feet above the floor, close to a window;

4. Using the spectrum analyzer (center frequency: 791 MHz, span: 10 MHz, RBW: 100 kHz, VBW: 1 kHz, no averaging) and the rest of the setup shown in Fig. 15, move the antenna to a few locations next to the window and change its azimuth in order to get the best DTV reception, that is, the highest C/(N+I) *and flattest spectrum possible*[2]. Using the laptop, run the program to acquire a few spectrum traces (typically five) separated by a delay of *one* second and compute the C/(N+I). Under *weak* signal conditions, record the reading in dBm at the top marker and add 2 dB[3]: this will be a good estimate of the DTV received power across the channel bandwidth. As a guide, -68 dBm is considered a *weak* DTV level, whereas -53 dBm is considered a *moderate* DTV level;

[2] With the 10-MHz span, we measure a *C/(N+I)* because intermodulation products created by the active antenna's amplifier add shoulders to the DTV spectrum. On the other hand, the 50-MHz span gives a broader view of the spectral surroundings, and therefore it is easy to tell the noise floor from the intermodulation products. It is then possible to make a better estimate of the C/N.

[3] This is the difference in dB between the total *gain* of the system (about 15 dB, taking into account the insertion losses shown in Fig. 15) and the correction factor used for the given resolution bandwidth (10 log_{10} (5.38 MHz/100 kHz) = 17 dB).

5. Do not move the antenna. Switch to a 50-MHz span in order to see both Channel 65 and Channel 67. Compute the C/N for Channel 67 using the above-mentioned computer program. Do *not* record the reading in dBm of the top marker;

6. With the antenna in the *same* location and orientation in the room, evaluate the quality of the NTSC picture (Channel 65) on the ITU-R impairment scale (see Table 7) and note the type(s) of impairments visible on the picture. This evaluation should last a few minutes. Repeat for three other NTSC stations (Channels 40, 43, and 24). The occurrence of *impulsive noise* on the NTSC picture (horizontal streaks, etc.) should also be recorded on the form. Also observe the susceptibility to impulsive noise in the subsequent *DTV* tests;

7. Switch to DTV reception with the antenna in the *same* location and orientation and the attenuator set to 0 dB;

8. Determine whether DTV reception is:

- *reliable* (not sensitive to people moving across the room) or
- *sensitive* to the movement of people across the room or
- *completely unreliable* (frozen and/or broken picture and concomitant loss of audio) in that case. Clearly, the DTV signal is then unusable.

If DTV reception is found to be *reliable,* perform steps 9 to 12; if DTV reception is either *sensitive or completely unreliable,* go directly to step 13 (i.e. switch antennas);

9. Attenuate the DTV signal until the reception becomes sensitive, while *moving* in proximity of the antenna to generate dynamic ghosts. Observe the effect on the DTV reception and look for the first visible impairments (blocking artifacts, and/or picture freeze, and/or loss of audio). Once a level *"x"* in dB has been found, disconnect the antenna signal from the receiver then reconnect it to confirm whether the margin for reliable reception is *"x"* or *"(x-1)"* dB, since the attenuator has 1-dB steps. After this verification, the actual reading *"y"* in dB of the attenuator is noted *"margin to the Threshold Of Visibility (TOV): y dB*" on the sheet form;

10. Attenuate the DTV signal until the reception becomes completely unreliable *without* moving across the room. Once a level *"w"* in dB has been found, disconnect the antenna signal from the receiver then reconnect it to confirm whether the margin to totally unreliable reception is *"w"* or *"(w-1)"* dB. After this verification, the actual reading *"z"* in dB of the attenuator is then noted "*margin to the Point Of Unusability (POU): z dB*" on the sheet form;

11. Set the attenuator back to 0 dB and move the tripod away from its original position (usually close to a window) while maintaining its original orientation in azimuth until the DTV reception becomes *completely unreliable.* Disconnect the antenna from the DTV receiver and connect it to the spectrum analyzer. Using the laptop and the spectrum analyzer, run the program to acquire a few traces (typically five) and compute the C/(N+I) *at the point of DTV failure, i.e. the POU. Do not move the antenna.* Then, switch back to NTSC and evaluate

the quality of the NTSC picture on the ITU-R impairment scale and note the type of impairments visible in the picture;

12. Put the tripod back to its original position in the room (peaked for maximum DTV power), reposition the antenna in azimuth for best NTSC picture quality on *Channel 40.* Then, *without moving the antenna,* determine whether DTV reception is possible at Channel 67, with the attenuator set to 0 dB.

13. Repeat the above procedure (steps 3-12) with the *second* antenna (Silver Sensor). However, steps 4 and 5 now have to be performed using *two* 25-dB amplifiers and a 3-dB attenuator. In other words, replace the 25-dB amplifier shown in Fig. 15 by a 47-dB amplifier. Moreover, under *weak* signal conditions, record the reading in dBm of the top marker and *subtract* 20 dB: this will be a good estimate of the DTV received power across the channel bandwidth;

14. If possible, assess DTV reception in another room. Measure the C/(N+I) using the markers. If the C/(N+I) and the spectrum shape are acceptable, then repeat steps 3 to 13.

The form used to record the test results is reproduced in the Appendix.

3.3.3 Test results

During Phase I, 46 sites were visited in the Ottawa area. These were mostly in suburban, one or two-storey residential houses, with the exception of:

- one high rise commercial building;
- two apartment buildings;
- one high rise apartment building;
- one three-storey condominium town house/garden home;
- one barn-like residence with metallic sidings and roofing in the rural area of Kemptville;
- a few residences also in rural areas (Chelsea, Metcalfe, for example)

As shown in Fig. 16, 45 out of 46 sites were within the realistic Grade A[4] contour for Channel 65 and *all* of our indoor sites were within the Grade B contour. These coverage plots were computed with CRC-COVLAB.

[4] Both grades of service are defined using a 9-m high directional *outdoor* antenna. For more details, see [4].

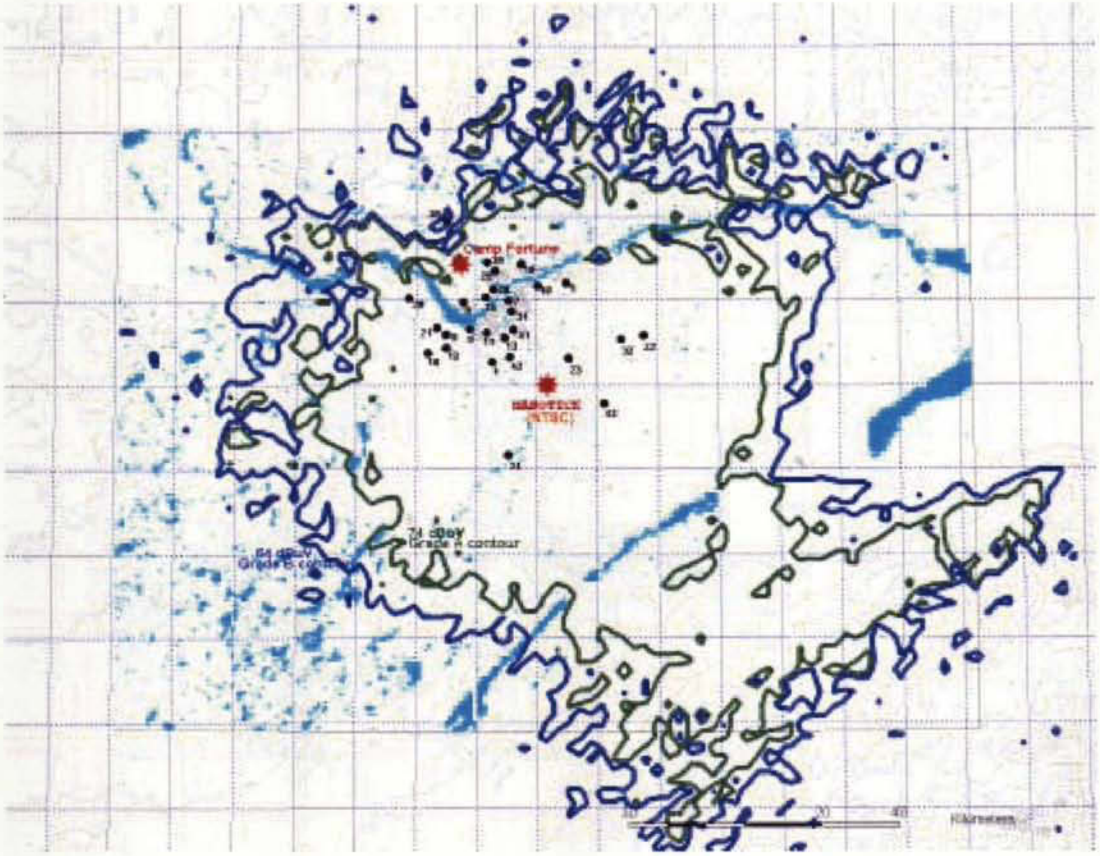


Figure 16. Urban, rural, and suburban DTV indoor test sites visited in the Ottawa area during Phase I, together with computer simulations of Grade A (inner contour, 74 dBu) and Grade B (outer contour, 64 dBu) realistic service contours for the co-sited NTSC station at Manotick (Channel 65). Site #38 is the only one outside of Grade A. For clarity, some sites are not shown. Also shown is the Camp Fortune transmitting site (see Section 3.3.3.7).

The radial distances from the transmitter ranged from 8.85 (site #23) to 50.7 km (site #38). The complete test results were compiled in an Excel chart and are available as a separate document.

3.3.3.1 Comparison of margins to TOV and to POU between receivers E and C

Table 12 presents a comparison between the performance of receivers E and C with respect to the margins defined in Section 3.3.2.

Site Number	Antenna	Margin to TOV (E) (dB)	Margin to POU (E) (dB)	Margin to TOV (C) (dB)	Margin to POU (C) (dB)	Δ_{E-C} (dB) Margin to TOV	Δ_{E-C} (dB) Margin to POU
#1 (Caron)	*TV800*	10	14	6	12	4	2
#1 (Caron)	*SS*	2	4	1	2	1	2
#4 (Guillet)	*TV800*	37	38	33	36	4	2
#4 (Guillet)	*SS*	31	32	29	30	2	2
#5 (Tam)	*TV800*	28	30	23	26	5	4
#5 (Tam)	*SS*	9	10	7	8	2	2
#7 (Mellaney)	*SS*	21	22	19	20	2	2
#8 (Gagnon)	*RCA*	35	38	34	36	1	2
#8 (Gagnon)	*SS*	18	19	16	17	2	2
#10 (Blanchfield)	*RCA*	33	36	29	31	4	5
#13 (Forde)	*RCA*	25	28	22	27	3	1
#13 (Forde)	*SS*	14	15	11	13	3	2

Notes:

- *TV800:* Recoton *TV800* active antenna;
- *SS:* Antiference *Silver Sensor* passive antenna;
- *RCA:* RCA Model *CANT200* active antenna.

Table 12. Margins to TOV and to POU for receivers E and C.

The above table shows that there was a 1 to 5-dB difference in the observed attenuation levels between receivers E and C; typically, that difference was about 2 dB. Since receiver E consistently outperformed receiver C, from March 28 on, the tests were done exclusively with receiver E and receiver C was used only as a backup.

3.3.3.2 Statistics on location availability for receiver E

Statistics on *location availability* using receiver E were compiled from our database of 46 sites. As mentioned in Section 3.3.2, the picture quality of Channel 65 (NTSC) was assessed using the ITU-R scale presented in Table 7.

For clarity, the results are presented in a "bullet" style:

- Three (**3**) sites were *rejected* because of technical problems at the transmitting site;

- **49 %** (21/43) of the sites had *reliable* DTV reception, i.e. *non-zero margins* (to TOV and to POU) with *both* antennas (i.e. *TV800* and *Silver Sensor or RCA* and *Silver Sensor*). These sites will be referred to as being the reliable sites. The NTSC picture quality ranged from 1.5 to 4.5 on the ITU-R scale, with a mean of 3.4 and a standard deviation of 0.9;

- **28 %** (12/43) of the sites *did not* receive DTV with *either* antennas (i.e. *TV800* and *Silver Sensor* or *RCA* and *Silver Sensor*). These sites will be referred to as being the unsuccessful sites. The NTSC picture quality ranged from 0.5 to 3, with a mean of 1.1 and a standard deviation of 0.8. Using the *active* antennas, the C/(N+I) ranged approximately from 1.7 dB to 25 dB, with a mean around 15 dB and a standard deviation of about 6 dB[5]. Using the *passive* antenna, the C/(N+I) ranged from as little as 0.5 dB to 30 dB[6], with a mean and a standard deviation around 8 dB[7];

- **23 %** (10/43) of the sites had various types of DTV reception. These sites will be labeled as being marginal. The NTSC picture quality ranged from 0.5 to 3.5, with a mean of 1.7 and a standard deviation of 1.1. The following combinations of DTV reception were observed at those sites:

    - Three (3) of these ten sites experienced *sensitive* DTV reception with one antenna and *reliable* reception with the other one (see the first three rows of Table 13 below);
    - Four (4) of these ten sites had *sensitive* reception with one antenna and *no DTV* reception with the other one (see rows 4 to 7 of Table 13);
    - Two (2) of these ten sites had *no DTV* reception with one antenna and *reliable* reception with the other one (see rows 8 and 9 of Table 13);
    - Only one of these ten sites had *reliable* reception with the active RCA antenna and *completely unreliable DTV* reception with the passive antenna (see the last row of Table 13).

---

[5] The C/(N+I) typically fluctuated by 1 or 2 dB during each measurement, due to the ever-changing scatterers in the vicinity of the receiving antenna.

[6] This figure (30 dB), observed at site #2 (Jean Edmonds Tower North, 19th floor), was way above the rest of the collected data *at the unsuccessful sites:* the measured C/(N+I) was otherwise less than 15 dB using the passive antenna. Using the *TV 800* antenna, the C/(N+I) ranged from 13 to 15 dB at site #2 (see Fig. 21*E)*, significantly lower than the 30 dB measured with the *Silver Sensor* antenna. Clearly excessive multipath distortion caused the failure of DTV at site #2.

[7] *Laboratory* tests using Receiver E indicated that its C/N at TOV was 15.3 dB for a moderate DTV signal of −53 dBm. Its C/N @ TOV for a *weak* signal of − 68 dBm was higher by a few tenths of a dB, being around 15.4-15.5 dB. The minimum decodable signal for this receiver was found to be − 78.5 dBm.

Site Number	Active Antenna (*RCA* except for Sites #3 and #7 where the *TV800* was used)		Passive Antenna (Silver Sensor)	
	DTV Reception	Picture Quality of NTSC (Ch. 65)	DTV Reception	Picture Quality of NTSC (Ch. 65)
7	Sensitive	0.5	Reliable	3
9	Sensitive	0.5	Reliable	1
36	Reliable	2	Sensitive	1
3	None	1	Very Sensitive	3
22	Sensitive	3	None	1
26	Sensitive	0.5	None	0.5
46	Sensitive	1	None	3
10	Reliable	2	None	2.5
25	Reliable	0.5	None	2
39	Reliable	3.5	Completely Unreliable	3

Table 13. Results obtained at the ten marginal sites using receiver E.

With the exception of sites #3, 7, and 9, the active antennas provided better DTV reception than the passive one. For sites #3 and #7 (both were located in high-rise buildings in downtown Ottawa), the recorded RF spectrum plots reveal that the 8-VSB spectrum was *slightly* less distorted with the *Silver Sensor* antenna than with an active antenna. This may be explained by the greater directivity of the passive antenna. Maybe, for some reason, the *TV 800* antenna was not operating properly at sites #7 and #3 (from site #8 on, the *RCA* antenna was used instead).

At site #9 (Kanata), surprisingly, the DTV spectrum was *flatter* with the *RCA* antenna, yet one could only achieve sensitive DTV reception in these conditions: *tone interference* can very likely explain these results (see Fig. 21*F*). A strong tone @ 794.4 MHz (approximately) and two weaker ones (about 12.5 dB below) @ 786.5 and 787.5 MHz are clearly visible on this plot. These tones were not visible with the passive antenna and were likely caused by a strong out-of-band transmitter (e.g. a pager) overloading the antenna's preamplifier, thus creating intermodulation products falling within (therefore not visible on the spectrum analyzer) and in the vicinity of Channel 67.

Another similar phenomenon happened at site #16 (Gatineau), where some transmitting device (a pager, presumably) was transmitting at the beginning of the test, adding a strong tone @ 787.5 MHz (approximately) and a minor one (15 dB below the strong one) around 787 MHz, thus impeding DTV reception. About 30 minutes into the test, for some unknown reason, the main interfering tone was now 10 dB lower (and most importantly, the "invisible" in-band interference was lower too) and from then on, reliable DTV reception was achieved. Again, the offending tones were not visible when the passive antenna was used.

Table 13 also shows that the NTSC picture quality on Channel 65[8] and the "quality" of DTV reception under these unfavorable conditions are not correlated.

[8] The picture quality of analog television is not only a function of the field strength, but also of the delay and amplitude of the ghosts (longer ghosts being more objectionable than short close-in ghosts of the same amplitude), the amount of impulsive noise, tone interference, etc.

3.3.3.3 Statistics on margins for receiver E

3.3.3.3.1 Margins to TOV ("Reliable Sites")

The Cumulative Frequency Distributions (CFDs) of margins to TOV for reliable reception defined in Section 3.3.2 have been plotted for active and passive antennas (see Figs. 17 and 18, respectively) for those 21 sites with reliable DTV reception with both antennas (called the reliable sites).

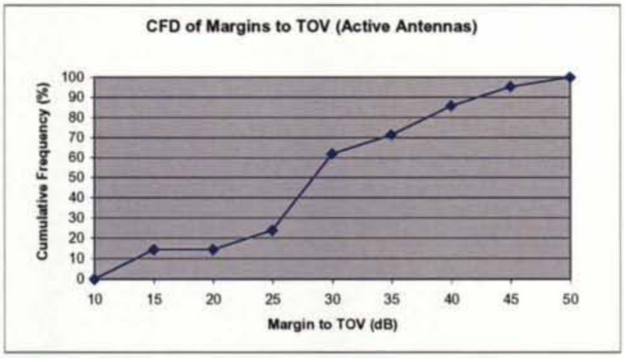


Figure 17. The CFD of the margins to TOV for both active antennas (reliable sites only). The median was about 29 dB.

For the active antennas used (Figs. 11 and 13), the margin to TOV ranged from 10 to 48 dB. Fig. 17 shows that 50% of these 21 sites had a margin to TOV of more than 29 dB with an active antenna.

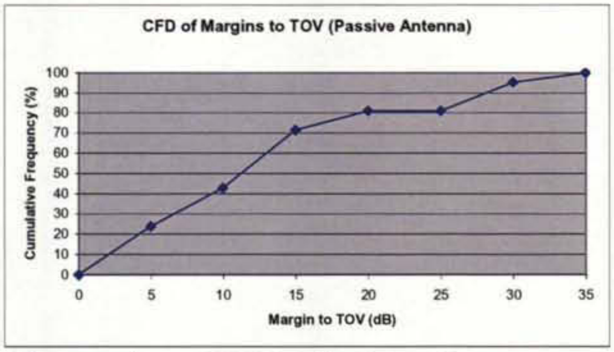


Figure 18. The CFD of the margins to TOV for the *Silver Sensor* antenna (reliable sites only). The median was about 11 dB.

For the passive antenna (Fig. 12), these margins ranged from 1 to 31 dB. Fig. 18 shows that 50% of those 21 sites had a margin to TOV of more than 11 dB with the *Silver Sensor* antenna.

3.3.3.3.2 Margins to POU (Reliable Sites)

The Cumulative Frequency Distributions (CFDs) of margins for completely unreliable reception defined in Section 3.3.2 – the Point of Unusability (POU) – have been plotted for active and passive antennas (see Figs. 19 and 20, respectively) for those 21 sites with reliable DTV reception with both antennas.

For the active antennas (Figs. 11 and 13), the margin to POU ranged from 14 to 49 dB. Fig. 19 shows that 50% of those 21 sites had a margin to POU of more than 30 dB with an active antenna.

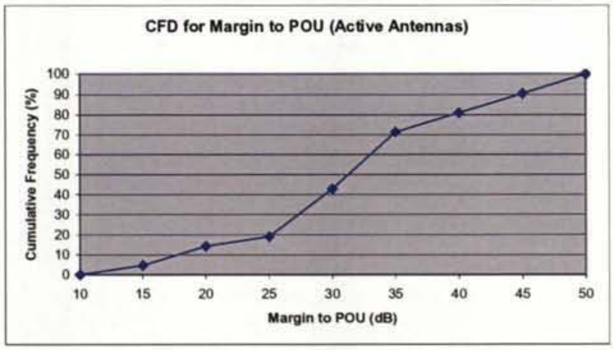


Figure 19. The CFD of margins to POU for both active antennas used during the tests (see Figs. 11 and 13) (reliable sites). The median was about 30 dB.

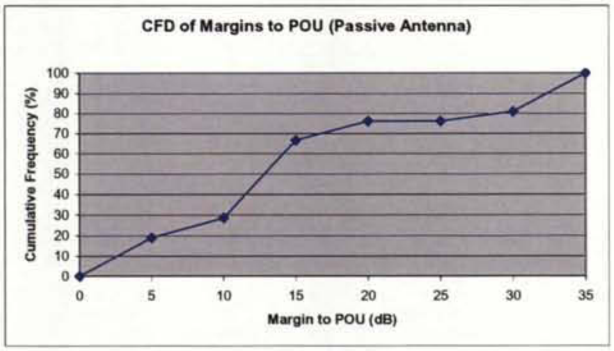


Figure 20. The CFD of margins to POU for the *Silver Sensor* passive antenna (reliable sites). The median was about 13 dB.

For the passive antenna (Fig. 12), these margins ranged from 2 to 32 dB. Fig. 20 shows that 50% of those 21 sites had a margin to POU of more than 13 dB with the *Silver Sensor* antenna.
The results shown in Figs. 17-20 are summarized in Table 14. Comparing the median margins to TOV and to POU for a given antenna type, we can see that the "cliff effect" of digital reception is taking place within 1 or 2 dB for indoor locations.

	Active Antennas	Passive Antenna
Median Margin to TOV (dB)	29	11
Median Margin to POU (dB)	30	13

Table 14. Median margins to TOV and to POU for the reliable sites (Receiver E). Taken from Figs. 17-20.

3.3.3.4 Statistics for the unsuccessful sites (Receiver E)

3.3.3.4.1 No DTV reception using an active antenna

DTV could not be received at a total of 13 sites using an *active* antenna and receiver E. The NTSC picture quality on Channel 65 ranged from 0.5 to 2 on the ITU-R scale, with a mean of 0.8 (*very annoying* impairments) and a standard deviation of 0.5. Let us examine in detail the causes of failure:

- *Low field strength only:* **7.7%** of these sites (1/13). The NTSC picture quality on Channel 65 was rated at 0.5 at this site (*very annoying* impairments);
- *Low field strength and multipath:* **84.6%** of these sites (11/13). The C/(N+I) ranged from 1.7 dB to 20.3 dB. The NTSC picture quality on Channel 65 ranged from 0.5 to 1.5, with a mean of 0.7 (*very annoying* impairments) and a standard deviation of 0.3;
- *Multipath only (with sufficient field strength to have a C/(N+I) > 20 dB):* **7.7%** of these sites (1/13). The C/(N+I) ranged from 20.2 dB to 24.9 dB. The NTSC picture quality was rated at 2 at this site (*annoying* impairments).

Now if the threshold of "sufficient field strength" is changed from having a C/(N+I) of *at least* 20 dB (which was close to the Canadian C/N protection ratio of 19.5 dB [5]) to 15.3 dB (consistent with the American C/N protection ratio of 15.19 dB [5] and CRC's own laboratory results for receiver E), we get the following statistics:

- *Low field strength only:* **7.7%** of these sites (1/13). The NTSC picture quality on Channel 65 was rated at 0.5 at this site (*very annoying* impairments);
- *Low field strength and multipath:* **46.1%** of these sites (6/13). The C/(N+I) ranged from 1.7 dB to 15.4 dB[9]. The NTSC picture quality on Channel 65 ranged from 0.5 to 1.5, with a mean of 0.8 (*very annoying* impairments) and a standard deviation of 0.4;

[9] At this site (#15), the C/(N+I) ranged from 13.61 to 15.37 dB, not high enough to be included in the "sufficient field strength" category.

- *Multipath only (with sufficient field strength to have a C/(N+I) > 15.3 dB):* **46.1%** of these sites (6/13). The C/(N+I) ranged from 15.0 dB[10] to 24.9 dB. The NTSC picture quality on Channel 65 ranged from 0.5 to 2, with a mean of 0.9 (*very annoying* impairments) and a standard deviation of 0.6.

A threshold of "sufficient field strength" set to 20 dB appears to be more appropriate for service planning.

3.3.3.4.2 No DTV reception using a passive antenna

A *total* of 17 sites did not receive DTV using a *passive* antenna and receiver E. The NTSC picture quality on Channel 65 ranged from 0.5 to 3, with a mean of 1.2 (quite *annoying* impairments) and a standard deviation of 0.9. Let us examine in detail the causes of failure:

- *Low field strength only:* **18%** of these sites (3/17). The C/(N+I) was as low as 0.5 dB (site #38, Chelsea, outside the Grade A contour. See Fig. 16). The received power at this particular site was about –95 dBm, very close to the measured noise floor of receiver E. The NTSC picture quality at these sites ranged from 0.5 to 2.5 (*very annoying to slightly annoying* impairments);
- *Low field strength and multipath:* **76%** of these sites (13/17). The C/(N+I) ranged from 3 dB to 11.5 dB. The NTSC picture quality ranged from 0.5 to 2.5, with a mean of 1.1 (*very annoying* impairments) and a standard deviation of 0.7;
- *Multipath only (with sufficient field strength to have a C/(N+I) > 20 dB):* **6%** of these sites (1/17). At this site (#2), the C/(N+I) was about 30 dB and the NTSC picture quality was rated at 3 (*slightly annoying* impairments).

Now if the threshold of "sufficient field strength" is changed from having a C/(N+I) of *at least* 20 dB to 15.3 dB, we get the same results, since there were no data between 15.3 dB and 20 dB at these unsuccessful sites.

Clearly, in light of these figures – and setting a C/(N+I) of 20 dB as the threshold for sufficient field strength – a combination of low field strength *and* multipath was the most common cause of DTV reception failure for *both* active and passive antennas. Multipath reflections alone – with sufficient field strength to operate above threshold – were the main culprit on only one occasion for each type of antenna we used.

[10] At this site (#34), the C/(N+I) ranged from 15.0 dB to 16.3 dB, clearly high enough to be included in the "sufficient field strength" category.

3.3.3.4.3 Performance criteria used by the ATSC

The ATSC uses two different performance criteria:

- *Service availability:* "Percentage of total sites measured where reception was possible;"
- *System Performance Index:* "Percentage of sites with signal measured at or above the minimum required field strength where reception was possible."

Using these definitions, we get the following results for our DTV indoor tests:

- *Total number of sites:* 43;
- *Number of sites with signal measured at or above the minimum required field strength:* if we use a C/(N+I) ≥ 15.3 dB as a threshold, there were 35 such sites using an active antenna and 26 such sites using the passive one.

The results are presented in Table 15:

Performance criterion used by the ATSC	**Active Antenna**	**Passive Antenna**
Service Availability	58 % (25/43)	53.5 % (23/43)
System Performance Index	71 % (25/35)	88.5 % (23/26)

Table 15. Performance criteria applied to these DTV indoor reception tests.

3.3.3.5 Typical RF spectrum plots

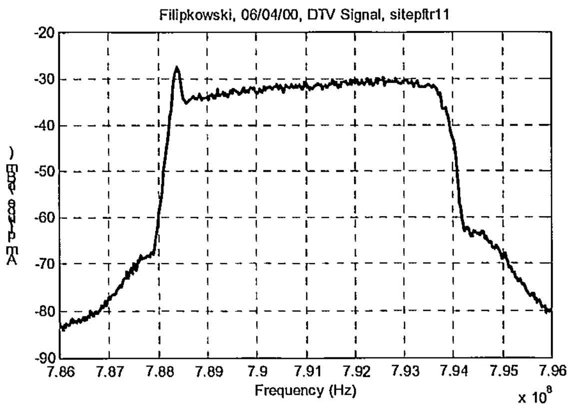
Because of the wide variety of scatterers found in the paths between the transmitter and the indoor sites, the 8-VSB spectrum plots on Channel 67 have quite different shapes. The following figures (Figs. 21 below) show typical RF DTV spectra observed during the field tests (center frequency: 791 MHz, span: 10 MHz, resolution bandwidth: 100 kHz, video bandwidth: 1 kHz, no averaging). An assessment of the picture quality of NTSC transmissions (see Table 7) on Channel 65 at these locations is also indicated.

- **A) Reliable DTV reception:**

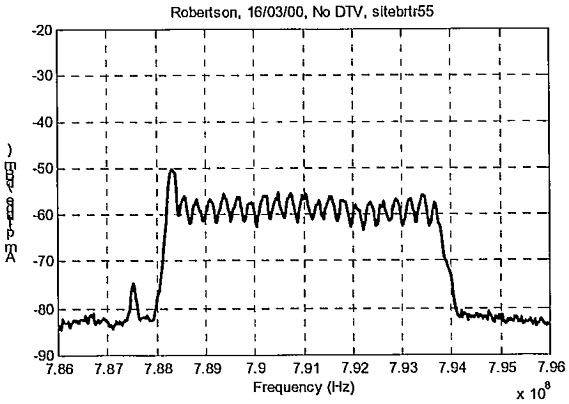
(High field strength and a close-in ghost)

(C/(N+I) ≈ 50 dB)

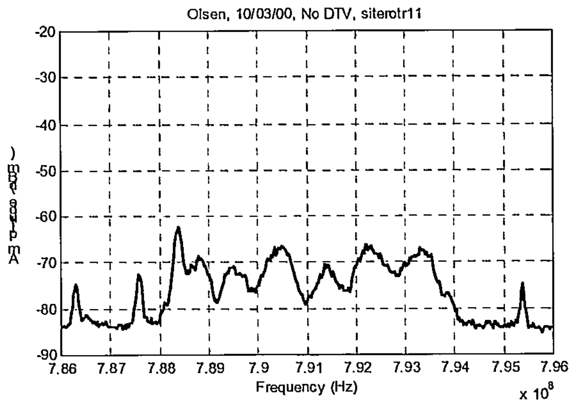
(NTSC: 4)



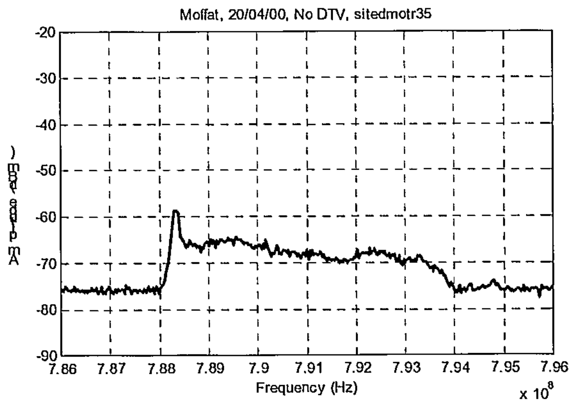
- **B) No DTV Reception:**
  (Multipath only)
  (C/(N+I) ≈ 25 dB)
  (NTSC: 0.5)



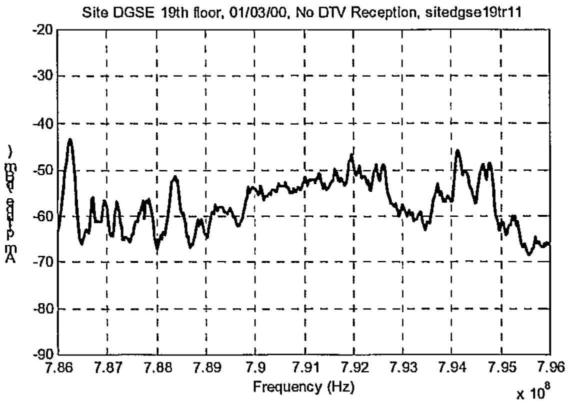
- **C) No DTV Reception:**
  (Low field strength and multipath)
  (C/(N+I) ≈ 7 dB)
  (NTSC: 0.5)



- **D) No DTV Reception:**
  (Low field strength and multipath)
  (C/(N+I) ≈ 8 dB)
  (NTSC: 2)



- **E) No DTV Reception:**
(Low field strength, in-band multipath distortion and out-of-band intermodulation distortion)
(C/(N+I) ≈ 14 dB)
(NTSC: 0.5)



- **F) Sensitive DTV Reception:**
(Multipath and tone interference)
(C/(N+I) ≈ 22 dB)
(NTSC: 0.5)

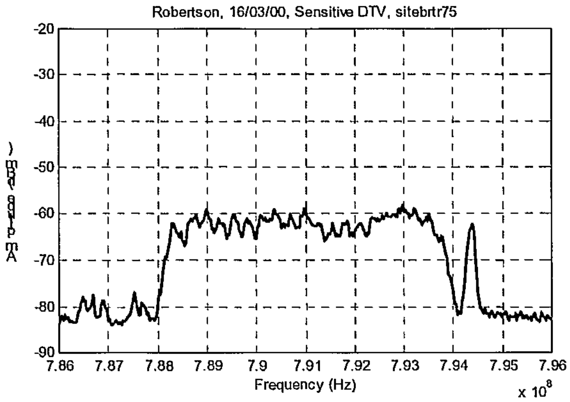


Figure 21. Some typical RF spectrum plots (resolution bandwidth: 100 kHz, video bandwidth: 1 kHz, no averaging), with the corresponding picture quality for NTSC (Channel 65). All these plots were taken using an active antenna, except Fig. 21*D*.

3.3.3.6 8-VSB signals at the Point Of Unusability (POU) with receiver E

Turning to Step 11 of the test procedure described in Section 3.3.2, we recall that the antenna was moved away from its original position in the room (usually close to an appropriately oriented window) until the POU has been reached. The results obtained with the *RCA* antenna are presented in Table 16. Reliable DTV reception with receiver E was possible with *both* antennas at all the sites shown below, except for sites 25, 26, and 39 where *reliable* DTV reception was achieved only with the *RCA* antenna: with the *Silver Sensor* either no DTV or sensitive reception or even *completely unreliable* reception were achieved and thus these three sites were labeled as marginal sites (see Table 13).

Site #	Reference C/(N+I) (dB)	C/(N+I)@POU (dB)	Average Difference in C/(N+I) (dB)	Reference Picture Quality of NTSC On Channel 65 (ITU-R Scale)	Picture Quality of NTSC@ POU (ITU-R)	Difference in Picture Quality (ITU-R)
13	31.5-32.6	25.0-25.9	6.6	3.5	2.5	1.0
14	32.9-33.5	23.8-24.8	8.9	3	2	1.0
16	24.4-25.4	22.1-22.8	2.5	2.5	2	0.0
17	31.7-32.9	24.1-24.8	7.9	2.5	2.5	0.0
18	26.8-28.0	18.8-19.1	8.5	2	1.5	0.5
20	The DTV signal was so strong that for practical reasons (the size of the room) it was not possible to reach the POU					
23	The DTV signal was so strong that for practical reasons (the size of the room) it was not possible to reach the POU					
24	49.3-49.7	14.2-15.4	34.7	4	4	0.0
25	21.4-22.5	17.3-18.6	4.0	0.5	2.5	-2.0
28	25.7-27.2	3.1 and 12.8-13.3[11]	13.4	2.5	2	0.5
29	22.2-22.3	10.0-11.3	11.6	3	3	0.0
30	35.2-36.6	20.1-21.1	15.3	1.5	2	-0.5
31	21.1-22.0	8.4-9.0	12.9	2.5	2.5	0.0
35	37.8-38.5	11.7-12.5	26.1	3.5	3.5	0.0
36	24.9-25.4	18.2-19.1	6.5	2	3	-1.0
37	32.3-33.9	20.6-21.0	12.3	2	1.5	0.5
39	25.4-26.1	18.1-19.8	6.8	3.5	2.5	1.0
41	26.6-28.3	23.9-24.8	3.1	3.5	3	0.5
42	34.8-35.8	14.2-15.3	20.6	4	3.5	0.5
43	46.8-47.5	36.7-37.2	10.2	4.5	2.5	2.0

Mean = 11.8 dB　　Mean = 0.2
Standard deviation = 8.3 dB　　Std = 0.9

Table 16. Behavior of 8-VSB signals before and at the Point Of Unusability (POU) (*RCA* antenna). The word "reference" is used here to describe the measurements made with the antenna at its *original* position in the room. DTV reception was reliable with *both* antennas (active and passive) at all these sites with the exception of sites #25, 36, and 39 (in bold) where it was reliable with the active antenna only (see also Table 13).

[11] There was some dynamic multipath caused by traffic at site #28, as evidenced by the strong fluctuations in the received C/(N+I)@POU. Fluctuations of the reference C/(N+I) were observed at this particular site but unfortunately could not be recorded because of limitations of the spectrum analyzer-laptop computer combination, namely the low maximum sampling rate of one whole spectrum trace per second. In light of this, the 3.1 dB found in Table 16 was not used to compute the average difference in C/(N+I) at this site.

Please note that Step 11 of the procedure was introduced during our visit to site #13: all the available data for the active antenna are presented in Table 16.

Because of the ever-present fluctuations of signal strength in an indoor environment (see columns 2 and 3 of Table 16), the *average* difference in dB between the reference C/(N+I) and the C/(N+I) @ POU was computed and is shown in the fourth column of Table 16.

At this point in the discussion, some typical spectrum plots (see Figs. 11-13) will provide further insight into the phenomenon. Fig. 22 shows the reference spectrum together with the spectrum at the POU location using the *RCA* antenna. These plots were taken at site #24, a barn-like residence with metallic sidings and roofing in the rural area of Kemptville. The signal strength was at its highest: about –28 dBm[12] across 6 MHz (see Step 4 of the procedure described in Section 3.3.2) and the C/(N+I) in Fig. 22*a* was close to 50 dB (see Table 16 for details).

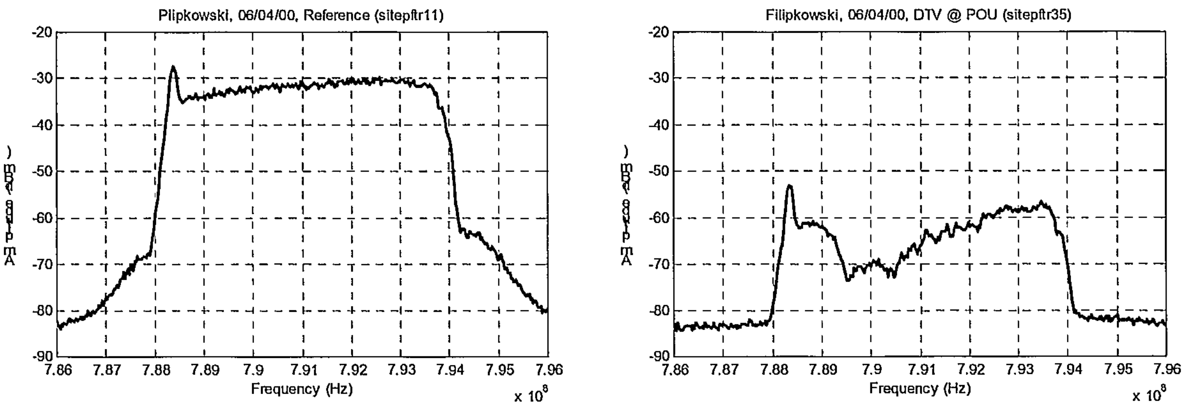


Figure 22. Spectrum plots of the received DTV signal at site #24 using the RCA antenna. a) Reference spectrum (with antenna close to the window): reliable DTV; b) DTV @ POU (with antenna 16 feet (5 m) away from the window).

Figure 22*b* shows the spectrum at the POU location, when the antenna was 16 feet (5 m) away from the window. The field strength had decreased by about 35 dB but the C/(N+I) was only slightly below threshold (see Table 16). The picture quality of Channel 65 at the DTV's POU position remained surprisingly good at 4.0. One striking feature of this plot is the 10-dB null[13] about 1-MHz wide around 790 MHz that caused the failure of DTV reception at this site.

Fig. 23 shows another reference spectrum together with the corresponding spectrum at the POU location using the *RCA* antenna. These plots were taken at site #31, a two-story residence in Orleans with brick at the front and aluminum sidings. The signal strength was about –60 dBm[14] across 6 MHz (see Step 4 of the procedure described in Section 3.3.2) and the C/(N+I) in Fig. 23*a* was about 21 dB (see Table 16 for details).

[12] Can be considered a "weak" DTV signal.
[13] Measured in a 100-kHz resolution bandwidth. The null will be deeper for *smaller* resolution bandwidths.
[14] Usually called the "strong" DTV power level.

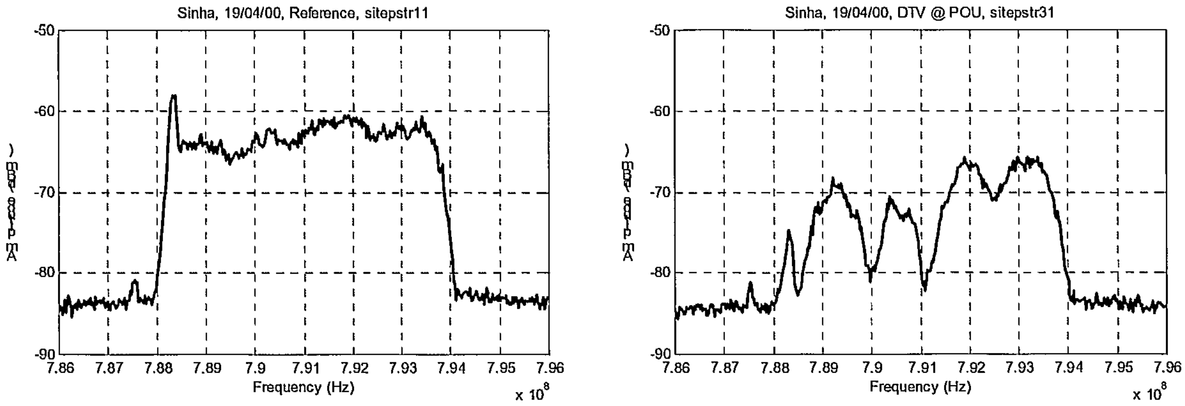


Figure 23. Spectrum plots of the received DTV signal at site #31 using the RCA antenna. a) Reference spectrum (with antenna close to the window): reliable DTV; b) DTV @ POU (with the antenna 10 feet (3 m) away from the window).

Figure 23*b* shows the DTV spectrum at the POU location, when the antenna was 10 feet (3 m) away from its original position, close to the window. The field strength had decreased by about 13 dB (in average) and the C/(N+I) was clearly below threshold (see Table 16). This time we can see three deep notches (of about 10 dB)[15] and one 5-dB notch. The dynamic multipath severely mutilated the spectrum: even the pilot carrier was hit. The 1.5-MHz periodicity in this figure would theoretically correspond to two rays with a differential delay of about 0.7 μs, that is a differential path length of about 200 m. Clearly, this difference in path length is not typical of *indoor* paths, but was very likely caused by scattering from nearby houses. Confirmation of this differential delay can be found in the assessment of the picture quality for Channel 65 at the DTV's POU location: a *strong* short (a few microseconds) *post* ghost was *then* visible in the picture.

Finally, Fig. 24 shows another reference spectrum together with the corresponding spectrum at the POU with the *RCA* antenna. These plots were taken at site #30 in Nepean, in a bedroom on the second floor of a cottage with brick at the front and vinyl sidings, only 16 km away from the transmitter. The signal strength was about –44 dBm[16] across 6 MHz and the C/(N+I) in Fig. 24*a* was about 36 dB (see Table 16 for details).

Figure 24*b* shows the spectrum at the POU location, when the antenna was 6 feet (1.8 m) away from its original position, close to the bedroom window. The field strength had decreased by about 15 dB (in average) and the C/(N+I) was clearly above threshold (see Table 16). This time two deep notches (of about 15 dB) are visible: one around 789 MHz and another one around 790 MHz and also a series of shallower 5-dB notches. Comparing Fig. 24*b* with other plots taken at this site, it is possible to get an appreciation of the time-varying nature and to some extent of the unpredictability of the indoor radio channel: for example the fade around 789 MHz was getting shallower or deeper every few seconds (based on the low sampling rate of the spectrum analyzer-laptop combination), a deep 15-dB notch appeared for a moment near 791 MHz, whereas the 10-

[15] Again measured in a 100-kHz resolution bandwidth.
[16] A DTV power level between "strong" and "moderate."

dB fade around 793.3 MHz hardly changed at all. The most obvious cause of these channel variations is simply having people moving in the room, near the receiving antenna.

The 0.7-MHz periodicity visible between a number of peaks in Fig. 24*b* would theoretically correspond to two rays with a differential delay of about 1.4 µs, that is a differential path length of about 420 m. Clearly, this difference in path length was again very likely caused by scattering from nearby houses. This is just one of the many echoes present in this particular room: for a far more complete characterization, channel-sounding techniques should be used.

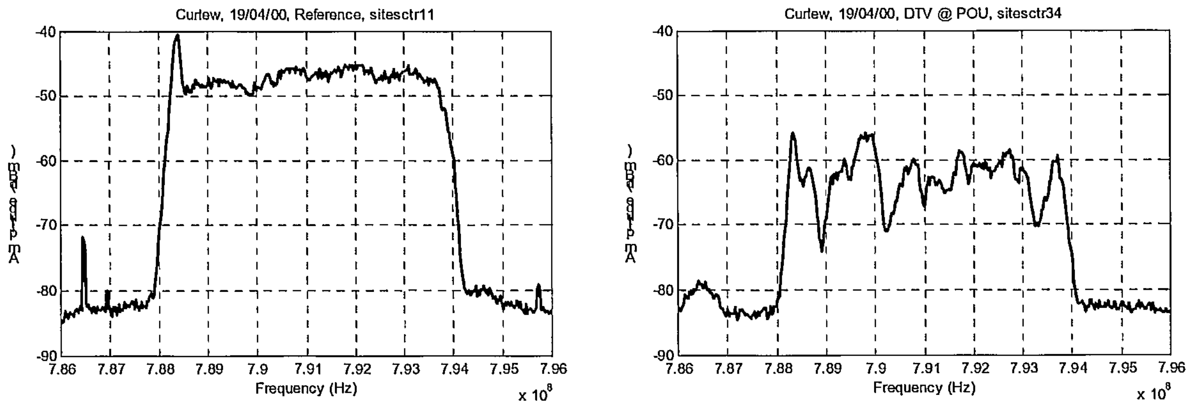


Figure 24. Spectrum plots of the received DTV signal at site #30 using the RCA antenna. a) Reference spectrum (with antenna close to the window): reliable DTV; b) DTV @ POU (with antenna 6 feet (1.8 m) away from the window).

As can be seen from these figures, the C/(N+I) @ POU is often difficult to estimate because the DTV spectrum is no longer "reasonably" flat.

The last column of Table 16 shows that the picture quality of NTSC signals was slightly lower at the DTV's POU location than at the reference position in the room, except for sites #25, 30, and 36, where the NTSC picture quality was better. A tentative explanation for each site follows:

- *Site #25:* the NTSC picture in the reference position (in front of a bay window in the living room) was so noisy that ghosts were not even visible; the video carrier was fading in and out with frequent loss of sync. The NTSC picture at the DTV's POU location was less noisy than at the reference position presumably because of higher field strength in that area (a dynamic standing-wave pattern): a 5-µs ghost and a 10-µs ghost were now visible. Since the first floor of that residence was mostly an open area, other reflections from adjacent windows were likely picked up when the tripod was moved to the DTV's POU location;
- *Site #30:* the ghosts were less severe in amplitude at the DTV's POU location than at the reference position. At this point, it is important to recall that since Channels 65 and 67 are co-sited, the *amplitudes* of the ghosts will be strongly correlated, but because of the small difference in wavelength (38.5 cm vs. 37.9 cm at mid-band), the *phases* of the echoes will be different, yielding a different degree of destructive or constructive addition between the strongest reflection and other echoes;

- *Site #36:* there were no more diagonal bars and the ghosts were shorter (less than 5 μs vs. 10 μs, therefore less objectionable) at the DTV's POU location than at the original position in the room.

Based on all the available data presented in Table 16 and the above spectrum plots (Figs. 22-24), we can make the following observations:

- Two things happen when the antenna is moved away from a suitably oriented window: 1) the field strength decreases and 2) the level of multipath reflections increases. It would be interesting to establish which one is the main cause of DTV reception failure;
- The mean of the "averaged" difference in C/(N+I) @ POU (fourth column) was 11.8 dB with a standard deviation of 8.3 dB: so there is a moderate decrease in field strength when we moved the antenna away from its original position;
- The mean difference in picture quality for NTSC between the reference and the POU for DTV was 0.2 with a standard deviation of 0.9: *the picture quality of Channel 65 did not vary significantly when the antenna was moved away from its original position in the room* (usually close to a window);
- Twelve sites had a C/(N+I) @ POU above 15.3 dB: thus *multipath caused the failure of DTV in 67 % (12/18) of the sites where this experiment has been performed* (sites #20 and 23 are not considered here since the POU could not be reached);
- By moving the antenna away from its original location – peaked for maximum DTV power and spectral flatness – until the POU has been reached, other reflections tend to be picked up from adjacent houses or buildings. These reflections get in through other doors and/or windows and combine with the "main signal" (i.e. strongest reflections picked up in the original location). Clearly since the "main signal" is somewhat weaker at the POU location, the other reflections from adjacent houses and buildings become more significant.

3.3.3.7 DTV reception versus antenna orientation

Turning to Step 12 of the test procedure described in Section 3.3.2, we recall that the antenna was repositioned for best reception of an NTSC station on Channel 40, from a different transmitting tower. The transmitter is located at Camp Fortune, on the north shore of the Ottawa River (see Fig. 16). The Camp Fortune tower is 39 km away from the Manotick tower. Using a great circle calculator program[17], with the latitude/longitude coordinates of both transmitting towers as inputs, the bearing between the true north and the radial connecting the two towers was found to be 325° (taking Manotick as a reference); in other words, 35° west of the true north.

Getting back to the procedure, we then determined whether or not DTV reception was possible in that case. This experiment has been performed only on 17 occasions, outlier sites excluded. Since the passive antenna had more directivity than the active loop, a separate analysis was deemed important for each antenna.

[17] Courtesy of Industry Canada's Spectrum Engineering Branch.

For the active loop antenna, the statistics were based on *11 sites,* since there were five (5) unsuccessful sites and one (1) site where DTV reception was already sensitive even when the antenna was peaked in the direction of Manotick.

For the passive antenna, the statistics were based on *9 sites,* since there were 6 unsuccessful sites and two (2) sites where DTV reception was already sensitive when the antenna was peaked in the direction of Manotick.

The results are shown in Table 17:

Quality of DTV reception with the antenna peaked at Channel 40 (Receiver E)	Number of sites where an active loop antenna was used	Number of sites where a passive antenna was used
Reliable	36.4 % (4/11)	33.3 % (3/9)
Sensitive	36.4 % (4/11)	11.1 % (1/9)
Completely Unreliable	0 % (0/11)	11.1 % (1/9)
No DTV	27.3 % (3/11)	44.4 % (4/9)

Table 17. DTV reception versus a specific antenna orientation (i.e. peaked for best NTSC reception on Channel 40 from Camp Fortune).

From this limited data, some conclusions can nonetheless be drawn.

DTV reception appears to be strongly dependent upon the orientation of the receiving antenna, even with a loop having a rather poor directivity.

Since sensitive or very sensitive DTV reception is not much better for the typical viewer than completely unreliable reception or no DTV at all, we can lump together the last three rows of Table 17 and call this condition "undependable" DTV reception (see Table 18 below):

Quality of DTV reception with the antenna peaked at Channel 40	Number of sites where an active loop antenna was used	Number of sites where a passive antenna was used
Reliable	36.4 % (4/11)	33.3 % (3/9)
Undependable	63.6 % (7/11)	66.6 % (6/9)

Table 18. DTV reception versus a specific antenna orientation (i.e. peaked for best NTSC reception on Channel 40 from Camp Fortune) this time with only two categories: "reliable" and "undependable."

Table 18 confirms our earlier conclusion: directional antenna or not, reliable DTV reception appears to be strongly dependent upon the antenna orientation. Clearly more tests are needed with these and other improved indoor antennas.

3.3.4 Conclusions (indoor tests)

A summary of the indoor test results is presented in Table 19:

Quality of DTV reception	Active Loop Antenna		Passive Antenna	
	Number of Sites	Mean NTSC rating (Ch. 65)	Number of Sites	Mean NTSC rating (Ch. 65)
Reliable	58 % (25/43)	3.0	53 % (23/43)	3.5
Sensitive	12 % (5/43)	1.1	5 % (2/43)	2
Completely Unreliable	0 % (0/43)	—	2 % (1/43)	3
No DTV	30 % (13/43)	0.8	40 % (17/43)	1.2

Table 19. Performance of active and passive antennas with receiver E.

For the tests done at the original antenna location (usually close to an appropriately oriented window), a combination of low field strength and multipath appears to be the most common cause of DTV failure if we set the threshold for sufficient field strength to a C/(N+I) of 20 dB.

The test procedure (see step 11 in Section 3.3.2) also involved – whenever possible – moving the receiving antenna away from its original position until the POU has been reached. Based upon the data gathered at those reliable sites, it appears that multipath caused the failure of DTV in most (**67 %**) of the sites where this experiment was performed.

For the indoor sites, the ATSC Service Availability was 58 % with the active antenna and 53.5 % with the passive one; the ATSC System Performance was 71 % with the active loop and 88.5 % with the passive antenna.

It seems that the benefits of using an active indoor antenna – chiefly boosting the received signal strength[18] – usually outweighs the potentially negative effects of increased levels of intermodulation distortion. However, it is important to note that this conclusion is valid for the Ottawa area with a relatively small number of TV stations on the air and where both the DTV and its co-sited NTSC station are in the same portion of the UHF band. These benefits may be lost when more DTV stations go on the air.

The test procedure (see step 12 in Section 3.3.2) involved repositioning the antenna for best reception of an NTSC station on Channel 40 coming from a different transmitting tower. We then determined whether or not DTV reception was possible in that case. From our limited data, it can be said that reliable indoor DTV reception appears to be strongly dependent upon the antenna orientation, regardless of its directivity. Clearly more tests are needed with these and other improved indoor antennas.

[18] On the one hand, 35 out of 43 sites (81 %) had a C/(N+I) of at least 15.3 dB using an active antenna; on the other hand, 26 out of 43 sites (60 %) had a C/(N+I) of at least 15.3 dB using the passive antenna.

4 CONCLUSIONS AND FUTURE WORK

4.1 Conclusions

The laboratory tests results showed that the earliest receivers tested were very sensitive to the phase of the echo. The latest receivers tested showed a good improvement to the sensitivity of the phase of the ghost and also for the range of operation of the equalizer for post-echo with a delay range of up to 40 μsec in comparison to 20 μsec for the earlier receivers. The next generation of receivers needs improvement on how they handle pre-echoes and dynamic multipath. These improvements will have a direct impact on indoor reception.

The field tests results showed that the 8-VSB system performed as expected when received with an outdoor 10 meter high antenna: DTV could not be received at only 4 of the 46 sites visited, mainly due to low field strength.

Reliable indoor DTV reception could be achieved using simple set-top antennas (active and passive) at about 50% of the 43 sites visited. Indoor reception of DTV failed with either a passive or an active antenna at 28% of these sites mainly due to a combination of multipath and low field strength. For the ten (10) remaining sites, various combinations of DTV reception were observed: for example, reliable DTV reception with the active antenna, and no DTV reception with the passive one, etc. Based on the available data, reliable indoor DTV reception also appears to be strongly dependent upon the antenna orientation and location, regardless of its directivity.

4.2 Areas of Future Work

- In future laboratory tests, it is recommended to measure the robustness of the receiver to random noise at the very strong level (-15 dBm), which could happen at reception sites close to a transmitter. The dynamic range of the receiver, which is the maximum and minimum signal RF level at the receiver input until TOV level is reached, will also provide useful information. The single echo test with a constant phase and random noise is not very useful in this context because of the sensitivity to the phase of the ghost. The single echo test with a phase rotation (0.1 Hz) with and without random noise is a better alternative, and gives a good indication of the C/N required when the receiver is under severe multipath conditions in the field.

- Phase I of the field test focused on characterizing the transmitter and identifying preliminary sites. However, the outdoor field tests results showed a correlation between the DTV noise margin and the NTSC ITU grade when the signals were not affected by very strong multipaths. During the second phase, sites with strong static and dynamic multipath will have to be identified. In addition, indoor test sites will also be characterized with an outdoor setup in close proximity.

- From the field test results, it appears that a better approximation of the real-world multipath conditions could be obtained by adding pre-echoes and dynamic multipath to the combinations of multipath used so far in laboratory. The characteristics of real-world multipath signals could also be collected in the field using special test signals and recorders, to be used later to simulate channels in the laboratory;

- Additional tests are needed to further characterize the transmitter out of band emission. These tests will verify the D/U level for DTV lower and upper adjacent channel interference into NTSC. These tests need to be done close to the transmitter site where sufficient signal strength is available;

- The active antennas that were tested so far (see Figs. 11 and 13) boosted the signal strength but did not spatially "filter" the multipath reflections because of their lack of directivity; on the other hand, the passive antenna (Fig. 12) did a better job at filtering those reflections but could not provide the necessary boost in signal strength in difficult locations. Trying to assess whether or not an active *directional* indoor antenna can achieve the best of both worlds, tests will be performed with an *amplified* version of the passive antenna. We are also planning to test improved indoor antennas as they become available and suggest possible improvements;

- More tests are needed to assess the impact of the intermodulation products created by the antenna's amplifier on the performance of DTV receivers. Active antennas should be equipped with higher quality amplifiers having lower noise figure, good VSWR performance across the UHF band, and their distortion performance properly characterized (e.g. in terms of two-tone third-order intercept point IP3);

- We have visited mostly suburban one or two-storey houses. During the second phase, more tests will be performed in high rise apartment and commercial buildings in dense urban areas;

- Channel characterization of difficult sites will be done using either a pseudonoise (PN) sequences or a "chirp" signal to obtain more information on the statistics and the dynamics of multipath signals;

- Improved DTV receivers will be tested in the laboratory and in the field as they become available;

- Possible coverage improvements which could be provided by an on-frequency repeater, will be evaluated;

- Finally, we will try to identify suitable changes to the modulation schemes and/or to the receivers' design to improve indoor DTV reception.

The results of this work will provide very useful information for an efficient implementation of terrestrial digital television services in Canada.

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Appendix: Evaluation Sheet for Indoor Tests

DTV Indoor Reception Tests: 8-VSB LOS: Yes No

Site Number:________ Date________ Time:________

Weather:________

Name: ________ Location: ________

GPS readings: LAT:________ LONG:________

Distance from Tx: ________ Bearing: _____°

House Material:________

Tinted glass: Yes No

Room:________ Floor:________

Position of the tripod in the room:________

Blinds: Up Down

DTV Reception: Receiver E

Antenna: RCA CANT200

C/(N+I) (file name: Site):	dB	Number of traces acquired:
C/N (file name: Site):	dB	Number of traces acquired:
Margin to The Threshold Of Visibility (TOV):	dB	Margin to the Point Of Unusability (POU): dB
Comments on Spectrum: **(Marker @ 791 MHz + 2 dB for *weak* DTV:** dBm)		
Distance from original position of tripod:	feet	Number of traces acquired:
C/(N+I) @ POU or sensitive reception (file name: Site): dB		
Comments on NTSC (Ch. 65) at the point of failure for DTV (POU): ITU-R Grade: Sound: OK Dropouts		
DTV reception if the RCA *is peaked for Ch. 40 (NTSC)* ?		

Antenna: Silver Sensor

C/(N+I) (file name: Site):	dB	Number of traces acquired:
C/N (file name: Site):	dB	Number of traces acquired:
Margin to The Threshold Of Visibility (TOV):	dB	Margin to the Point Of Unusability (POU): dB
Comments on Spectrum: **(Marker @ 791 MHz – 20 dB for *weak* DTV:** dBm)		
Distance from original position of tripod:	feet	Number of traces acquired:
C/(N+I) @ POU or sensitive reception (file name: Site): dB		
Comments on NTSC (Ch. 65) at the point of failure for DTV (POU): ITU-R Grade: Sound: OK Dropouts		
DTV reception if the Silver Sensor *is peaked for Ch. 40 (NTSC)* ?		

ITU-R Impairment Scale for NTSC:

5: Imperceptible;
4: Perceptible but not annoying;
3: Slightly annoying;
2: Annoying;
1: Very annoying.

RCA CANT200 for NTSC Reception:

Channel 65: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Channel 43: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Channel 40: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Channel 24: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Silver Sensor for NTSC Reception:

Channel 65: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Channel 43: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Channel 40: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________

Channel 24: ITU-R Grade______Sound: OK Dropouts Impulsive Noise: Yes No ________