Performance Comparison of ATSC 8-VSB and DVB-T COFDM Transmission Systems for Digital Television Terrestrial Broadcasting

(Invited paper)

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Abstract

This paper compares the performances of ATSC 8-VSB and DVB-T COFDM transmission systems for Digital Television Terrestrial Broadcasting. The comparison is based on the most recent laboratory test results and theoretical analysis.

1. Introduction

After a decade of intense research and development, Digital Television Terrestrial Broadcasting (DTTB) has finally reached the point of implementation stage. DTTB services have been available in North America and Europe, since November 1998. Many countries have announced their choice for a DTTB system and their implementation plan. There are two very different digital modulation techniques used in DTTB systems: the Trellis Coded 8-Level Vestigial Side-Band (8-VSB) modulation system developed by the Advanced Television Systems Committee (ATSC) [1]; and the Coded Orthogonal Frequency Division Multiplexing (COFDM) modulation adopted in the Digital Video Terrestrial Broadcasting (DVB-T) standard [2]. Another DTTB transmission system, also based on COFDM, the Bandwidth Segmented Transmission (BST)-OFDM system for Terrestrial Integrated Service Digital Broadcasting (ISDB-T), has recently been finalized in Japan [24, 25].

Since there are more than one DTTB systems, many countries and administrations are now engaged in the process of selecting a DTTB system. Each country has specific characteristics and needs. The selection of a DTTB system must be based upon how well each of the modulation systems meets specific conditions such as spectrum resource, policy, coverage requirements and network structure, reception conditions, type of service required, objectives for program exchange, cost to the consumers and broadcasters, etc.

This paper compares the performances of the ATSC 8-VSB and the DVB-T COFDM transmission systems under different impairments and operating conditions. First, a general system level comparison is presented. It is followed by the comparison of the most up-to-date laboratory test results and theoretical analysis. The differences in the system threshold definitions are discussed. A calculated fair performance comparison of 8-VSB and COFDM is provided. The 6, 7 and 8 MHz version of systems should exhibit the same performance, since identical modulation and channel coding schemes are used. In addition, a brief performance and implementation analysis is also presented for the two modulation systems under different network infrastructures. Whenever possible, the impact on the broadcasters or consumers are discussed. Possible performance improvements are indicated.

It should be pointed out that both systems are working systems and are already providing viable DTV services. However, the performance benchmarks quoted in this paper only indicate current technologies. Meanwhile, the tests have been conducted in different laboratories, under different test environments and using receivers from different manufacturers over more than one generation of products. Some minor differences are likely to appear. On the other hand, with the technical advances, both systems will achieve some performance improvements [27].

2. General System Comparison

Generally speaking, each system has its own unique advantages and disadvantages. The ATSC 8-VSB system is more robust in an Additive White Gaussian Noise (AWGN) channel, has a higher spectrum efficiency, a lower peak-to-average power ratio, and is more robust to impulse noise and phase noise. It also has comparable performance to DVB-T on low level ghost ensembles and analog TV interference into DTV. Therefore, the ATSC 8-VSB system could be more advantageous for Multi-Frequency Network (MFN) implementation and for providing HDTV service within a 6 MHz channel.

The DVB-T COFDM system has performance advantages with respect to high level (up to 0 dB), long delay static and dynamic multipath distortion. It could be advantageous for services requiring large scale Single Frequency Network (SFN) (8k mode) or mobile reception (2k mode).

However, it should be pointed out that large scale SFN, mobile reception and HDTV service cannot be achieved concurrently with any existing DTTB system over any channel spacing, whether 6, 7 or 8 MHz. Specific system parameters must be selected for each particular implementation.

3. System Performance Comparison

3.1 DTTB signal peak to average power ratios

The COFDM signal can be statistically modeled as a two-dimensional Gaussian process [3]. Its Peak to Average power Ratio (PAR) is somewhat independent of the filtering. On the other hand, the 8-VSB PAR is largely set by the roll-off factor of the spectrum shaping filter, i.e., 11.5% for the ATSC 8-VSB signal. Studies show that the DVB-T signal PAR (signal for 99.99% of the time) is about 2.5 dB higher than the ATSC [3-5].

For the same level of adjacent channel spill-over, which is the major source of adjacent channel interference, the DVB-T system requires a larger transmitter (2.5 dB or 1.8 times power) to accommodate the 2.5 dB additional output power back-off, or a better channel filter with additional side-lobe attenuation. However, the high PAR has no impact on system performance. It just adds some start-up cost for the broadcasters.

3.2 C/N thresholds

Theoretically, from a modulation point of view, OFDM and single carrier modulation schemes, such as VSB and QAM, should have the same C/N threshold over Additive White Gaussian Channel (AWGN). It is the channel coding, channel estimation and equalization schemes, as well as other implementation margins (phase noise, quantization noise, inter-modulation products), that result in different C/N thresholds.

Both DVB-T and ATSC system used concatenated forward error correction and interleaving. The DVB-T outer code is a R-S(204, 188, t = 8) with 12 R-S block interleaving. The R-S(204,188) code, which is shortened from R-S(255, 239) code, can correct 8-byte transmission errors and is consistent with the DVB-S (satellite) and DVB-C (cable) standards for commonality and easy inter-connectivity.

The ATSC system implemented a more powerful R-S (207,187, t = 10) code, which can correct 10-byte errors, and used a much larger 52 R-S block interleaver to mitigate impulse and co-channel NTSC interference. The differences of R-S code implementations result in about 0.5 dB C/N performance benefit for the ATSC system. Meanwhile, the ATSC system implements a R = 2/3 trellis coded modulation (TCM) as the inner code, while the DVB-T system uses a sub-optimal punctured convolutional code (same as the one used in the DVB-S standard for commonality). There is up to 1 dB coding advantage in favor of the ATSC system. Therefore, the implementation difference in forward error correction gives the ATSC system a C/N advantage of about 1.5 dB. This 1.5 dB difference is unlikely to be reduced with the technical advances or system improvements.

The Grand Alliance prototype receiver implemented a Decision Feedback Equalizer (DFE). The DFE causes very small noise enhancement, but it also results in a very sharp Bit Error Rate (BER) threshold, because of the error feedback. On the other hand, the DVB-T will suffer a C/N degradation of about 2 dB as the system is utilizing in-band pilots for fast channel estimation and, until now, implementing one-tap linear equalizers. [6, 7]. The aggregate C/N performance difference, based on today's technology, is about 3.5 dB in favor of the ATSC system over AWGN channel [5, 8, 9].

From the transmitter implementation point of view, a DVB-T transmitter has to be 6 dB (3.5 dB C/N difference plus 2.5 dB PAR), or 4 times, more powerful than an ATSC transmitter to achieve the same coverage and the same unwanted adjacent interference limit. However, it should be pointed out that the AWGN channel C/N performance is only one benchmark for a transmission system. It is an important performance indicator, but it might not represent a real-world channel model. Meanwhile, the equalization and Automatic Gain Control (AGC) systems designed to perform well on a AWGN channel might be slow to respond to moving echoes or signal variations. The additional 2 dB implementation margin now found in the DVB-T system can be reduced in the future.

In Europe, the Ricean channel model is used in the DTTB spectrum planning process [7, 21]. The computer simulation results show that the C/N threshold differences for Gaussian channel and Ricean channel (direct path to multipath power ratio K = 10 dB) is about 0.5 to 1 dB, depending on the modulation and channel coding used [2]. The actual C/N threshold values recommenced for the planning process factored in 2 dB noise degradation caused by channel estimation/equalization and receiver noise floor [7].

However, the C/N difference between a Gaussian channel and a Ricean channel, i.e., 0.5 to 1 dB, is preserved.

The frequency planning for the ATSC system has been done with different approaches. In the US, the FCC uses a Gaussian channel performance [5]. In Canada, a generous 1.3 dB C/N margin is allocated for multipath distortion (direct path to multipath power ratio K = 7.6 dB), which is much like the European approach [15].

Table 1 presents the C/N thresholds (AWGN channel) for the two DTTB systems based on computer simulations [1,2] (DVB-T system simulation assumed 100% channel state information) and the most recent laboratory RF back-to-back test results available [5, 7, 9, 26]. Usually, there is a difference of about 0.2 to 0.5 dB between the tests conducted in the high UHF band and the ones done in the VHF bands. The performance also depends on the RF tuner used in the receiver. A single conversion tuner will result in better performance than a double conversion tuner, but the adjacent channel interference performance will be compromised. Varying RF signal levels can also result in C/N threshold differences [5].

The DVB-T system threshold was defined as a Bit Error Rate (BER) of 2E-4 before the R-S decoding [2]. After R-S decoding, it corresponds to a BER of about 1E-11, or Quasi Error Free (QEF) reception, which is equivalent to one error hit every few hours. This threshold definition is often used for data transmission.

The ATSC threshold was actually derived subjectively from the video picture Threshold Of Visibility (TOV), assuming certain video error concealment or resilient techniques are implemented in the receiver. The corresponding objective measurement was defined at BER = 3E-6, or Segment Error Rate (SER) = 2E-4, after the R-S decoding. This SER translates into an 8-VSB symbol error rate after equalizer (before trellis decoding) of 0.2. It also indicates a byte error rate of about 1.4E-2 after the trellis decoding [10]. It can be seen that the ATSC threshold is defined much lower than that of the DVB-T. A correction factor should be added to the ATSC threshold for a fair comparison. However, measurement on different receivers may result in different values depending on their implementation. For a AWGN channel, the correction factor should be around 0.8 dB [19], when a Decision Feedback Equalizer is used.

Table 1: C/N thresholds based on test results

C/N (AWGN)	Theoretical	RF test
ATSC	14.8 dB	15.2 dB
DVB-T	16.5 dB	19.2 dB

Table 2: System E_b/N_o thresholds

E_b/N_o (AWGN)	**Theoretical**	**RF test**
ATSC 6/7/8 MHz R = 2/3 R_b = 19.4/21.6/27.5 Mbps	10.6 dB	11.0 dB
DVB-T 6/7/8 MHz R=2/3, GI=1/16 R_b = 17.4/20.5/23.4 Mbps	11.9 dB	14.6 dB
DVB-T 6/7/8 MHz R=3/4, GI=1/16 R_b = 19.6/23.1/26.4 Mbps	12.9 dB	15.6 dB (estimated)

3.3 Fair comparison of the system C/N performances

It should be pointed out that the threshold values presented in Table 1 are not a fair comparison, because the systems have different data rates, and their thresholds are also defined differently.

One alternative is to use the E_b/N_o, or carrier to noise ratio per bit to evaluate the system performance, as it takes account of the system data rate.

$$E_b/N_o \text{ (dB)} = C/N - 10 \log (R_b / BW) \qquad (1)$$

where R_b is the coded system data throughput and BW is the system bandwidth. For the 6 MHz ATSC system, the data rate is R_b = 19.4 Mbps [1]. The comparable DVB-T 6 MHz system, with R = 2/3 coding and 1/16 guard interval (assuming 2k mode and GI = 1/16 for a comparable equalization range with the ATSC system), R_b = 17.4 Mbps [2]. For the DVB-T system using same coding but different guard interval length, the system C/N should be the same, while E_b/N_o will be different, due to the different data throughput.

Based upon the above discussions, factor in the data rate and threshold definition differences, the calculated system E_b/N_o thresholds are presented in Table 2. From the RF back-to-back test data, the ATSC system presently has a 3.6 dB advantage for AWGN channel. Again, it should be mentioned that improvements are possible for both systems and AWGN channel might not be the best channel model for DTTB. It should also be noticed that a 2 dB margin should be added to the DVB-T theoretical (simulation) results to account for the channel estimation/equalization system implementation margin [7, 25].

Since both DVB-T and ATSC systems can be scaled for different channel spacing, i.e., 6, 7 and 8 MHz, without changing the channel coding scheme, the system E_b/N_o values presented in Table 2 are generally valid for 6, 7 and 8 MHz systems.

3.4 Multipath distortion

The COFDM system has a strong immunity against multipath distortion. It can withstand echoes of up to 0 dB. The implementation of a guard interval can eliminate the inter-symbol interference, but the in-band fading will still exists. A strong inner error correction code and a good channel estimation system are mandatory for a DVB-T system to withstand 0 dB echoes. With the R = 2/3 convolutional coding, it needs about 7 dB more signal power to deal with the 0 dB echoes [4, 8]. Soft decision decoding using an eraser technique can significantly improve the performance [11]. For static echoes with levels less than 4 to 6 dB, the 8-VSB system, using a Decision Feedback Equalizer (DFE), yields a smaller noise enhancement [9].

The DVB-T system guard interval can be used to deal with both advanced or delayed multipath distortions. This is important for SFN operation. The ATSC system can not handle long advanced echoes, as it was designed for a MFN environment where they almost never happen.

The DVB-T 2k system can withstand moving echoes up to several hundred Hz, while the ATSC system can withstand only up to a dozen Hz [5, 9, 26]. Therefore, the DVB-T 2k system is preferred for mobile applications.

3.5 Mobile reception

COFDM can be used for mobile reception, but lower-order modulation on OFDM sub-carriers and a lower rate of convolutional coding (e.g., R =1/2 [23]) have to be used for reliable reception. Therefore, there is a significant penalty in data throughput for mobile reception in comparison to fixed reception. Usually, QPSK or 16QAM with R = 1/2 would be used for mobile reception providing data rates of up to 6 or 12 Mbps, respectively [26].

It is nearly impossible to achieve the 19 Mbps data capacity required for one HDTV program and associated multi-channel audio and data services in a mobile environment. Meanwhile, in the high UHF band, assuming a receiving terminal travelling at 120 km/hr, the OFDM sub-carrier spacing should be larger than 2 kHz to accommodate the Doppler effects. This indicates that only DVB-T 2k mode is viable for mobile reception. However, the 2k mode was not intended to support large scale SFN. If QPSK is used on OFDM sub-carriers, the data rate is 4.98 Mbps (BW = 8 MHz, R = 1/2, GI = 1/4) [2]. Using 16QAM modulation, the data rate is 9.95 Mbps (BW = 8 MHz, R = 1/2, GI = 1/4). With higher order of modulation, the system will be sensitive to the fading and Doppler effects, which, in turn, will require more transmission power.

In the case of mobile reception under SFN environment, since the mobile receiving terminal relative speed to different transmitters are often different, these will result in strong Doppler effects which have to be dealt with by channel estimation and error correction system. Non-punctured convolutional inner code, R = 1/2, are recommended for mobile implementation.

One potential problem to offer mobile service is the spectrum availability. Since mobile reception requires different modulation and channel coding than the fixed services, it will likely have to be offered in other channels than the fixed reception DTV/HDTV services, which usually opt for maximum data throughput. Many countries have difficulties to allocate one fixed service DTV channel to every existing analog TV broadcasters. Finding additional spectrum for mobile service might be difficult. Meanwhile, since mobile service is mostly intended to deliver audio, data and low-resolution video services to car drivers or passengers on bus and train, it is in direct competition with Digital Audio Broadcasting (DAB) and the third generation Personal Communications System (PCS) services. It might also need approval of the proper regulatory authorities.

3.6 Spectrum efficiency

OFDM, as a modulation scheme, is slightly more spectrum efficient than single carrier modulation systems, since its spectrum can have a very fast initial roll-off even without an output spectrum-shaping filter. For a 6 MHz channel, the useful (3 dB) bandwidth is as high as 5.65 MHz (or 5.65/6 = 94%) [2] in comparison with the 5.38 MHz (or 5.38/6 = 90%) useful bandwidth of the ATSC system [1]. OFDM modulation has, therefore, a 4% advantage in spectrum efficiency.

However, the guard interval that is needed to mitigate the strong multipath distortions and the in-band pilots inserted for fast channel estimation significantly reduce the data capacity for the DVB-T system. For example, the DVB-T offers a selection of system guard intervals, i.e., 1/4, 1/8, 1/16 and 1/32 of the active symbol duration. These are correspond to data capacity reductions of 20%, 11%, 6% and 3%, respectively. The 1/12 in-band pilot insertion will result in a 8% loss of data rate. Overall, the data throughput reductions are up to 28%, 19%, 14% and 11% for the different guard intervals. Subtracting the previous 4% bandwidth efficiency advantage for the OFDM system, the total data capacity reductions for the DVB-T system, in comparison with the ATSC system, are 24%, 19%, 10% and 7%, respectively. This means that, assuming equivalent channel coding scheme for both systems, the DVB-T system will suffer a 1.4, 1.9, 3.7 or 4.7 Mbps data capacity reduction for a 6MHz system. The corresponding data rates are 14.8, 16.4, 17.4 and 17.9 Mbps respectively [2]. This apparently wasted capacity in the pilots and guard interval is used to provide DVB-T with better performance in static and dynamic multipath environments.

The above spectrum efficiency analysis is based on a MSN approach. In SFN environment, it is possible to use one frequency (channel) to cover a large geographical area, which might result in overall saving of spectrum for DVB-T system.

3.7 HDTV capability

Research on digital video compression showed that, based on current technology, a data rate of at least 18 Mbps is required to provide a satisfactory HDTV picture for sports and fast action programming [20]. Additional data capacity is required to accommodate multi-channel audio and ancillary data services.

Based on the DVB-T standard, with equivalent channel coding scheme as the ATSC 8-VSB system (R = 2/3 punctured convolutional code, or ITU-mode M3 [7, 21]), the 6 MHz DVB-T system data throughput is between 14.7 Mbps and 17.90 Mbps, depending on the guard interval selection. Therefore, it is difficult for the DVB-T system to provide HDTV service within a 6 MHz channel, unless a weaker error correction coding is selected. For example, by increasing the convolutional coding rate to R = 3/4 and selecting GI = 1/16, the data rate becomes 19.6 Mbps, which is comparable with the ATSC system data rate of 19.4 Mbps. However, this approach will require at least 1.5 dB additional signal power [2]. Estimated system performance is listed in Table 2. Increasing the coding rate will also compromise the performance against the multipath distortions, especially for indoor reception and SFN environments.

Other techniques are available for decoding the COFDM signal without using the in-band pilots [12, 13], which could significantly improve the spectrum efficiency. Unfortunately, those techniques were not fully developed when the DVB-T standard was finalized.

3.8 Interference into existing analog TV services

The current 4 dB C/N difference in planning parameters (see Table 3) requires the DVB-T system to transmit 2.5 times more power for the same service area. However, the higher power consumption is not really a major concern for DTV implementation. In many countries, the government policy requires analog TV and DTV to co-exist for a prolonged period of time and no additional spectrum resources are available for DTV implementation. DTV can only occupy unused allotments and taboo channels. It is expected that one of the key limiting factors will be the DTV interference into the existing analog TV services during the analog TV-to-DTV transition period. The higher transmission power requirement of the DVB-T system would make the planning more difficult and cause additional interference. Extra measure must be taken to increase the co-channel spacing, or reduce the DTV transmission power (or coverage).

3.9 Single Frequency Network (SFN)

The 8k mode DVB-T system was designed for large scale (nation-wide or region-wide) SFN, where a cluster of transmitters are used to cover a designated service area. It uses a small carrier spacing, which can support very long (up to 224 µs) guard intervals. It can also sustain 0 dB multipath distortion, if a strong convolutional code is selected (R < 3/4). However, at least 7 dB more signal power is required to deal with the 0 dB multipath distortion [4, 8]. This extra power requirement is in addition to the 6 dB transmitter headroom mentioned previously. One alternative to reduce the excess transmission power is to use a directional receiving antenna, which would likely eliminate 0 dB multipath distortion. Such an antenna will also improve the reception of ATSC 8-VSB signals.

Another problem that might impact a large-scale SFN implementation is co-channel and adjacent channel interference. In many countries, it might be difficult to allocate a DTV channel for large-scale SFN operation that will not generate substantial interference into existing analog TV services during the analog TV to DTV transition period. Finding additional tower sites at desired locations and the associated expenses (such as property, equipment, legal, construction, operation, and environmental studies) might not be practical or economically viable.

On the other hand, the SFN approach can provide stronger field strength throughout the core coverage area and can significantly improve the service availability. The receivers have more than one transmitters to access (diversity gain). They have better chance to have a line-of-sight path to a transmitter.

By optimizing the transmitter density, tower height and location, as well as the transmission power, SFN might yield better coverage and spectrum economy, while maintaining satisfactory level of interference to and from neighboring networks [22].

The ATSC system was not specifically designed for SFN implementation. Limited on-channel repeater and gap filler operation is possible, if enough isolation between the pick-up of the off-air signal and its retransmission can be achieved [14]. An another option is a full digital on-channel, where signal is demodulated, decoded, and re-modulated. The transmission error in the first hop can be corrected and the system does not need a high level of isolation between pick-up and retransmission antennas.

The key difference between a DTV and an analog TV system is that the DTV can withstand at least 20 dB of co-channel interference, while the analog TV co-channel threshold of visibility is around 50 dB. In other words, DTV is up to 30 dB more robust than analog TV, which provides more flexibility for the repeater design and planning. For an ATSC system repeater implementation [14], using a directional receiving antenna will increase the location availability as well as reduce the impact of fast moving or long delay multipath distortions. The operational parameters will depend on the population distribution, terrain environment and intended coverage area.

It should be pointed out that under any circumstances, for a RF transmission system (ATSC or DVB-T, SFN or MFN), 100% location availability is not achievable.

3.10 Impulse noise

Theoretically, OFDM modulation should be more robust to time-domain impulse interference, because the FFT process in the receiver can average out the short duration impulses. However, as mentioned previously, the channel coding and interleaver implementation also play an important role. The stronger R-S(207,187) code with 52-segment interleaver makes the ATSC system more immune to the impulse interference than the DVB-T using R-S(204,188) code with 12-segment interleaver [9]. For the inner code, the shorter constraint length of 2 for ATSC (7 for DVB-T) also results in shorter error bursts, which are easier to correct by the outer code.

The impulse noise interference usually occurs in the VHF and low UHF bands, and is caused by industrial equipment and home appliances, such as microwave ovens, fluorescent lights, hair-dryers and vacuum cleaners. High voltage power transmission lines, which often generate arcing and corona, is also an impulse noise source. The robustness of the carrier recovery and synchronization circuits against impulse noise can also limit the system performance.

3.11 Tone interference

Since a COFDM system is a frequency domain technique, which implements a large amount of sub-carriers for data transmission, a single tone or narrow band interference will destroy a few sub-carriers, but the lost data can be easily corrected by the error correction code. On the other hand, tone interference will cause eye closing for the 8-VSB modulation. The adaptive equalizer could reduce the impact of the tone interference, but, in general, the DVB-T system should outperform the ATSC system on tone interference by a large margin (> 10 dB) [4, 9]. However, tone interference is just another performance benchmark. In the real world, a DTTB system shall never experience a tone interference dominated environment as a well engineered spectrum allocation plan is made to avoid that problem. Co-channel analog TV interference is a special "tone interference-like" case. It will be addressed in the next section.

3.12 Co-channel analog TV interference

As mentioned in the last paragraph, co-channel analog TV interference will destroy a limited number of COFDM sub-carriers on specific portions of the DTTB band. A good channel estimation system combined with soft decision decoding using eraser technique should result in good performance against the analog TV interference. The ATSC system used a much different approach. A carefully designed comb-filter is implemented to notch out the analog TV's video, audio and color sub-carriers to improve the system performance.

Both systems have similar performance benchmarks. It should be pointed out that the comb-filter was turned off in Australia's comparative test [9], where a 7 MHz analog TV interference signal was used to test a 6 MHz ATSC system. In the DTV spectrum planning process [15], the co-channel analog TV interference was not identified as the most critical factor. The DTV interference into the existing analog TV services is a more serious concern.

3.13 Co-channel DTV interference

Both DTV signals behave like an additive white Gaussian noise. Therefore, the co-channel DTV interference performance should be highly correlated with the C/N performance, which is largely dependent upon the channel coding and modulation used. There is about 3 to 4 dB advantage for the ATSC system, see Table 3, as it benefits from its better forward error correction system. Good co-channel DTV C/I performance will result in less interference into the existing analog TV services. It will also mean better spectrum efficiency once the analog services are phased out.

3.14 Phase noise performance

Theoretically, the OFDM modulation is more sensitive to the tuner phase noise. The phase noise impact can be modeled into two components [16, 17]: (1) a common rotation component that causes a phase rotation of all OFDM sub-carriers; (2) a dispersive component, or inter-carrier interference component, that results in noise-like defocusing of sub-carrier constellation points. The first component can easily be tracked by using in-band pilots as references. However, the second component is difficult to compensate. It will slightly degrade the DVB-T system noise threshold.

For a single carrier modulation system, such as 8-VSB, the phase noise generally causes constellation rotation that can mostly be tracked by phase lock loop. A tuner with a better phase noise performance might be needed for the DVB-T system [18]. Using single conversion tuner or double conversion tuner will also cause performance differences. Single conversion tuners have less phase noise, but are less tolerant to adjacent channel interference. A tuner that covers both VHF and UHF bands will be slightly worse than a single band tuner.

3.15 Noise figure

Generally speaking, noise figure is a receiver implementation issue. It is system independent. A low noise figure receiver front end can be used for ATSC or DVB-T system to reduce the minimum signal level required. The critical parameter for planning purpose is sensitivity, which accounts not only for the noise figure, but also the susceptibility of the system to effects such as self-interference and inter-modulation products.

A single conversion tuner has low noise figure and low phase noise, but its noise figure is inconsistent over different TV channels. Some channels have better noise figure than others. Single conversion tuners provide less suppression on adjacent channel interference. They are also inconsistent over different channels. On the other hand, a double conversion tuner has a higher noise figure and higher phase noise. It can achieve better adjacent channel suppression. Its noise figure and adjacent channel suppression are also very consistent over different frequencies.

Tuner performance is very much linked to the cost (materials, components, frequency range, etc.). With today's technology, for low cost consumer grade tuners, the single conversion tuner noise figure is about 7 dB. The double conversion tuner is around 9 dB. Tuner noise figure only impacts the system performance at the fringe of the coverage, where signal strength is very low and there is no co-channel interference present. This situation might only represent a very small percentage of the intended coverage areas, since most of the coverage is interference limited. However, some countries do regulate receiver noise figure.

3.16 Indoor reception

The DTTB system indoor reception needs more investigation. There is no published large scale field trial data to support a meaningful system comparison. In general, indoor signals suffer from strong multipath distortion, due to reflections between indoor walls, as well as from outdoor structures. The movement of human bodies and even pets can significantly alter the distribution of indoor signals, which causes moving echoes and field strength variation.

The indoor signal strength and its distribution are related to many factors, such as building structure (concrete, brick, wood), siding material (aluminum, plastic, wood), insulation material (with or without metal coating), and window material (tinted glass, multi-layer glass).

Measurements on indoor set-top antennas showed that gain and directivity depend very much on frequency and location [21]. For "rabbit ear" antennas, the measurement gain varied from about -10 to -4 dB. For five-element logarithmic antennas, the gains are -15 to +3 dB [21]. Meanwhile, indoor environment often experiences high level of impulse noise interference from power line and home appliances.

3.17 Systems scaled for different channel bandwidths

The DVB-T system was originally designed for 7 and 8 MHz channels. By changing the system clock rate, the signal bandwidth can be adjusted to fit 6, 7 and 8 MHz channels. The corresponding hardware differences are the channel filter, IF unit, and system clock. On the other hand, the ATSC system was designed for a 6 MHz channel. The 7/8 MHz systems can also be achieved by changing the system clock, as for the DVB-T case. However, the ATSC system implemented a comb-filter to limit the co-channel NTSC interference. The comb-filter might need to be changed to deal with different analog TV systems that it will encounter. The use of comb-filter is not mandatory and might not be needed, if co-channel analog TV interference is not a major concern. For instance, some countries might implement DTV on dedicated DTV channels where there is no analog co-channel interference.

Generally speaking, a narrower channel results in a lower data rate for both modulation systems, due to slower symbol rate. However, it also means longer guard interval for DVB-T system and longer echo correction capability for the ATSC system. One minor weak point for the 6 MHz DVB-T 8k system is that its narrow sub-carrier spacing (about 829 Hz) might cause the system to be more sensitive to the phase noise.

4. DTV Implementation Parameters

Countries that adopts the same DTTB system could still use different implementation plans, emission masks and technical parameters in their spectrum allotment process, depending on their spectrum resources and policy, population distribution, service quality, etc.

For example, Canada adopted the ATSC DTTB system, but different DTV implementing technical parameters and emission masks [15] than the USA. Table 3 lists the Canadian [15], the American [5] and the European [7, 21] DTV technical parameters, or protection ratios, used in DTV planning. In the Canadian plan, a generous 1.3 dB C/N margin has been allocated for multipath distortion, which is similar to the EBU approach that uses a Ricean channel performance threshold as planning parameter [7]. Since noise and co-channel DTV interference are additive, a total C/(N+I) = 16.5 dB was allocated as the system threshold (in Table 3, $C/N = C/I_{co\text{-}ch\ DTV}$ = 19.5 dB, $C/(N+I) = C/N + C/I_{co\text{-}ch\ DTV}$ = 16.5 dB). Also in Table 3, the Canadian co-channel NTSC to DTV interference threshold of 7.2 dB is used. It allows the system to withstand, at the same time, a C/N or co-channel DTV interference of 19.5 dB. The adjacent channel DTV interference parameters are generally the same as the American ones, as shown in Table 3.

It should be pointed out that the protection ratios for DTV interference into analog TV system depend on many factors, such as the analog TV standards (NTSC, PAL and SECAM) and the system bandwidths (6, 7 and 8 MHz), as well as the subjective evaluation methods (CCIR Grade 3, Threshold of Visibility, continuous or tropospheric interference).

5. Conclusions

The final choice of a DTV modulation system is based on how well the two systems can meet the particular requirements or priorities of each country, as well as other non-technical (but critical) factors, such as geographical, economical and political connections with surrounding countries and regions. Each country needs to clearly establish their needs, then investigates the available information on the performances of different systems to make the best choice. It is hoped that the information provided in this paper could be helpful in reaching that goal.

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System Parameters (protection ratios)	**Canada** [15]	**USA** [5]	**EBU** [7, 21] ITU-mode M3
C/N for AWGN Channel	+19.5 dB (16.5 dB*)	+15.19 dB	+19.3 dB
Co-Channel DTV into Analog TV	+33.8 dB	+34.44 dB	+34 ~ 37 dB
Co-Channel Analog TV into DTV	+7.2 dB	+1.81 dB	+4 dB
Co-Channel DTV into DTV	+19.5 dB (16.5 dB*)	+15.27 dB	+19 dB
Lower Adj. Ch. DTV into Analog TV	-16 dB	-17.43 dB	-5 ~ -11 dB
Upper Adj. Ch. DTV into Analog TV	-12 dB	-11.95 dB	-1 ~ -10 dB
Lower Adj. Ch. Analog TV into DTV	-48 dB	-47.33 dB	-34 ~ -37 dB
Upper Adj. Ch. Analog TV into DTV	-49 dB	-48.71 dB	-38 ~ -36 dB
Lower Adj. Ch. DTV into DTV	-27 dB	-28 dB	N/A
Upper Adj. Ch. DTV into DTV	-27 dB	-26 dB	N/A

*: The Canadian parameter, C/(N+I) of noise plus co-channel DTV interference should be 16.5 dB

Table 3: DTV protection ratios for frequency planning.

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