Analysis of Comparative DTV Field Test Results from Several Parts of the World

Pierre Bouchard, Michèle Guillet, and Khalil Salehian

CRC Report No. CRC-RP-2001-05
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Abstract

A number of field tests have been performed by several countries in order to evaluate the performance of different digital terrestrial television transmission systems, and to compare them with existing analog systems.

In this report, some of these comparative tests are reviewed and analyzed, interesting findings and limitations of the tests are emphasized. The relevance of the results and the conclusions are also evaluated within the North American context.

Résumé

Plusieurs pays du monde ont fait des essais sur le terrain dans le but d'évaluer les performances des différents systèmes de transmission de la télévision numérique tout en les comparant avec les systèmes de télévision analogique déjà en place.

Ce rapport présente une analyse des résultats de ces tests comparatifs, en faisant ressortir leurs forces et leurs faiblesses tout en essayant d'évaluer la validité de leurs conclusions dans le contexte nord-américain.

Executive Summary

Field tests have been performed by several countries in order to evaluate the performance of different digital terrestrial television transmission systems, and to compare them with existing analog systems. A large number of variables have to be taken into account during field tests: the methodology, site selection criteria, the type and model of the equipment used, the environment in which the tests were performed (e.g. suburban, urban, and downtown areas), distance to the transmitter(s), the relative power of the digital and analog transmitters, terrain and topology specifics, receiving antenna height, etc. Controlling these factors and striking a balance between them is quite a difficult job for the experimenters who want to draw fair and unbiased conclusions from the test results.

In this document, some of these tests are reviewed and analyzed, a number of limitations of the tests are emphasized, and the relevance of the results and the conclusions are evaluated within the North American context.

The field tests selected in this report are:

- Australian tests, 1997;
- Hong-Kong tests, 1999;
- Brazilian tests conducted during the fall and winter of 1999/2000;
- MSTV/NAB tests performed in the USA in the fall of 2000.

The earliest of these tests, the Australian tests, compared the European DVB-T COFDM (2K), American ATSC 8-VSB, and PAL analog systems in the VHF band III in a 7-MHz channel environment. The test results showed almost similar performance for the two digital systems, and in a vast majority of cases, a satisfactory reception for both systems where a reasonable PAL picture existed. However, while the tests have had a number of unique characteristics, their principal weakness resides in the use of first generation DTV receivers and in particular, the ATSC receiver, the performance of which has been considerably improved over time. There were a large number of sites labeled as sensitive without mentioning anything about the cause and/or the severity of the problem. Using a variable antenna height has also introduced an unnecessary variable in the test procedure.

The Hong-Kong tests assessed the performance of the three digital standards: 8-VSB, DVB-T, and ISDB-T and compared them with the analog PAL-I system in the UHF band in an 8-MHz channel environment. The tests were also designed to study some other aspects such as capability of the digital systems to support Single Frequency Network (SFN) operation, mobile reception, compatibility with the existing analog TV system, etc. Unfortunately, there were many limitations in the procedure, and inconsistencies in the tests that limited the validity of the results and made them of very limited use for drawing reliable conclusions. Some of the limitations and inconsistencies were:

- The DTV systems have not been tested concurrently;
- The ERPs of the analog and digital systems were identical;
- Different measurements have been done with different receiving antenna heights;
- Some confusing results described in some detail in this document.

The tests in Brazil compared the performance in the UHF band of 8-VSB, DVB-T (2K), DVB-T (8K), and ISDB-T in a 6-MHz channel bandwidth. The test results showed a better performance for COFDM over 8-VSB, but this is mainly due to the site selection criteria that favored COFDM. The environment in which the tests have been performed was not representative of a typical broadcasting environment in North America, and the test results suffered from a combination of low transmitting antenna height and low ERP in a dense urban area. Different systems have not been tested concurrently and the repeatability of the tests was limited, giving different results for the same sites in different rounds of measurements. All these factors together yielded results not very significant statistically, and limited the validity of the conclusions.

The MSTV/NAB field trial in the USA used state-of-the-art implementations of ATSC and DVB-T systems. A large number of outdoor and indoor sites have been visited, making these tests the most extensive and comprehensive comparison of the two systems to date. Although the trial faced the controversial "COFDM receiver anomaly" problem, the test results as a whole remained valid. Two fixed antenna heights (30 feet and 6 feet) were used for outdoor measurements from five different transmitter sites. Four of these stations were operating in the UHF band and one in low VHF (Channel 2), providing an opportunity to study the effect of impulsive noise and other propagation characteristics associated with the low VHF band. The test results showed that using a 30-foot outdoor antenna, 8-VSB was received at a greater percentage of the sites than was DVB-T, but this was not always the case with a 6-foot antenna height. However, a more general conclusion that could be drawn from the results would be that 8-VSB performed better farther away from the transmitter and DVB-T performed better closer to the transmitter. Based on this conclusion, any test condition encompassing sites far from the transmitter favored 8-VSB. Results of indoor tests showed almost similar but disappointing success rates for the two systems. The poor performance of the two systems indoors limits the possibility of delivering reliable video or data services under these conditions.

One general conclusion that could be drawn from these tests would be that an almost equally reliable service from both 8-VSB and DVB-T could be expected with a 10-meter high outdoor antenna. More field tests on indoor and portable reception using standard and enhanced modes of operation, coverage improvement by gap fillers and SFN, the impact of improved ghost-handling capabilities of the receivers, etc, are urgently needed in order to draw more reliable conclusions on these vital topics.

At the end of this report, a number of dos and don'ts are presented to make experimenters aware of crucial factors for performing field tests based on which scientifically valid conclusions could be drawn.

Table of Contents

1. Introduction

In this report, results from a number of different comparative field tests with different Digital Television (DTV) transmission systems are reviewed and analyzed. Because of the large number of variables to control, fields tests are far more complex to conduct and the results are far more difficult to compare than their laboratory counterparts. In this survey, various limitations are emphasized and the usefulness of these results is assessed.

Performing realistic DTV broadcasting field tests presents specific difficulties. The cost is fairly high due to the high power levels required, the complexity of transmitting facilities, the requirement to obtain the necessary authorizations, procure the space availability to house the transmitter, and install the antenna on the transmission tower. There are time constraints due to the availability of the equipment, the time needed to perform the tests and, in the case of indoor tests, the burden of getting permission to go into people's home with the required instrumentation and perform the tests as efficiently as possible. In the case of a new technology like DTV, the availability of the rapidly-evolving state-of-the-art equipment (modems) is still another hurdle. Several of the constraints are beyond the control of the test engineers and this may limit the usefulness of the results.

Broadcasting services have different modes of operation from one country to the other: different objectives, different services, different regulatory and competitive environments. This influences the choice of specifics in field trials, which will in turn have an impact on the results.

Others factors such as methodology, repeatability of results, site selection, and number of sites are more under the control of the experimenters. They also have to be aware of tone interference, dynamic multipath caused by vehicular traffic or airplanes, and impulsive noise, all of which can come and go unexpectedly during the course of the trials. However, these factors are not always well documented in the final reports, which makes it difficult to compare field test results.

2. Field Test Results from Several Parts of the World

In this document, the results from four different field trials have been reviewed:

- Australian tests, 1997;
- Hong-Kong tests, 1999;
- Brazilian tests conducted during the fall and winter of 1999/2000;
- MSTV/NAB tests performed in the fall of 2000.

This section presents highlights of these field tests. All of these field tests compare the ATSC standard based on the 8-VSB modulation scheme [1] and standards based on COFDM modulation (DVB-T [2] and in some cases ISDB-T [3]).

Completeness, the level of analysis, the amount of detail on setup, actual conditions of the tests, and the methodology of the published results vary tremendously. Different generations of equipment have also been used. Therefore, results and depth of analysis differ vastly in quality, making comparison between field tests difficult.

2.1 Australian Field Tests

2.1.1 General description

The DTTB field trial for Australia was conducted in Sydney in October and November 1997, in all 27 days of testing. The European DVB-T COFDM (2K)[1] and the American ATSC 8-VSB systems were tested in the environment of Sydney in VHF Band III (7-MHz channel environment) along with PAL analog Channels 7, 9, and 10. DTV was broadcast on Channel 6 (174 to 181 MHz) and Channel 8 (188 to 195 MHz).

These 1997 test results are the earliest data included in this survey. In light of recent advances in receiver technology, the principal weakness of the data obtained lies in the fact that it used "grandfather" (i.e. first generation) receivers. In particular, the ATSC receiver used was the original Zenith blue rack[2] whereas the most recent 8-VSB receivers available today clearly would handle multipath conditions much better.

The Australian tests had a number of unique characteristics:

- First direct comparative tests between the two systems;
- First extensive tests of both systems in a 7-MHz channel environment;
- First tests of VHF PAL adjacent channel operation[3];
- First test of ATSC in a PAL environment;
- First test of DVB-T at VHF;

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[1] Using 64-QAM, a code rate of 2/3, RS (208, 188), a guard interval of 1/8 (32 μs), a measured C/N threshold in AWGN of 19.1 dB, and a transport stream bit rate of 19.35 Mbps.

[2] The equalizer window was 23 μs.

[3] Channel 7 with visual carrier @ 182.25 MHz, Channel 9 with visual carrier @ 196.25 MHz, and Channel 10 with visual carrier @ 209.25 MHz.

- The effects of impulsive noise were also tested.

The field trial *did not* cover [4]:

- UHF Bands IV and V;
- Co-channel interference;
- Long term level variations (seasonal);
- Variable weather conditions (rain and lightning);
- Performance in MATV and cable systems;
- Indoor reception[4];
- Portable and Mobile reception.

The ERP of the DTV stations was 4 kW using a 400-W transmitter and the transmitting antenna was 223 m high. The ERP for PAL was 100 kW, using a 10-kW transmitter. Thus DTV was transmitted 14 dB *below* the peak of sync power of PAL.

A calibrated 7-dBi (at Ch. 8) VHF receiving antenna was used for the bulk of the test. Its front to back ratio measured in the field was 28 dB on Ch. 9. The antenna was peaked for maximum analog level. Some tests were also carried out using a 2-dBi dipole antenna whenever the consumer's antennas were thought to be "rabbits ears." The outdoor receiving antenna was raised on a mast *up to* 10 m (30 ft) above ground to coincide with the height of the consumers' antennas around the site. *Clearly, varying the height of the receiving antenna introduced an unnecessary variable.*

Measurements were performed at 108 sites; distances from the transmitter ranged from 0.4 to 100 km. The sites were generally distributed along arcs ("generally distributed around the compass"). Sites were selected to include a combination of the following characteristics [4]:

- Population concentrations and centers, representing the majority of the population;
- Rural reception;
- Urban reception, multi-storey residential;
- Suburban: houses up to two storey with various types of terrain and foliage;
- Suburban: industrial, terrain and foliage variable with impulsive noise;
- Power line interference: impulsive noise in both low to high field strength areas;
- Existing translator areas: assessment of need for DTTB translators;
- Shadowed reception for moderate populations: possible need for further DTTB gap fillers;
- Over-water reception, e.g. over Sydney Harbor, yielding high dynamic multipath;
- Beach area reception: Northern and Southern beaches with complex multipath profiles;
- Aircraft flutter: fast dynamic multipath;
- Omni-directional antenna reception in urban and suburban environments, to assess the use of "rabbit ear" antennas.
- Reception through distribution systems, e.g. residential units, hotels, and hospitals;

[4] In fact, Australia, like Brazil, did about ten indoor sites, but reliable records of these tests are not available.

- Reception through vehicle traffic producing flutter and/or impulsive noise.

2.1.2 Test results

Table 1 presents an analysis of failed sites, i.e. where there were either no DTV pictures or unwatchable pictures due to constant errors whereas in both cases, the PAL pictures were watchable. This analysis is based on an unnumbered plot in [4] entitled "DTTB Environmental Robustness - decode failure or constant picture errors."

Cause of DTV failure (PAL pictures with no objectionable impairment)	**Percentage of sites for 8-VSB**	**Percentage of sites for COFDM**
Multipath & low field strength	42 % (5/12)	23 % (3/13)
Low field strength only (PAL ≤ 50 dBμV/m)	17 % (2/12)	15 % (2/13)
Multipath only	25 % (3/12)	0 %
Impulsive Noise	8 % (1/12)	23 % (3/13)
Aircraft Flutter (fast-varying multipath)	8 % (1/12)	0 %
Impulsive Noise and low field strength	0 %	23 % (3/13)
Low field strength as one possible cause of failure	58 % (7/12)	61 % (8/13)
Number of failed sites	11 % (12/108)	12 % (13/108) (Possible causes of failure have not been identified at 2 of the 13 sites)

Table 1. Causes of failure (failed sites) for 8-VSB and COFDM (Australian field tests).

Table 2 presents an analysis of the *sensitive* sites, i.e. where DTV pictures were intermittently unwatchable due to dynamic multipath, impulsive noise, or airplane/vehicle flutter. Again, the PAL pictures were watchable in all cases. This analysis is based on an unnumbered plot in [4] entitled "DTTB Environmental Robustness causing fluctuating BER – picture errors." Unlike the previous table, there does not seem to be *multiple* causes, although that last plot in [4] is quite difficult to read. This may be because the field strength levels were adequate at these sensitive sites since "low field strength" was not listed as a possible cause of sensitive reception in this plot.

Cause of intermittent failure at the sensitive sites (PAL pictures with no objectionable impairment)	Percentage of sites for 8-VSB	Percentage of sites for COFDM
Multipath only	18 % (10/55)	23 % (10/43)
Impulsive Noise	22 % (12/55)	44 % (19/43)
Aircraft Flutter	27 % (15/55)	2 % (1/43)
Number of sensitive sites	51 % (55/108) (The possible cause of intermittent failure has not been identified at 18 sites)	40 % (43/108) (The possible cause of intermittent failure has not been identified at 13 sites)

Table 2. Causes of failure (sensitive sites) for 8-VSB and COFDM (Australian field tests). These are approximate percentages as the plot in [4] is quite difficult to read.

Unlike Table 1 (failed sites), Table 2 suggests that multipath affected almost equally DVB-T and ATSC systems. For DVB-T, about 44 % of the sites suffering from sensitive reception have been affected by impulsive noise, compared to 22 % for ATSC.

A bit of background material would be helpful here:

Theoretically, considering just modulation without channel coding and synchronization, COFDM modulation should be more robust than 8-VSB modulation against impulsive interference, since the implementation of a large size FFT in the receiver can effectively average out the short-term disturbance of impulse noise. The DVB-T system was intended for UHF implementation only, and no additional measure was implemented to protect it from impulsive interference, though it is an issue in the lower UHF band as well [5].

On the other hand, the ATSC system was designed for both VHF and UHF operation. Strong channel coding, 12 to 1 interleaved trellis-coded modulation and R-S (207,187) code, were implemented rather than the sub-optimal punctured convolutional code and weaker R-S (204,188) code used in the DVB-T system for compatibility with the DVB-S system. The ATSC system also implemented a longer interleaver, which can effectively mitigate a long burst of interference [5].

During the field tests, at some sites the power generator of the mobile test van had to be turned off to keep its impulsive noise from interfering with COFDM reception. Thus, power was supplied to the DVB-T receiver by an UPS. These sites did not appear in the plot [4] used to compile Table 2. Finally, the sensitivity of the DVB-T system to impulsive noise *increased* towards low field strength and would be improved by increased transmission power [4].

In light of Tables 1 and 2, successful *and reliable* reception (i.e. a DTV picture *without* impairments) was possible with 8-VSB at about 38 % (41/108) of sites whereas with COFDM at about 48 % of the sites (52/108). As always, some caution must be used in interpreting these results. For example, the BER as well as the severity of the impaired video and audio at these sensitive sites have not been presented in the report [4]. This may explain the assertion found in the conclusion of [4]: "when there was a reasonable analog PAL picture, both 8-VSB and COFDM worked at the *vast majority* of sites." Moreover, Sydney was in many respects quite a difficult reception environment, with multipath from tall buildings and interference from overhead power distribution lines. However, there was no co-channel interference (CCI). From the laboratory measurements conducted at the time, CCI would be expected to disadvantage ATSC much more than DVB-T [4].

2.1.3 Conclusions from the Australian field tests

- *There was no significant difference between the rates of failure for 8-VSB (12 sites) and DVB-T (13 sites);*
- *For both systems, the cause of failure for the majority of the sites was at least in part due to low signal strength;*
- *As expected, at the failed sites, 8-VSB was more affected by multipath than COFDM whereas COFDM was more affected by impulsive noise;*
- *The sensitivity of the DVB-T system to impulsive noise increased towards low field strength and would be improved by increased transmission power;*
- *The sensitivity of 8-VSB to airplane flutter was found over the whole field strength range, with only large changes in level improving the performance. Hence increasing the transmission power is unlikely to significantly improve 8-VSB sensitivity to flutter;*
- *Surprisingly, the number of sensitive sites for both systems (55 for ATSC vs. 43 for DVB-T), where DTV reception was intermittently impaired by either dynamic multipath, impulsive noise, or airplane/vehicle flutter, was much higher than the number of failed sites. But the severity of the impairments at these sensitive sites remains unknown. Then again there has not been many comparative tests performed at VHF where impulsive noise prevails, so it is difficult to say if a high number of sensitive sites is commonplace or not in this frequency band;*
- *Taking into account both failed* ***and*** *sensitive sites, reliable DTV reception was achieved at about 38 % of the sites with 8-VSB and about 48 % of the sites for COFDM.*

2.2 Field Tests in Hong Kong

2.2.1 General description

The overall objective of this trial was to assess the performance in the Hong Kong environment of the three Digital Terrestrial Television (DTT) standards: 8-VSB, DVB-T, and ISDB-T. This environment is quite different from Canada, with its very high density of buildings and tropical monsoon climate. Moreover, certain areas along the coastline of the Victoria Harbor suffer from the effect of *tidal fading*. During a certain period during the day, very strong multipath reflections from the sea surface combine destructively with the direct path and severely affect the reception of analog (PAL-I) signals. For a location where the water level rises and falls due to the tides, there is a high probability that the geometry will be favorable to such destructive

interference between direct and reflected rays. However, as this phenomenon is atypical in Canada, this topic will not be further studied in this review.
The trial was set up to study the following aspects:

- the propagation characteristics (outdoor and indoor) and coverage of DTT transmissions;
- the ability of DTT signals to be conveyed by In-Building Co-axial Cable Distribution Systems (IBCCDS)[5] and the compatibility with the existing analog television equipment and NICAM service;
- the support for Single Frequency Network (SFN) operation;
- compatibility with the existing analog television transmission, co-channel, adjacent channel and image channel performance;
- picture and sound quality;
- the effect of tidal fading on DTV reception;
- the effect of overall encoding / decoding delay.

The trial was conducted in three stages during the following periods:

- Technical trial of the ISDB-T system: May 1999 to June 1999
- Technical trial of the DVB-T system: August 1999 to September 1999
- Technical trial of the ATSC system: November 1999.

Limitation: The three DTV systems have not been tested in the field during the same period; this clearly introduces seasonal variations that make comparisons between systems much more difficult.

Two DTT transmitting stations, namely the Master Station and the Slave Station, were established for the field measurements and for the evaluation of the Single Frequency Network capability (for DVB-T and ISDB-T).

Master station:

- Location: Temple Hill;
- Height of the antenna above sea level: about 496 m (the actual height of the tower remains unknown);
- The main beam of the antenna was oriented towards southeast;
- Maximum Effective Radiated Power (ERP): 100 W[6].

[5] This distribution system is the most common method of reception in Hong Kong.
[6] The result of the technical trial was normally obtained with the Master Station transmitting at 100 W. Only under certain test cases, the transmitter power of the Master Station was increased to 1 kW to investigate the effect of increased transmitter power. Unfortunately, the results of these special tests were not further mentioned in the report.

Slave station:

- Location: Sai Wan Shan;
- Height of the antenna above sea level: 199 m (the actual height of the tower remains unknown);
- The beam of the antenna was oriented towards the east;
- Maximum ERP: 10 W.
- For 8-VSB tests, the slave station was not used.

The radial distance between the master and slave stations was 9 km.

The power levels shown take into account the potential interference to existing analog services in Hong Kong and Mainland China. They can be considered typical for this area.

Channels used for the tests:

- Channel 32 (558-566 MHz) for PAL-I;
- 560-566 MHz for ATSC, DVB-T, and ISDB-T signals.

Table 3 below presents the various DVB-T modes tested [2].

	DVB-T Modes (8-MHz Channel)						
	Mode A	**Mode B**	**Mode C**	**Mode D**	**Mode F**	**Mode H**	**Mode L**
Number of Carriers	2K	2K	8K	8K	2K	2K	8K
Modulation	64-QAM	64-QAM	64-QAM	64-QAM	QPSK	16-QAM	16-QAM
Guard Interval	1/8	1/4	1/32	1/16	¼	¼	1/16
Code Rate	2/3	2/3	2/3	2/3	½	½	½
Net Bit Rate (Mbps)	22.12	19.91	24.13	23.42	4.98	9.95	11.71
Required C/N for QEF after R-S (AWGN) (Simulation Results)	16.5	16.5	16.5	16.5	3.1	8.8	8.8

Table 3. DVB-T modes tested during the Hong Kong trial [6]. The threshold C/N ratios are **simulation results**. Quasi Error Free (QEF) conditions correspond to a BER = 10^{-11}.

A PAL-I transmitter also operating on Channel 32 with a 100-W ERP was set up at the master station (Temple Hill) as a reference. The ERPs for the analog and the digital television system were *identical*, a departure from the field tests conducted in other countries. As mentioned in a recent footnote, certain tests have been conducted with *a 1-kW* ERP but it is not clear whether or not the results of these special tests appeared in the official Hong Kong report from the DTT Steering Committee [6].

The picture quality of both PAL and DTV signals has been assessed using the five-point ITU-R subjective scale. Clearly, this scale is poorly suited for digital video assessment because of the well-known cliff-effect of digital systems.

According to the test procedure described in the Appendices of [6], outdoor tests have been conducted at the street level and on rooftops. The procedures are similar, with a few exceptions:

- *Street level:* the log-periodic antenna was raised 10 m above ground; it was peaked for maximum signal level under LOS conditions. In the presence of shadowing caused by mountains or buildings, the antenna was peaked for best PAL picture quality. *Limitation: different peaking criteria introduce an unnecessary variable*;
- *Rooftop level:* The *height* and the orientation of the receiving antenna *were adjusted* for maximum signal level under LOS conditions. In the case of shadowing caused by mountains or buildings, the antenna was peaked for best PAL picture quality. A "domestic" antenna (available in Hong Kong) was used instead of a log-periodic. A 150-m cable carried the signals to the survey van. Figure 8 of Appendices 1, 2, and 3 of [6] shows a Yagi-type antenna. A bandpass amplifier was also used to compensate downlead losses. *Limitations: again, this introduces the height of the receiving antenna as another unnecessary variable. Moreover, the procedure did not specify whether or not the receiving Yagi antenna was tripod-mounted.*

There were exceptions to these "rules", probably for practical reasons (e.g. low overhead power distribution lines and/or trees). For example, during the ATSC trial ([6], Appendix 3):

- Measurements at Sites #14 and #15 were taken at the street level: the receiving antenna was raised 8.5 m and 9 m above ground, respectively. These sites were obstructed by buildings;
- Sites #17 and #18 (obstructed by buildings, measurements at the rooftop level): unfortunately, the height of the receiving antenna does not appear in the report.

Limitation: measurements conducted with different antenna heights and/or antenna types are obviously much more difficult to compare. Moreover, the height of the building above ground would have been a much more useful piece of information than the height of the antenna above the roof.

2.2.2 Limitations of the Hong Kong field trials

- The outdoor tests have been conducted on a limited number of sites (18 for ATSC, 21 for DVB-T, and 19 for ISDB-T) and the radial distances from the transmitter ranged approximately from 1 km to about 11 km, i.e. very close to the transmitter. *This condition is very different from the North American context where Grade B contours in UHF have a radius of about 80 km.* Moreover, a large proportion of these sites (nine for ATSC, 11 for both DVB-T and ISDB-T) were in LOS with the Temple Hill transmitter, which is atypical in a broadcasting situation where viewers usually receive reflected signals. The remaining sites were obstructed by buildings or hills;

- The *indoor* tests have also been conducted on a very limited number of sites: a total of five sites inside *four* public housing estates during the ATSC and DVB-T[7] trials and *three* public housing estates (three sites) during the ISDB-T trial. The first two sites for ISDB-T have been visited during the other two trials, *but on different floors.* Site #3 seems to be common to all three trials, but unlike the other two, Table 3 (Appendix 1 of [6]) did not say whether tests have been conducted in the corridor of the first floor;

- Very limited information has been provided on the actual setup used indoors: for example no information has been provided on:

    - the antenna height above floor;
    - exact indoor antenna type (we learn that it is an active antenna with a gain between 0 dB (?) and 30 dB and a noise figure of 3.0 dB);
    - selection of the antenna location in the room (close to a window, in the middle of the room, or any convenient location ?);
    - the type of DTV and analog receivers used.

- The authors did mention that for all three DTTB systems, the antenna was put inside flats or corridors of the housing estates. The type of building material remains unknown. We can surmise that it was either brick or concrete;

- Since the measurement technique used for indoor tests was similar to the procedure outlined for outdoor tests, we can assume that the indoor antenna was peaked for maximum signal under LOS conditions and peaked for best PAL picture quality in the case of obstructed LOS;

- Given the impact of multipath, random noise, and interference on the DTV receiver's performance, it seems peculiar that very little information on these impairments has been presented in the report [6]. It is therefore quite difficult to assess the level of multipath found at those outdoor sites, let alone impossible to say whether or not significant pre-ghosts prevailed. For example, during the ATSC trial, using the picture quality of PAL signals as a reference and looking at the first nine sites presented in Table 2 (Appendix 3 of [6]) where LOS conditions prevailed, we see a large spread in the picture quality of PAL signals: between 2 ("annoying" impairments) to 5 ("imperceptible" impairments; *note: such a high picture quality is normally achieved in the studio only*). On the other hand, sites #10 to 18 were obstructed by buildings or hills and the picture quality of PAL was rated between 1 and 3.5. Once again, the authors gave little information on the type of impairments visible in PAL: the word "ghosting" appears twice in Table 2 for obstructed sites #13 and 15. On the other hand, the terms "wavy lines" or "wavy pattern" in Table 2 may suggest the presence of interference;

- Laboratory tests have focused primarily on protection ratios for co-channel and adjacent channel interference, and the overall encoding decoding delay of the three DTV systems.

[7] The same sites were visited, with the exception of site #1, where measurements were made on the 12th floor, Block 1 of the Mei Tung Estate, during the DVB-T trial, and on the 6th floor during the ATSC trial. A different room of site #1 was visited during the ISDB-T trial.

Given the impact of the DTV receiver's performance on the test results, it seems surprising that neither multipath tests nor random noise laboratory tests with/without static multipath have been reported. Moreover, neither the manufacturer's name nor the year of its production was disclosed in the report[8]. Same thing for the PAL receiver. For example, the authors could have labeled the DTV receiver(s) with letter(s) and given indications of their performance in the laboratory (e.g. the width of their equalizing window under slowly-varying multipath conditions);

- Careful observation of the various impairments in the analog picture provides additional evidence on the types and the severity of channel impairments present at a given time. By necessity, the assessment of the picture quality of PAL signals was done *some time after the string of DTV measurements have been performed* since they both used Channel 32: the level of dynamic multipath (e.g. caused by traffic), impulsive noise, tone interference, etc., may have changed drastically during this time.

*2.2.3 **Some examples of confusing results** (taken from the ATSC outdoor trial, Appendix 3 of [6])*

- *Blocking artifacts* appeared from time to time at Site #13 (@ 3.4 km, at the street level, with shadowing caused by buildings): clearly, this was a sensitive site as TOV conditions were already there, which in turn implies no margin. Was there dynamic multipath caused by traffic ? Nevertheless, a 24-dB margin *to TOV* was achieved. The C/N was 31.6 dB, whereas the C/N@TOV was 27.56 dB...;

- For Site #18 (@ 7.8 km, with buildings causing some shadowing), it is difficult to understand how a C/N@TOV (using noise injection) of 14.21 dB could be achieved, *as this was even better than laboratory test results*[9] ... same thing (this time slightly better or identical to laboratory results) for sites #4, #14, #16, and #17;

- *Thirteen (13) sites out of 18 had a margin to TOV (attenuation method) larger than the C/N ratio in dB;*

- The picture quality of off-air PAL-I signals was rated at *5* on the ITU-R scale for Site #1 and Site #6. *Usually, such a high picture quality is only achieved in the studio.*

Given the above-mentioned limitations and confusing results, very little insight would be gained from a detailed analysis of the ISDB-T trial in Hong Kong. Therefore, we will focus on the ATSC and DVB-T outdoor and indoor trials.

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[8] One exception: Table 4 of Appendix 2 [6] reveals that NDS and V-TER DVB-T receivers were used during *mobile tests.*

[9] But assessing the noise power during these C/N measurements in the field can sometimes be very tricky. So maybe in that case (i.e. a C/N @ TOV of 14.21 dB) the out-of-band noise had an unusual shape.

2.2.4 ATSC and DVB-T outdoor test results

Table 4 shows the percentage of successful sites for the ATSC and DVB-T systems during the Hong Kong trial. It must be stressed that these outdoor tests had only 17 sites in common.

ATSC (8-VSB)	**DVB-T (Mode A @ 22.12 Mbps)**
89 % (16/18)	80 % (16/20)

Note: at Site #4, the COFDM modulator worked properly with mode B only.

Table 4. Outdoor sites with reliable reception during the Hong Kong trial.

The Hong Kong report [6] presents raw data and did not provide much in the way of an analysis of the results. A close examination of outdoor test results (Tables 2 of Appendices 2 and 3 in [6]) reveals that:

- Reliable DTV reception was achieved at 16 sites during the ATSC trial; the other two sites suffered from sensitive reception;
- Modes A to D have the same threshold C/N ratio in a Gaussian channel (see Table 3) and were tested at 11 of those 20 sites;
- Modes H and L were tested at Site #21 because higher bit rate modes A and B failed (see Table 2 below);
- The margin to TOV was typically *smaller* during the DVB-T trial, with a mean difference of 3.6 dB, based on the 13 common sites with *reliable* reception using a high-bit rate mode. This difference of 3.6 dB is comparable to the difference in C/N (AWGN threshold) between ATSC 8-VSB and DVB-T signals;
- Modes A to D had identical margins[10] to TOV, but like the ATSC tests, *thirteen (13) sites out of 21 had a margin to TOV larger than the C/N ratio in dB.* Moreover, one of these 13 sites had *sensitive* DTV reception and thus rigorously did not have any margin to TOV at all. Another one of these 13 sites did not receive DTV at all[11] using mode A but had a 32-dB margin to TOV using modes H or L.

Finally, as a way of illustrating some of the flaws in the test procedures used in Hong Kong, Table 5 below compares results taken at the Kowloon Bay Sport Centre:

[10] Except for Site # 20 where the margin to TOV was 1 dB smaller with mode B than modes A, C, and D.
[11] The C/N at this site (#21) was only 10.6 dB.

	DVB-T Trial Site #16	ATSC Trial Counterpart (Same site but labeled #13)
Mode(s)	A to D	8-VSB
DTV Reception	Reliable	Sensitive
Antenna Type	Log-periodic	Log-periodic
Antenna Height (m)	10	10
Field Strength (dBµV/m)	64.8	76
C/N (dB)	27	31.6
Margin to TOV (dB)	26	24 (Should be 0 dB since TOV conditions were already achieved *without* attenuation)
Picture Quality of PAL (Five-point scale)	1.5 Noise and multipath	3 Noise and multipath

Table 5. Results from the Kowloon Bay Sport Centre (outdoor site @ 4 km from the main transmitter) visited during the ATSC and DVB-T trials.

Table 5 reveals that this was a sensitive site during the ATSC trial despite the higher field strength: strong multipath conditions might explain the poor performance of the ATSC receiver. The latest generation of ATSC receivers might have handled this condition better. Spectrum plots would have helped assessing the level of multipath found at this site. Was the 11-dB difference in field strength caused in part by the undocumented 10-dB increase in transmitter power or simply by the ever-changing channel characteristics ?

2.2.5 ATSC and DVB-T indoor test results

The authors mentioned [6] that during the DVB-T trial, additional tests have been performed with a "consumer-type" set-top box at three of these four sites[12], using modes A, B, F, and H. We can surmise that the "main" DVB-T receiver was a professional unit. But unlike analog receivers, the consumer and the professional DTV receivers typically share the same chipset, the same tuner, etc, so similar performance should be expected; the main difference being that the professional unit will usually display the C/N ratio, the BER before or after the Reed-Solomon, the equalizer taps, etc.

Some additional facts:

- The slave station at Sai Wan Shan was not used during the indoor tests.
- Modes C @ 24.13 Mbps and D @ 23.42 Mbps have only been tested at Site #1: both failed;
- Mode L @ 11.71 Mbps has only been tested at Site #1 and performed reliably.

Table 6 shows the results for both trials.

[12] This time, however, the operators restricted their measurements to the margin to TOV.

	ATSC (8-VSB)	DVB-T (Mode A)	DVB-T (Modes F & H)
Number of sites	5	5	2
Reliable reception	100 % (5/5)	40 % (2/5) (two sites failed with mode A but were reliable with modes F and H)	100 % (2/2)

Note: as mentioned earlier, the tests were conducted in the same buildings for both systems, however often on different floors.

Table 6. Results for the indoor tests in Hong Kong with ATSC and DVB-T.

2.2.6 Single Frequency Network (SFN) tests using the DVB-T system

Single Frequency Network (SFN) tests using the DVB-T system were also conducted. The signal was sent from the master station (Temple Hill) to the slave station (Sai Wan Shan) using a 7.2-GHz microwave link. Very little information can be found in Appendix 2 of [6] on the SFN tests. Only *one* site has been tested: Chivas Godown, Chai Wan, approximately 1 km east of the slave station.

First, the receiving antenna was oriented towards the master station. Very high field strengths were measured: 80 dBμV/m from Temple Hill and 81 dBμV/m from Sai Wan Shan. Therefore, the D/U ratio was –1 dB[13]. Modes A-D were tested. The margin to TOV (using an attenuator) was 44 dB (for mode A ?). Both SDTV and HDTV were used.

Then the receiving antenna was oriented towards the slave station. Again very high field strengths were measured: 90 dBμV/m from the slave station and 69 dBμV/m from the master station. Mode A was tested. The margin to TOV (using an attenuator) was 54 dB. Only SDTV was transmitted.

In both cases, the static delay was 25 μs.

2.2.7 Mobile reception tests using the DVB-T system

Some limited mobile tests were conducted using a survey vehicle travelling at speeds up to 70 km/h (the speed limit in Hong Kong). The percentage of time that satisfactory DTV reception was achieved was used to quantify the performance of the DTT systems. Tests along four different routes were conducted:

- Kwun Tong Bypass (Laguna City to Kowloon Bay);
- Diamond Hill Route (Po Kong Village Road to Hammer Hill Road to Lung Cheung Road);
- Whampoa Garden Route (a number of streets inside Whampoa Garden);

[13] Reception was possible mainly because of the strong convolutional code used (R = 2/3).

- Eastern Corridor (Taikoo Shing to Causeway Bay).

Modes F (QPSK) and H (16-QAM) with and without SFN were tested using an NDS and a V-TER DVB-T receiver. The success rate was usually very high (≥ 96.7 %) except for the Kwun Tong Bypass (91 %) and the Whampoa Garden Route where shadowing from neighboring high-rise buildings caused the success rate to drop as low as 4.5 % with the V-TER receiver in mode F and using the SFN configuration. The field strength was probably very low along the Whampoa Garden route, as mode F required only a very modest C/N (see Table 3). The success rate of mobile reception appeared to be dependent upon the design of the receiver [6].

Though not statistically valid, it seems that during the *ISDB-T* mobile trial, the QPSK/DQPSK modulation scheme provided a slight advantage over the 16-QAM modulation scheme. For instance, measurements in the Kwun Tong Bypass *without* SFN indicated that the average success rate for DQPSK modulation reached 97.2% while the average success rate for 16-QAM was only 28.6% [6].

2.2.8 Conclusions from the field tests in Hong Kong

Unfortunately, the results of these tests are of limited use for several reasons.

First of all, the ERPs involved, both for DTV and PAL signals (100 W each, yielding a 0-dB difference between analog and digital television signals), and the selection of the outdoor and indoor sites less than 11 km away from the transmitter are far from being typical of the North American context where Grade B contours for regular UHF stations have a radius of about 80 km. The number of outdoor and (especially) indoor sites tested was too low to be statistically valid.

The report [6] and the three appendices (in all about 184 pages) are replete with tables presenting only raw field data; surprisingly very little information can be found on each indoor/outdoor site, no spectrum analyzer plots have been presented. No statistics on the location availability have been compiled, and no attempts have been made to find the causes of failure. We find general statements like "The performance of all three DTT systems was much better than existing PAL-I systems with more stable picture and sound quality and more robust reception" [6].

There are also a number of inconsistencies in the results reported and suspected methodology problems. For example, the three DTT systems have not been tested in the field during the same period; this clearly introduces seasonal variations that make comparisons more difficult. Moreover, some of the measurements have been performed at different antenna heights, introducing another unnecessary variable.[14]

Under these circumstances, it is inappropriate to use these results to estimate the performance of different DTT systems in the North American context. Clearly, extrapolation of the Hong Kong

[14] After the writing of this section, the first author found that very similar comments had been posted on the ATSC Web site at http://www.atsc.org/papers/HK.html.

field test results to enhanced VSB or COFDM (QPSK) in North America is also very difficult to make.

2.3 Field Tests in Brazil

2.3.1 General description

The Brazilian field tests were conducted in the city of São Paulo by the SET/ABERT group and MacKenzie University in the fall of 1999 and the winter of 2000. Four systems were tested: 8-VSB, DVB-T (2K)[15], DVB-T (8K)[16], and ISDB-T[17] [7]. For DTV transmission, UHF Channel 34 with a 6-MHz bandwidth was used.

The outdoor receiving antenna[18] was set between 8 and 10 m high and oriented toward the strongest signal and lowest multipath degradation. Changing the antenna height between 8 and 10 meters introduced an unnecessary variable in the measurements.

2.3.2 Limitations of the field tests in Brazil

While the test results are interesting, there are a number of factors that limit the validity of the results:

- Different systems were not tested concurrently, which means it is unlikely that the transmission channel conditions have been identical for all systems;
- All four systems have only been tested at 27 sites;
- Only 8-VSB and DVB-2K were tested at 127 sites;
- A combination of low transmitting antenna height and low ERP in a dense urban environment represent only a special case limiting the effectiveness of the coverage of a broadcasting system, and is not representative of many other typical situations;
- São Paulo has a very dense urban environment with a congested electromagnetic spectrum in which a large number of illegal PAL translator stations operate;
- Concerning the severe multipath conditions found in this special case, the choice of the test sites were in favor of COFDM;
- Low transmitter power for PAL transmission (1 kW peak) versus DTV (2.5 kW average[19] so DTV is transmitted 4 dB *above*) makes the service comparison of little interest.

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[15] Using 64-QAM, a code rate of ¾, a guard interval of 1/16, and a bit rate of 19.75 Mbps.

[16] Using 64-QAM, a code rate of 2/3, a guard interval of 1/32, and a bit rate of 18.09 Mbps.

[17] This system was tested at the end of the trial and the following "4K" mode was very likely used most of the time: 64-QAM, a code rate of 3/4, a guard interval of 1/16, a 0.1-s interleaver, and a bit rate of 19.3 Mbps.

[18] About ten *indoor* sites have been visited during the trial, but reliable and detailed test results are not available.

[19] A 5 kW average power transmitter was operated at 2.5 kW. However, as shown in the RF interconnection scheme in [7], a BIRD power meter has been used for power measurement in both analog and digital systems. No mention has been made of the necessary calibrations needed to enable such a power meter to correctly read the average power of a digital signal.

2.3.3 Test results

Initially, 152 locations were selected on the intersections of some arcs and radials (arcs at every 3 km until 15 km and then at every 5 km until 40 km, and 17 radials from 357° to 237° at 15° separation) within the coverage area. Twenty-eight of these locations (mostly located at a distance of 40 km from the transmitter) were removed after theoretical coverage calculations, using a prediction software – and not confirmed by any measurement – showed that they suffered from low signal strength (< 45 dBμV/m for PAL-M, COFDM, 8-VSB, or for all ?).

During the first phase, measurements for DVB-T (2K) and 8-VSB were taken at 127 sites. All four systems (8-VSB, DVB-T (2K), DVB-T (8K), and ISDB) were tested only at 27 sites selected from these original 127 sites. Of the selected 27 sites, 17/27 (about 63%) sites were located at a distance between 3 and 12 km from the transmitter. Locations in proximity of the transmitter have been overrepresented in the subset used for comparing the four systems. There were only 2/27 sites (7 %) with a C/N below 19 dB, and the 4-dB advantage of the ATSC system could not have produced a better coverage. These two facts also have made the test conditions in favor of the COFDM system.

Table 7 shows the success rate for 27 sites at different radial distances from the transmitter, and Table 8 shows the percentage of sites (among 127 sites) having different problems affecting the received signal (Note that these problems do not imply that the system did not work).

Distance from the transmitter (km)	8-VSB	DVB-T (2K)	DVB-T (8K)	ISDB-T
0-10	82 %	87 %	100 %	100 %
10-20	75-82 %	79-90 %	86-98 %	94-100 %
20-30	73-75 %	73-79 %	82-86 %	91-94 %

Table 7. Rates of successful reception for 27 sites versus distance from the transmitter.

Type of Problem	Percentage of Locations
Multipath	100 %
Impulse Noise	23 %
Low signal level	15 %
Doppler Effect	2 %
Signal Fading	2 %

Table 8. Problems affecting received signals among all 127 sites.

It should be noted that in the São Paulo area where the DTV systems have been tested, the very high incidence of degradation of the DTV signal caused by multipath (clearly visible in Table 8) has mainly been due to dense high-rise buildings and low transmitting antenna height.

ATSC failed at 26 sites (20.5% of the 127 sites), 12 of which (about 9 % of 127 sites) had a C/N below the threshold of the ATSC system in a Gaussian channel. DVB-T (2K) failed at 34 sites (26.8 %), 16 of which (about 12 %) were below the C/N AWGN threshold. However, these failure rates do not totally reflect the reception problems of the systems, but in many cases, they are indications of inadequacy in the power and the antenna height of the transmitter used.

The repeatability of measurements at the 27 sites (selected as a subset of the 127 sites to compare the four systems) is limited. There are significant differences between the results for some of the sites in the first set of measurements (all 127 sites) with the results for the same sites in the second set of measurements (27 sites). In addition to these differences, a system might have worked at a given site in the first series of tests and failed in the second, or vice-versa. For example, there were 11 sites where DVB-T (2K) failed in the first set of measurements and worked in the second, and three other sites where DVB-T (2K) worked the first time but failed the second time.

A better receiver has been used for DVB-T (2K) for measurements during the second set of measurements (27 sites), and comparing the results of the same sites with the first set of measurements (127 sites), the failure rate of DVB-T (2K) was now significantly lower. However, in spite of using the same receiver for ATSC, the failure rate got slightly worse when comparing the same 27 sites in the two series of tests. Table 9 shows the failure rates of the two systems for the same 27 sites in the two sets of measurements.

Limited repeatability and small sample size make the results not statistically significant.

	ATSC	DVB- T (2K)
Failure rate for the 27 sites as part of the 127 sites	40.7 %	59.3 %
Failure rate for the 27 sites subset of the 127 sites (new chip for DVB-T (2K), but same ATSC receiver)	44.4 %	29.6 %

Table 9. Comparison of the failure rates in the two series of measurements conducted at the same 27 sites.

Many residential buildings in Brazil use collective antennas for television reception. Unfortunately the tests in São Paulo didn't make any use of such a practical situation but instead, used an antenna of 10-meter high above ground level. Using a 10-meter high antenna makes little practical sense in very dense areas where most of the buildings are about 50 m high.

2.3.4 Conclusions from the Brazilian field tests

The low ERP (a transmitter power of 2.5 kW) for DTV and low height of the transmitting antenna (its exact height and gain remain unknown) combined with the dense urban environment does not represent a typical broadcast system, be it in North America or in several other parts of the world. These conditions produce a situation of low field strength and strong multipath. The *strong multipath, as well as the large percentage of sites in proximity of the transmitter, biased the results in favor of DVB-T.*

The conditions in which the DTV systems were tested favored the COFDM system, especially for the subset of 27 sites where the four systems have been tested. In the report, emphasis was on results from this subset and not on the full set of 127 sites where 8-VSB and DVB-T (2K) were tested.

Finally, in São Paolo, communal rooftop antennas are commonly used to distribute the signal in dense populated areas. The use of an 8 to 10-m high antenna in these areas does not represent realistic receiving conditions.

2.4 MSTV/NAB Field Tests in the USA

2.4.1 General description

The purpose of these tests was to compare the performance of ATSC and DVB-T, using state of the art implementations of the two systems technologies. These tests were completed during the summer and the fall of 2000 by MSTV and NAB, and were conducted in the Washington/Baltimore area, which had zones with severe multipath, interference, and low signal levels, and in the Cleveland area, which offered challenges of impulsive noise and other propagation characteristics associated with the low VHF band.

During the Washington/Baltimore tests, the DTV signals from four different UHF stations were used. About 200 outdoor sites and 44 indoor sites have been visited. The stations were [8]:

- WRC-DT (antenna height of 636 feet AGL (about 194 m), ERP of 813 kW on Channel 48);
- WETA-HD (antenna height of 414 feet AGL (about 126 m), ERP of 75 kW, on Channel 27);
- WUSA-DT (antenna height of 673 feet AGL (about 205 m), ERP of 646 kW, on Channel 34);
- WBAL-DT[20] (antenna height of 998 feet AGL (about 304 m), ERP of 255 kW, on Channel 59).

WKYC-DT (Channel 2) in Cleveland was selected because it was the first low-VHF allocation on the air. It was broadcast from the same top-mounted antenna as an NTSC station on Channel 3, at 823 feet (251 m) above ground. The DTV transmitter was capable of a maximum average power of 5 kW, but was certified for the field test at 4.66 kW average and an ERP of 7.2 kW was obtained for Channel 2 [8]. About 100 outdoor sites and 22 indoor sites have been visited in the Cleveland area.

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[20] WBAL was substituted for WBFF-DT where both 8-VSB and DVB-T often failed due to adjacent channel interference from WBFF TV (NTSC) into WBFF-DT. The D/U were outside the range of the receivers used because of significant differences in transmitter height and power levels between DTV and NTSC.

In both Washington/Baltimore and Cleveland, outdoor reception was tested at two different antenna heights: 30 feet and 6 feet. Reception was considered successful if during a period of five minutes there were *five hits* (defined as macro blocking, freeze frame, or no picture for no more than one second) *or less.*

Before discussing the results of these tests, it would be helpful to provide specifics details about the testing.

Initially, it has been proposed to test two modes of DVB-T (8K): the one tested with 64-QAM, a ¾ code rate, a guard interval of 1/16, and a data rate of 19.76 Mbps and a second more robust mode with a stronger error correction code of 2/3, the same guard interval and a data rate of 17.56 Mbps. However, Zenith strongly objected to the testing of COFDM receivers at the lower data rate on the ground that it was unfair to its receivers which could only operate at a fixed bit rate of 19.39 Mbps. Thus to secure Zenith's participation to the field test, it was agreed to only test COFDM at the higher bit rate of 19.76 Mbps.

Some points should also be mentioned about the so-called "COFDM receiver anomaly," which was raised in conjunction with these tests.

After the field data collection was completed, both 8-VSB and COFDM receivers were sent to Zenith labs to assess the impact of COFDM on the American table of DTV allocations. During testing, an unexpected characteristic in the lower ((N-3) and (N-4)) NTSC rejection for the COFDM receiver was discovered. At the measured moderate signal level, the receiver exhibited a lower rejection characteristic. The DTV-into-DTV interference performance of the DVB-T receiver did not exhibit similar characteristics. This has been explained by the receiver manufacturer as being related to the peak automatic gain control (AGC) method used [8]. COFDM receivers were not designed to operate with high-power adjacent NTSC stations. NTSC stations operate at much higher power levels than do DTV stations. Even more problematic was that the higher peak power of the visual carrier compared to the average power of the DTV signal. The COFDM receivers used in the tests had an AGC stage with a range of about 18 dB and a filter designed for 8-MHz systems with a much lower rejection than its ATSC counterpart. Therefore, if an interferer like an adjacent NTSC station triggered the AGC, the wanted signal would be attenuated by 18 dB. This was confirmed by tests at Zenith Labs. This may have affected a number of sites in the case of WRC-DT (Channel 48) since a NTSC station was operating on Channel 45, but the test results as a whole are nonetheless valid.

2.4.2 Test results

For outdoor tests, 185 sites for WRC-DT, WUSA-DT, and WETA-DT, and 83 sites for WBAL-DT have been tested. Using a 30-foot receiving antenna, the 8-VSB signal was successfully received at a greater percentage of the sites than was COFDM for *all four* UHF stations (overall success of 75% for 8-VSB vs. 48% for COFDM). However, low signal strength was the cause of failure in 55% of the failed sites for COFDM and 40 % for 8-VSB. Farther away from the transmitter, up to 55 miles (88.5 km) 8-VSB outperformed COFDM because of the lower C/N required.

With a 6-foot high receiving antenna, COFDM was received at a greater percentage of sites than 8-VSB for *all four* UHF stations for sites close to the transmitters (grids and clusters) (overall success rate of 42% for COFDM vs. 36% for 8-VSB). At greater distances from the transmitter (arcs), the performance was very close between the two systems. However, the fact that the signal from either system could be received at less than 50% of the sites was very disappointing.

During these field tests (in the Washington/Baltimore area), 44 indoor sites were also visited. Both a single bowtie and a log-periodic antenna ("Silver Sensor") were used. The results showed almost similar performance for both systems, and the reception was successful only at about 30 % of the sites. For both the bowtie and the log-periodic antennas, 8-VSB held a slight advantage indoors for signals from three of the four stations whereas COFDM held a slight advantage for signals from the fourth (WUSA-DT). Once more, the indoor test results were disappointing for both systems.

Table 10 shows the percentage of successful sites for indoor and outdoor (30 and 6 feet) reception for different stations in Washington/Baltimore tests.

Antenna Height	System	WBAL-DT	WRC-DT	WUSA-DT	WETA-DT
30 ft	8-VSB	72 %	79 %	85 %	60 %
30 ft	COFDM	51 %	52 %	62 %	29 %
6 ft	8-VSB	33 %	37 %	47 %	24 %
6 ft	COFDM	39 %	42 %	55 %	29 %
Indoors (Silver Sensor)	8-VSB	15 %	33 %	42 %	41 %
Indoors (Silver Sensor)	COFDM	7 %	31 %	44 %	32 %

Table 10. Reception statistics by station in the Washington/Baltimore area.

Table 11 shows the overall success rate for Washington/Baltimore tests. Note that the number of sites is actually the sum of DTV measurements in all sites from different stations. For example, if the signal from three stations were measured in one site, it was considered as three sites.

Antenna	Number of sites	COFDM	8-VSB
Outdoor (30 ft)	638 (1)	48 %	75%
Outdoor (6 ft)	638 (1)	36 %	42 %
Indoor (Silver Sensor)	176 (44x4)(2)	28 %	32 %
Indoor (Bowtie)	176 (44x4)(2)	27 %	30 %

(1) There were 185 sites for WRC-DT, WUSA-DT, WETA-DT, and 83 sites for WBAL-DT.

(2) The signals from four DTV stations were tested at 44 indoor sites.

Table 11. Overall success rate for DTV reception for all stations in the Washington/Baltimore tests.

During the Cleveland tests, a total of 98 outdoor and 22 indoor sites have been tested. The MegaWave indoor antenna has been used. Table 12 shows the overall success rate for the Cleveland DTV tests. Note that in all cases 8-VSB had a higher overall rate of success as compared with COFDM.

Antenna	Number of sites	COFDM	8-VSB
Outdoor (30 ft)	98	60 %	73 %
Outdoor (6 ft)	98	14 %	28 %
Indoor (MegaWave)	22	17 %	26 %

Table 12. DTV reception rates according to receiving conditions during tests in Cleveland.

Analysis by distance showed that during the Cleveland tests for outdoor reception with a 30-foot antenna, closer to the transmitter, COFDM outperformed 8-VSB by showing a higher percentage of successful reception but at farther distances, the situation was reversed. It should be noted that the Washington/Baltimore tests also gave the same results and the same analysis showed an overall higher success rate for COFDM at closer distances and a higher success rate for 8-VSB at farther distances from the transmitter.

Using a 6-foot outdoor antenna, the Cleveland tests results were in favor of 8-VSB at all distances from the transmitter. However in Washington/Baltimore tests, again COFDM had a greater percentage of success closer to, and 8-VSB had greater rate of success farther from the transmitter.

In order to compare reception of the two digital systems with NTSC during the Cleveland tests, the total number of sites with a specific ITU-R rating (or better) of the picture quality of NTSC was considered and among those sites, the percentage of successful sites for each DTV system was found. Table 13 shows the success rate for the two DTV systems for the sites having NTSC ITU-R rating of 3 or better, 2 or better, and 1.5 or better. As an ITU-R grade of 3 (or 2 or 1.5) could usually be achieved at farther distances from the transmitter, this analysis encompasses farther sites for which the results have already been in favor of 8-VSB.

NTSC(co-located at Channel 3)	COFDM	8-VSB
ITU-R Grade 3 or better	78 %	92 %
ITU-R Grade 2 or better	66 %	80 %
ITU-R Grade 1.5 or better	63 %	77 %

Table 13. Rate of successful reception vs. picture quality of NTSC during the Cleveland tests.

2.4.3 Impulsive noise analysis in the Cleveland area

Since impulsive noise is difficult to capture and measure in the field, its assessment has been made subjectively by making comments on the impulsive noise conditions found in the NTSC pictures during the tests [8].

Table 14 correlates impulsive noise observations with DTV reception problems. Impulse noise was observed on the NTSC Channel 3 picture, on the spectrum analyzer, or the vector signal analyzer at about 40 % of the sites with a 30-foot-high outdoor antenna [8]. As expected, a large number of failed sites were subjected to impulse noise, especially COFDM receivers (79 % of the sites).

COFDM		**8-VSB Reference Receiver**	
Sites with no DTV reception	**Impulsive Noise @ 30 ft on NTSC Channel 3**	**Sites with no DTV Reception**	**Impulsive Noise @ 30 ft on NTSC Channel 3**
Using an outdoor antenna at 30 feet (based on Fig. 25 of [8]):			
39	79 %	26	17 %
Using an outdoor antenna at 6 feet (based on Fig. 26 of [8]):			
84	55 %	71	54 %

Table 14. The effects of impulsive noise during the Cleveland tests (failed sites).

2.4.4 Conclusions from the MSTV/NAB field tests

In total, over 5000 individual measurements were recorded during the MSTV/NAB field trial, making these tests by far the most extensive and comprehensive side-by-side comparison of 8-VSB and COFDM that has been performed anywhere in the world at the time of writing.

COFDM failed more often because of a low C/N in the conditions tested (in a noise-limited coverage area).

With an outdoor antenna at 30 ft, the 8-VSB signal was received at a greater percentage of sites than was COFDM for both the Washington/Baltimore (UHF) and the Cleveland (VHF) tests.

With an outdoor antenna 6 ft high, the COFDM was successfully received at a larger number of sites than 8-VSB in the Washington/Baltimore area. On the other hand, in the Cleveland area, 8-VSB was successfully received at twice as many sites as COFDM at 6 ft. However, the performance of both systems was poor and disappointing.

Generally, 8-VSB performed better farther away from the transmitter and COFDM performed better closer to the transmitter.

The results of these field tests show that both systems are suitable for a broadcast service with an outdoor reception at 30 feet, but concerning outdoor reception at 6 feet and indoor reception, neither is adequate for a practical broadcast service under the conditions used to test the systems.

3. Summary of Field Test Results

In Section 2, a description of the comparative field tests and field test results conducted in Australia, Brazil, Hong Kong, and the United States has been presented. The tests were conducted in very different conditions, using different equipment, different methodologies, and presented different results (Hong Kong and Brazil didn't try to find possible causes of reception failure). In addition, the level of documentation available varied significantly from one campaign to the next, which made the comparison job difficult and sometimes impossible for lack of information.

There are also significant differences in the type of television broadcasting services in individual countries. North American broadcast services normally cover large areas - about an 80-km radius - whereas in Hong-Kong or Brazil, the tests were conducted in much smaller coverage areas, respectively 11-km, and 30-km radius.

Low signal strength was usually at least partially responsible for sites with poor or no reception, often in combination with multipath or impulse noise in the case of VHF.

As expected, 8-VSB has a C/N advantage of about 3 dB over DVB-T. This advantage hasn't always translated into higher reception rate in conditions with severe multipath and when the coverage area is small (10-30 km). COFDM handles multipath better than 8-VSB, however, it is more affected by impulse noise as expected [9].

There were different COFDM systems tested, several 2K and 8K DVB-T implementation and ISDB-T.

The results from Hong-Kong are not really reliable because of the limited number of sites visited and the fact that comparative measurements of the different systems were taken months from each other (introducing unnecessary channel variations). Moreover, these tests results clearly indicate setup and/or methodology problems.

Comprehensive indoor tests results are sorely missing, given the importance of properly characterizing the indoor propagation channel not just for television broadcasting, but also for future data services. This type of test has usually been performed at a limited number of sites, with the exception of those of MSTV who did over 40 sites in the Washington/Baltimore area. Reliable indoor test results were not available for Australia and Brazil.

4. Types of Tests Still Needed

The field tests conducted so far have shown that both 8-VSB and COFDM can provide a reasonably good service with a 10-m high outdoor directional antenna.

There has been insufficient field tests conducted on:

- *indoor and portable reception* as the current implementations of ATSC and DVB-T did not perform well enough to provide a broadcast service in these conditions. To get repeatable and comparable results in these propagation channels, a rigorous test methodology is more than ever essential;
- more robust mode of transmission such as enhanced 8-VSB, 2-VSB and DVB-T (QPSK and 4-QAM);
- comparative ease of reception;
- the use of SFN and gap fillers;
- the impact of impulsive noise on DTV reception (indoors and outdoors) in the VHF *and* UHF[21] bands;
- the impact of pre-echoes on the 8-VSB modulation with state-of-the-art receivers;
- the Japanese ISDB-T system.

Appendix: Dos and Don'ts of Field Tests

Do:

- Describe the methodology used in sufficient details together with the results;
- Document the environment of the field tests;
- Describe the desired service;
- Duplicate the conditions of the desired service as much as possible;
- Describe the necessary compromises;
- Limit the number of variables as much as possible (antenna height, orientation of antenna, season, modes of operation, ...);
- Describe the type of receiver used (at the very least, disclose its generation) and present relevant performance data like laboratory results from random noise and multipath tests;
- Use the latest generation DTV modems available;
- Do enough sites to be statistically representative;
- Clearly define the expected coverage area;
- Check the collected data continuously to ensure consistency;
- Be circumspect of bizarre or unexpected results and investigate further to find possible causes, especially for indoor sites, where impulsive noise from household appliances, etc. or tone interference, dynamic multipath from vehicular traffic or airplanes may come and go without warning;

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[21] As an example, the ubiquitous microwave oven (2.45 GHz) is a source of impulsive noise in the high UHF band.

- Find an appropriate calibration site and make daily visits to check for proper operation of the transmitter and of the receiving equipment;
- Select sites to be as close as possible to typical users' reception conditions;
- Make a deliberate attempt to select sites incorporating a diversity of construction types and locations representative of expected typical users of the service in the respective markets;
- When comparing DTV reception for different systems:
    - It is ***critical** to perform the tests simultaneously* in time to minimize channel variations;
    - Use the exact same site and receiving conditions (antenna position, location, type of antenna, antenna height,...). For example, during indoor tests, take pictures of the actual antenna position in the room;
- Table 2 in Appendix 2 of [6] reveals a valuable time-saving technique: first try a high bit rate mode; if successful reception is possible, then there is no need to try lower bit rate modes because of their lower C/N threshold. On the other hand, if reception fails using a high bit rate mode, it makes sense to try more robust modes;
- List possible limitations of the tests results and the test methodology (what you set out to test and what you do not plan to test and for what reason);
- Identify the possible cause(s) of reception failure whenever possible. A lot of insight can be gained from a careful analysis of failed and/or sensitive sites.

Don't:

- Eliminate sites without explanation;
- Change the test procedure unless mandatory;
- When doing comparative tests, be careful not to inadvertently select sites that favor a system compared to another;
- Try to test too many variables at once.

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