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ASSOCIATION FOR **MAXIMUM SERVICE TELEVISION, INC.** MSTV

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Re: Written *Ex Parte* Presentation: MM Docket No. 00-39 (Review of the Commission's Rules and Policies Affecting the Conversion to Digital Television)

Dear Ms. Salas:

Pursuant to Section 1.1206 (b)(1) of the Commission's rules, The Association for Maximum Service Television, Inc. (MSTV) hereby submits the attached report entitled "*Assessment of the Impact of DTV on the Cost of Consumer Television Receivers*" to be included as part of the record in MM Docket No. 00-39. The study was conducted by Arthur D. Little, Inc. for the Association for Maximum Service Television, Inc. and the National Association of Broadcasters.

Yours truly,

Victor Tawil

Cc: Michael Powell, Chairman, FCC
Kathleen Abernathy, Commissioner, FCC
Michael Copps, Commissioner, FCC
Kevin Martin, Commissioner, FCC
Kenneth Ferree, Bureau Chief, Cable Services Bureau, FCC
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Robert Pepper, Chief, Office of Plans and Policy, FCC

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Arthur D Little

Assessment of the Impact of DTV on the Cost of Consumer Television Receivers

Final Report to:

Maximum Service Television (MSTV) and National Association of Broadcasters (NAB)

September 10, 2001

Arthur D. Little, Inc.
Cambridge, Massachusetts
02140-2390 U.S.A.

Reference 74003

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1 Executive Summary

1.1 Introduction

Arthur D. Little, Inc. (ADL) was commissioned by the Association for Maximum Service Television, Inc. (MSTV) and the National Association of Broadcasters (NAB) [MSTV, NAB] to develop cost estimates and estimates of the cost decline overtime for the incremental direct material required to enable consumer electronics television (TV) sets to receive over the air ATSC digital TV transmissions. This report also estimates the effect of these incremental costs on the retail prices for DTV sets. Also included are estimates of costs and retail prices for stand-alone set-top box "transverters" that can transcode ATSC transmissions to NTSC compatible signals, allowing existing analog TVs to receive ATSC signals.

1.2 Scope and Methodology

This project applies standard engineering and business analysis methods to publicly available information and the non-proprietary knowledge base of ADL staff, NAB staff, and MSTV staff. Additionally, interviews have been conducted with selected industry participants having knowledge or opinions that are relevant to this analysis, to supplement available information and validate key assumptions.

Three distinct market adoption scenarios for DTV receiver implementation were developed, which are explained in Section 1.3. For each scenario, estimates were made for overall sales and incremental material costs. The rate of market adoption and reduction in cost due to production volume were factored and used to predict the incremental cost of adding a DTV receiver to a new TV set at the time of manufacturing. Both manufacturing cost and retail price of the integrated DTV set is estimated.

To project the rate of adoption of integrated DTV receivers, Bass diffusion approach was utilized. The Bass approach is a widely applied and accepted model for the adoption (diffusion) of new products and technology by consumers.

The cost reduction of related semiconductors, which are a major cost factor in the DTV receiver, was estimated over time by applying the effects of a manufacturing "Learning Curve". The latter is based on industry historical experience in which prices decline with increasing, cumulative production volume.

Finally, the effects of a "Forward Pricing" policy [Japan High Tech Review, 1990] are examined in a sensitivity analysis. Forward pricing is a new-product introduction strategy commonly employed in the semiconductor industry.

These methodologies will be described in greater detail in Section 5 of this report, "Cost Analysis".

In performing this analysis, we have made a number of key assumptions regarding the market and regulations. Section 4.2 provides more details on the "Key Assumptions".

1.3 Study Scenarios

Three DTV adoption scenarios have been defined for this study. Although the proposed FCC actions have not been finalized, it is believed that these options are within the range of possibilities currently under consideration.

- ***Baseline Scenario:*** This scenario assumes that Digital TV adoption is driven solely by natural market forces whereby a consumers' purchase decision is based entirely on the benefits of a DTV receiver relative to the additional cost;

- ***Mandate Scenario:*** This scenario assumes that the government institutes a mandate requiring inclusion of a DTV receiver in all sets sold [manufactured] subsequent to a specified future date:

  - Institution of a government mandate that all TV sets 13 inches and above sold after January 1, 2004 should have the capability of receiving digital television;
  - January 1, 2004 is assumed the cut-off date based on the FCC's proposed DTV transition rule which states that, by May 1, 2002, all commercial television stations must commence digital service, and all non-commercial television stations must begin [digital transmission] by May 1, 2003 [FCC, 1997; 47 CFR, 2000]. Under these assumptions, by January 1, 2004, most households should have the ability to access digital television content.

- ***Phased Mandate Scenario:*** This scenario assumes that the government institutes a phased mandate whereby initially more sophisticated, high end receivers would be required to include a DTV receiver and, over time, the requirement would be extended to include lower end models:

  - Effective in 2003, all TV sets manufactured with screen sizes 32 inches and above (approximately 19% of total TV sales) must have the capability of receiving digital television;
  - Effective in 2004, all sets with screen sizes 25 inches and larger (summed at approximately 56% of total TV sales); must have the capability of receiving digital television;
  - Effective in 2005, all sets having screen sizes 19 inches or above (summed at approximately 85% of total TV sales) must have the capability of receiving digital television; and
  - Effective in 2006, all TV sets must have the capability of receiving digital television;
  - This phased mandate scenario is based on the FCC's proposed approach in its *Report and Order and Further Notice of Proposed Rule Making in the Matter of Review of the*

Commission's Rules and Policies Affecting the Conversion To Digital Television: "One approach to minimize the impact of such a requirement would be to phase it in over time to take advantage of declining costs associated with electronics manufacturing volumes and apply the requirement initially only to receivers with large screen sizes, e.g. 32 inches and above" [FCC, 2001c].

1.4 Summary of the Analysis

1.4.1 DTV Market Penetration

Our analysis of DTV penetration is based on the Bass Adoption model utilizing adoption factors from historic adoption of color television. The major findings are shown in Figure 1-1 and Figure 1-2, and summarized below:

Figure 1-1 Estimated DTV Cumulative Sales Under Study Scenarios

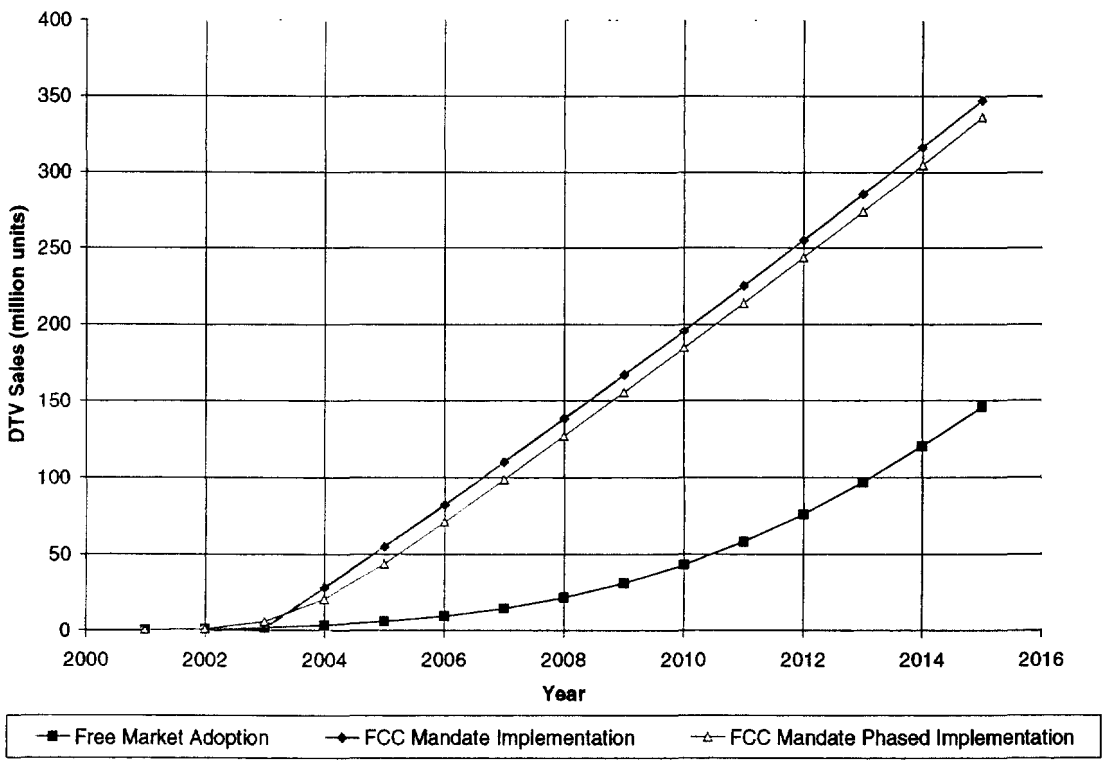
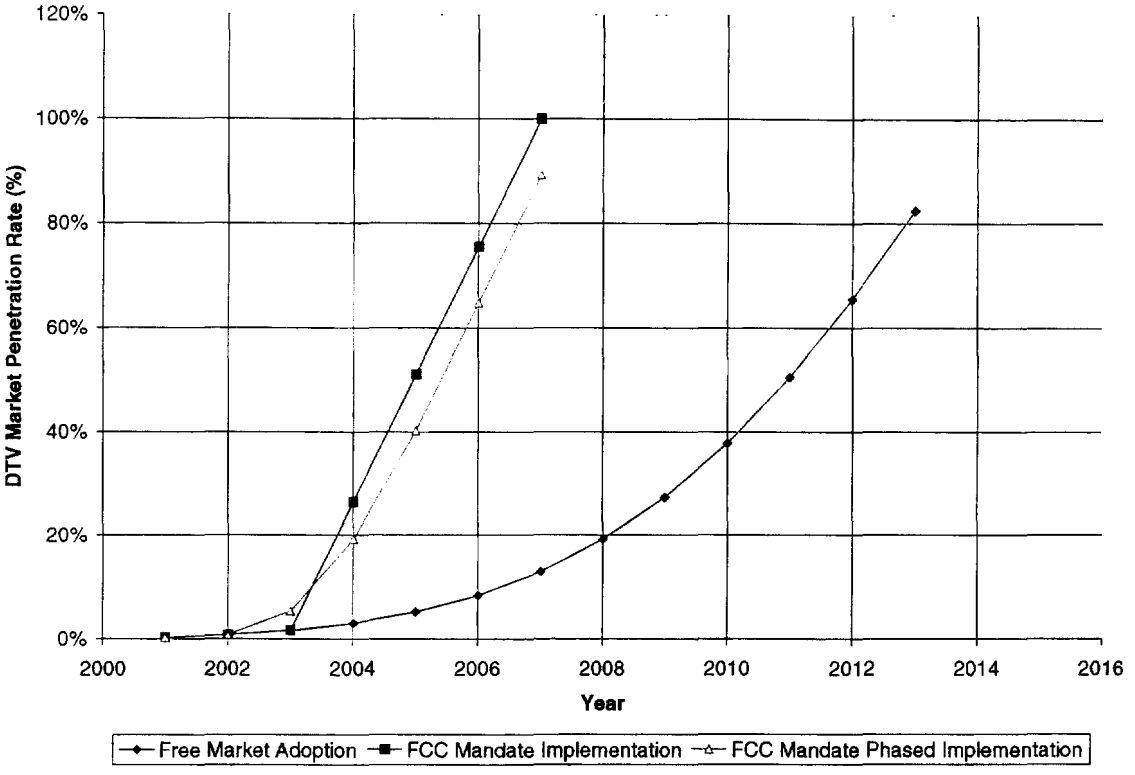


Figure 1-2 Estimated DTV Market Penetration Rates Under Study Scenarios



- Free Market Adoption Scenario - Assuming free market adoption of integrated DTV sets without governmental influence, we project that cumulative DTV sales will grow to approximately 9.3 million units by 2006. The corresponding penetration is projected to reach only 8.5% by 2006 (assuming 109.3 million TV households [Carmel Group, 2001a] in 2006, and each DTV sale represents a new adopting household). This is well below the FCC target of 85% by 2006 and, based on this projection, the 85% target penetration will not be reached until 2014 or later under this baseline scenario.

- FCC Mandate Scenario - Assuming the FCC were to institute a full government mandate beginning 2004, we project that cumulative DTV sales will be substantially higher relative to the baseline scenario. According to our projections, DTV sales would grow to approximately 82.5 million units by 2006, implying that 75.5% of US households would have DTV reception capability by 2006. The FCC target of 85% penetration could be reached in 2007 under this scenario.

- Phased Mandate Scenario - Assuming the FCC were to institute a phased mandate beginning in 2003, cumulative DTV sales are projected to reach approximately 71 million by 2006, with a corresponding 65% DTV penetration. The 85% FCC target penetration rate could be reached in 2007 under this scenario.

We have compared DTV market penetration projections under our Bass Adoption baseline scenario with the adjusted forecast numbers from CEA [CEA, 2001a] for the 6 years from 2001 to 2006. We obtained the CEA adjusted integrated DTV sales forecast by applying 20% on the CEA projected DTV sets and display sales (Note: Twenty-percent (20%) is the ratio of the integrated DTV sales over the total CEA forecasted DTV sets and display sales numbers. [CEA, 2001d]). Our projections are in line with those from the CEA especially in initial 3 years with the CEA adjusted forecasts a little bit higher. Since 2003, ours projection exceeds the CEA adjusted projection ending with 2.6 million sets higher in 2006. The major discrepancies of these two forecasts may lie in different forecast methodologies and the assumptions applied.

1.4.2 Manufacturing Learning Curve

The analysis also considers the impact of the manufacturing "Learning Curve" on the incremental manufacturing cost to add DTV receivers to television sets as well as the incremental retail price to consumers. This assumes that, as the cumulative number of manufactured units' increases, the manufacturing cost falls exponentially due to the availability of integrated components and improvements in manufacturing processes. Refer to Section 5.2.2, "Learning Curve Theory" for more details.

Under all scenarios, we assume that the initial, incremental material cost will be approximately $100 per set in 2001. Adjusted for typical manufacturing and retail markups, this corresponds to approximately a $180 initial retail price increase to the consumer for a 'leader' model television set. The incremental cost impact over time under each of the scenarios considered is summarized as follows and shown in Figure 1-3. The same DTV market penetration rates comparison is shown in Figure 1-2.

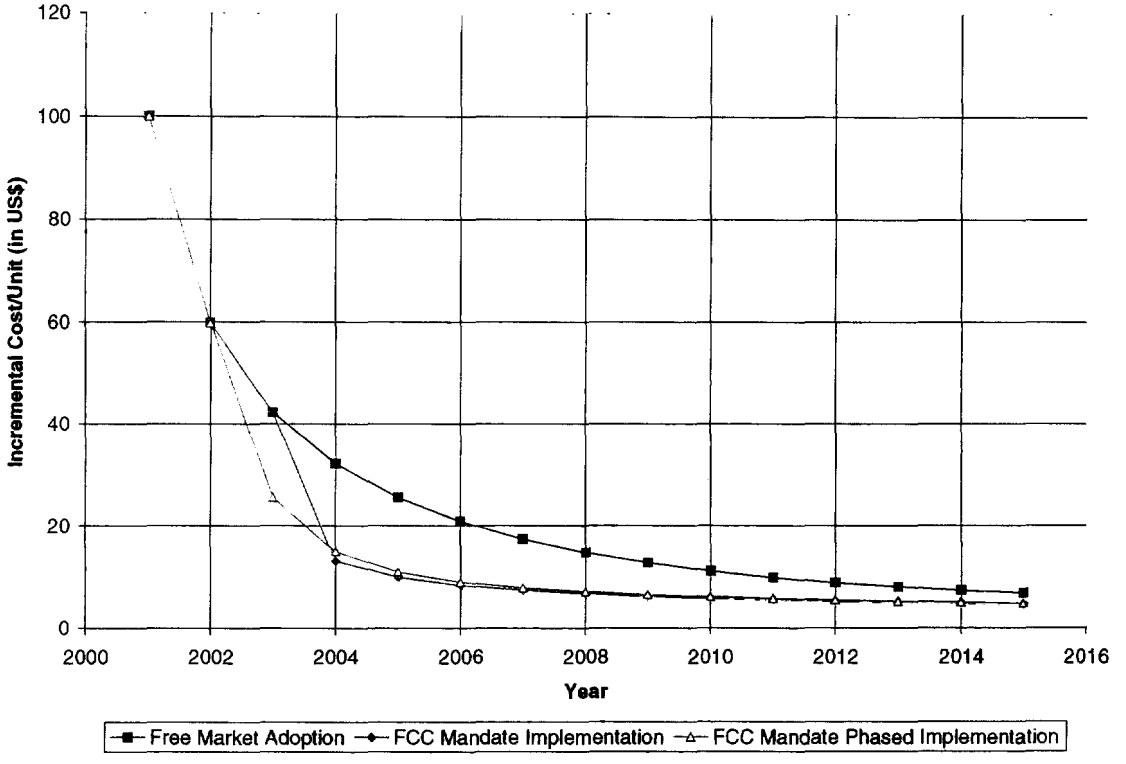
Specifically:

- Under the free market adoption (baseline) scenario, the incremental material cost to incorporate a DTV receiver is projected to decrease from $100 to approximately $21 by the year 2006. Adjusted to reflect typical manufacturing and retail markups, the incremental price to consumers is projected to decrease from $180 to $38 by 2006.

- Under the full mandate scenario, the incremental material cost is projected to decrease more rapidly due to increased DTV sales beyond 2004. The $100 incremental material cost is projected to decrease to approximately $8.40 by 2006, which corresponds to a projected retail price increase of approximately $15.

- Under the phased mandate scenario, the incremental material cost is projected to decrease from $100 initially to $9 by 2006. The corresponding incremental retail price is estimated to be $16.

Figure 1-3 Incremental Cost Curves under Study Scenarios



1.4.3 Sensitivity Analysis

To explore the sensitivity of the analysis results on key assumptions, a sensitivity analysis has been conducted, whereby the sensitivity of the results were tested relative to variations in annual TV sales, TV sales growth and incremental material cost. Note that this sensitivity analysis was applied only to the baseline scenario, as the sensitivity under this scenario will be indicative of the sensitivity under the other two scenarios.

- Variation in annual TV sales - The analysis conducted previously is based upon current annual TV sales of 25 million units per year [CEA, 2001b]. This figure however does not include the current 5 million TV/VCR combination sales [CEA, 2001b]. By increasing the current annual TV sales to 30 million units to include this category, total annual TV sales will effectively increase by 20% and the cumulative DTV sales would increase by 20% for each year under the three studied scenarios. For example, in year 2001 DTV sales will increase from the previously projected 0.21 million sets to 0.25 million, and the cumulative DTV sales in 2006 would be 11.16 million vs. 9.6 million sets previously projected for that year.

Assuming the same number of US TV households, the DTV market penetration rate will be increased accordingly. As of year 2006 under the higher projected TV Sales case, the DTV market penetration would increase from 8.5% to 10.2% in 2000 and the FCC's 85% target market penetration will be reached in 2013, one year earlier than in the previous case.

The incremental cost to incorporate a DTV receiver in new television sets, both manufacturing cost and retail price, will be the same under both annual TV Sales cases, since the cumulative sales doubling rate in the learning curve would be the same.

- Variance in annual TV sales growth – the sales forecast has been estimated under three different TV sales growth rates: low (0.75%), medium (1.5%) and high (3%). The cumulative DTV sales forecast would range from 9 million to 10 million in 2006 under the baseline scenario. The estimated DTV penetration rates range from 8% to 9% accordingly. The 85% target rate would not be realized until 2013 even under the high growth assumption.

- Variance in Incremental Cost – the cost projections have been made under a range of incremental cost assumptions: low ($80), medium ($100) and high ($150). The DTV incremental cost as of 2006 would be in the range of $16.7 to $31.3 per TV set. The incremental retail price would be in $30 to $56 range by applying the same manufacturers and retail markups.

Based on the sensitivity analysis above, we conclude that the results of this report are not overly sensitive to the key assumptions.

1.4.4 Results of Cost/Price Analysis

The cost and price impact has been examined on both integrated TV receivers and set-top box "transverters" in our analysis.

1.4.4.1 SDTV Receivers

The following reference model for an ATSC receiver is assumed in SDTV receiver analysis:

- The TV set will be dual-mode, having the capability of receiving both analog NTSC as well as digital ATSC; and
- The TV will have the ability to transcode any valid ATSC format (i.e. from standard definition through high definition of any interlaced format) to a format that can be displayed on low level (i.e. standard definition 350 x 240) and main profile.
- Digital TVs (DTVs) are defined as TV sets capable of receiving any format of ATSC and transverting and displaying the received digital signals as Standard Definition, 480I, or SDTV only. The study excludes High Definition TVs (HDTV, 1080I or 720P) or Enhanced Definition TVs (EDTV, 480P). The results, therefore, do not include the cost of HDTV or EDTV receivers or display technology.
- Based on current consumer preference experience we assume that consumers will want so called "cable ready" DTVs, which, similar to today's analog NTSC "cable ready" TVs, will demodulate both 8-VSB broadcast signals as well as QAM cable signals. Therefore we

assume that the minimal implementation of a SDTV leader model set will be "cable ready" and capable of demodulating both 8-VSB and QAM physical layers.

This analysis focused on four study cases consisting of two market segments – "market leader (low-end)" televisions and "high-end" televisions, under two scenarios – "FCC mandate" and "free market" adoption (See Figure 3-1).

The results of market penetration and cost/price analysis for leader models over time for each of these cases are summarized in the above Figure 1-1 and Figure 1-3. As can be seen, the government mandate scenario will bring down the costs to customers more rapidly, which is due to increased unit sales and greater manufacturing efficiencies. This applies to both leader models and high-end sets. High-end models typically require about half of the incremental cost to add a DTV receiver as compared to a leader (low-end) TV set, since high-end sets already include some internal digital signal processing and memory components to support such features as picture-in-picture, line doubling resolution enhancement, etc. On the other hand, high-end sets normally have a higher manufacturer price markup (2.5 times the direct material cost compared to 1.5 times direct material cost for the market leader models) and a higher retail profit margin (35% compared to 20%, respectively). This translates to an incremental retail price increase to add a DTV receiver to a high-end set, that is approximately 94% of the retail price increase to add a DTV receiver to a market a leader model.

For example, the incremental direct material cost and corresponding retail price increase to incorporate a DTV receiver in a low-end set in 2001 is $100 and $180 respectively, and will decline to $21 and $38 respectively by 2006 under the free market rollout scenario. The comparable incremental cost and price for a high-end model is approximately $50 and $169 respectively in 2001, and is expected to fall to $11 and $35 by 2006.

1.4.4.2 Set-top Box Transverter

Incremental cost analysis of the set-top box (STB) transverter has also been included in the report, since a consumer might consider the purchase of a transverter instead of an integrated DTV in the following two cases:

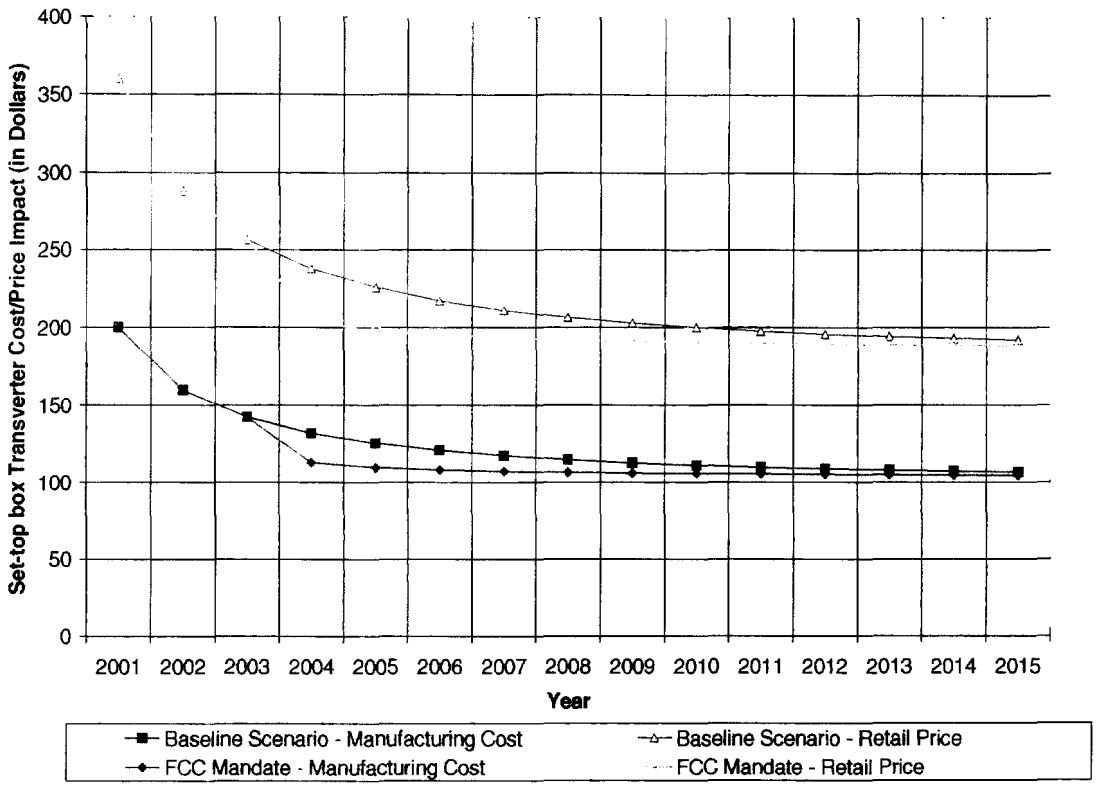
- To extend the useful life of an otherwise good analog NTSC television; and,
- When purchasing a new television, and a package consisting of a new analog television plus a transverter is more cost effective or better suits the consumers needs than any integrated DTV. (This would probably only be the case if the consumer were forced to consider a higher-end model to get a DTV receiver as their first-choice model, the one that best fits their cost/feature needs, is not available with an integrated DTV receiver).

It is assumed that the typical transverter will be capable of receiving all 18 modes of DTV and will convert whatever mode received to SDTV 480I. The typical transverter may also be capable of receiving and converting "basic" (i.e. non-scrambled) digital cable channels thus it will be "cable-ready". This typical configuration will serve as our "reference" design in this analysis.

The SDTV set-top transverter total cost and retail price decline is shown in Figure 1-4. Analog NTSC addressable cable set-top boxes currently cost approximately $100 per set and we anticipate that they will remain at this price point throughout the study period. Given the technological content of the analog set-top box, it is reasonable to assume that inclusion of a DTV receiver will initially cost $100 and that this incremental cost will fall relative to the same manufacturing learning curve associated with DTV sets. That is, given the technological similarities between SDTV set-top transverter, digital satellite set-top boxes, and DTV receivers, the set-top box transverter is expected to benefit from the same manufacturing volumes and learning curve, associated with these other products. Therefore, the cost of a set-top box transverter is expected to fall in relation to that of the integrated DTV receiver.

For example, similar to DTV receiver free market adoption baseline scenario, a set-top box transverter with total manufacturing cost of $200 in 2001 would cost only $121 by 2006, translating to a retail price of $218 by applying the same markup factors as those of a leader model TV set. With the FCC mandates, however, the manufacturing cost and retail price by 2006 could be as low as $108.4 and $195 respectively.

Figure 1-4 SDTV Set-top Box Transverter Cost/Price Analysis



1.4.5 Key Uncertainties

Since the analysis in this report is based upon certain estimates and assumptions - e.g. projections of future sales and predictions of cost behavior, there is uncertainty regarding the precise accuracy of the analysis outputs. Factors capable of altering the findings include the following:

- ***Free market vs. FCC Mandated DTV adoption***

The single factor with the greatest potential impact on DTV adoption that we now face is that of FCC policy yet to be defined relative to DTV. As can be seen from this analysis, the results based on the free market adoption scenario differ significantly from the results gained under the FCC mandated scenarios. That is, cumulative DTV sales, market penetration and the incremental cost to incorporate DTV receivers in newly manufactured sets, are all very sensitive to the course chosen by the FCC. This is the most important factor having the greatest potential impact on these factors.

- ***Price Elasticity and Market Adoption***

The purchasers of low-end TV sets are expected to be more price sensitive than buyers of more expensive, higher-end sets. Therefore, the sales projections of integrated DTVs in initial years may be substantially lower due to price elasticity effects, which have not been considered in this analysis.

That is, the initial $180 retail price increase for the inclusion of a DTV receiver could substantially impact purchasing decisions regarding low-end sets. ADL learned from interviews with a manager of a leading consumer electronics store that "consumers of 'leader' sets are not likely to pay more than $60 premium for inclusion of a digital receiver".

The manufacturing cost learning curve suggests that the incremental retail price for inclusion of a digital receiver will not fall to $60 until 2004 under the free market adoption case, and under the government mandate scenarios it will not reach $60 until 2003.

Prior to this time, sales of low-end "leader" models can only be explained by the behavior of "early adopters" who will pay a significant premium to have the latest product advancements. There is a risk that sales in these early years will not reach the projected level. Changes in cumulative sales would impact the manufacturing learning curve, thereby pushing the estimated cost reductions and sales projections further into the future.

- ***Forward Pricing***

Should the manufacturers adopt a Forward Pricing strategy, the retail prices may be dramatically lower in the initial years of introduction. This approach could significantly fuel a more rapid acceptance and adoption of DTV receivers than indicated by our projections, resulting in faster cost reductions.

2 Introduction

2.1 Report Organization

Details regarding methodology, assumptions and the analysis of information collected are discussed in greater detail in the remainder of this report. The overall organization of this discussion is as follows:

- ***Introduction:*** General background on the project and overview of the methods applied;
- ***Scope and Approach:*** Synopsis of the scope of the project and the overall approach to realize the objectives;
- ***Key Assumptions and Data Sources:*** Brief summary of the information collected for the study and introduction of a number of key assumptions applied in the analysis;
- ***Cost Analysis:*** This chapter describes the application of Bass Adoption Theory to the sales projections and the application of a "Learning Curve" approximation to the current cost estimates to develop estimates for market adoption and the incremental cost to incorporate DTV receivers in televisions over time and under the studied scenarios;
- ***Conclusions:*** Summary of the results obtained and principal conclusions reached in the analysis.

2.2 Background

The Advanced Television Systems Committee (ATSC) standard for U.S. broadcast digital TV (DTV) is a significant technological advance which, upon widespread DTV adoption, is expected to benefit all stakeholders. Specifically,

- Consumer electronics manufacturers, distributors and retailers would benefit from the creation of a market for a new, higher valued category of DTV receivers and video equipment. This would perhaps encourage the early retirement of the installed base of analog NTSC TV receivers (NTSC TV);
- Broadcasters would benefit by having a wider variety of transmission choices which allow for a mix of higher quality, higher resolution programs (HDTV) or, alternatively, a larger number of standard definition (SDTV) programs with the attendant additional revenue generating potential;
- Wireless systems and others with interest in acquiring spectrum would benefit from the spectrum made available from the more spectrally-efficient ATSC transmission standard; and

- The government would, by serving the mandate, be acting in the public interest providing new and valued services to consumers. The government would also collect fees for the use of the newly freed spectrum.

While there are clear benefits to the major stakeholders of achieving long-term widespread adoption of DTV, each of the stakeholders has legitimate short-term concerns as to which is the best pathway between today's largely Analog Television (ATV) world and tomorrow's Digital Television (DTV) future.

The key issue is, how can we overcome the classic *"chicken and egg"* dilemma:

- Consumers find the costs of current ATSC compatible receivers to be too expensive, given the limited ATSC program transmissions today;

- Given the limited number of ATSC compatible receivers currently in use, there is little incentive for broadcasters to incur additional operating costs and make the substantial capital investments needed to support simulcast of both NTSC and compelling ATSC programming, such as HDTV [CEA, 2000b]; and

- Manufacturers of consumer TVs and the companies developing and manufacturing integrated circuits (IC) for these TVs have limited incentives to invest in the substantial research and development (R&D) needed to drive down the costs of DTV and thereby increase the installed base of ATSC compatible receivers.

A possible mechanism to overcome this dilemma is based on the historical government action deployed by Congress to accelerate the penetration of TVs capable of receiving UHF transmissions. In this case, Congress directed the Federal Communications Commission (FCC) to develop regulations mandating the inclusion of UHF tuners in all television sets sold. This was known as the All Channel Receiver Act. While history demonstrates the success of government action in accelerating the deployment of compatible UHF TVs, there are legitimate questions being raised about undertaking a similar approach to accelerate the adoption of ATSC compatible TVs. In this instance, the main issue is cost. To incorporate an UHF tuner, the cost was sufficiently low enough to have a minimal effect on annual TV sales. In the case of adding an ATSC receiver to TVs, there is general agreement that the incremental cost would be a larger percentage of the base cost of a TV than that of an UHF tuner. This concern is of particular significance with respect to the low-end (so-called *leader model*) TVs that currently sell for retail prices below $250. Furthermore, there is not a consensus regarding the current or future cost of adding a DTV receiver to a conventional TV.

The FCC has opened the possibility of initiating regulatory action to accelerate the adoption and deployment of DTV receivers. This could represent a *"win-win"* situation for all stakeholders by achieving the rapid deployment of both DTV receivers in concert with the rapid growth of DTV broadcast programs.

To further clarify the consequences of such action, the Association for Maximum Service Television, Inc. (MSTV) and The National Association of Broadcasters (NAB) have

commissioned Arthur D. Little, Inc (ADL) to conduct this study and develop a fact base and perspective on costs and other key issues that a decision maker would need to consider in developing DTV policy.

This report attempts to address a number issues, but the focus is on one central topic comprising two key questions:

- What is the estimated incremental material cost impact on the bill of material for a typical TV receiver to incorporate an ATSC receiver; and
- What are the retail price consequences of these extra costs?

The following report addresses these central questions.

2.3 Related FCC Rulemaking Activities

In 1997, the FCC's *Fifth Report and Order* [FCC, 1997] adopted rules to implement the Telecommunications Act of 1996. This action provided that initial eligibility for advanced television licenses issued by the FCC should be limited to existing broadcasters, and conditioned on the eventual return of either the current 6MHz channel or the new digital channel. The FCC issued initial licenses for DTV, established service rules, including a requirement that broadcasters continue to provide free, over-the-air television service, and set the target date of 2006 as the completion of the transition.

After the adoption of the *Fifth Report and Order*, Congress made the 2006 reversion date statutory by enacting the Balanced Budget Act of 1997. This act provides that "[a] broadcast license that authorizes analog television service may not be renewed to authorize such service for a period that extends beyond December 31, 2006" unless the FCC grants an extension based on specific criteria enumerated in the statute [47 USC, 2000a]. In the meantime, Congress mandated that 85% of households in a market must be able to receive digital broadcast stations' signal before analog spectrum is returned [47 USC, 2000a].

The FCC is permitted to extend the December 31, 2006 deadline on a market-by-market basis if less than 85% of the households in its market have at least one of the following [FCC, 2001c]:

(1) digital TV receivers;
(2) analog television receiver equipped with a digital/analog transverter; and,
(3) access to a multi-channel video provider (Cable TV operator) that carries local digital broadcast stations.

In order to reach the goal of having digital TV in 85% of households, the FCC has requested public comment on the following issues:

- Whether the demodulation capability requirement should extend to full HDTV signals or only to SDTV signals;

- Whether there should be a phase-in approach that would initially apply a mandate only to larger screen receivers (e.g. 32 inches or larger) and then over time apply to an increasing percentage of smaller screen TV sets;
- Whether there are other plans that would result in new TV receivers being equipped with DTV capability, increasing the penetration of digital reception into U.S. households; and
- How to construct any DTV demodulation requirement within the constraints of its statutory authority, including the All Channel Receiver Act (ACRA).

2.4 Overview of Digital Television Technology

DTV provides a number of consumer or viewer benefits over analog transmission. The benefits include reception of a greater variety and more channels/programs, higher quality image and sound, support for wide-format and/or high definition (HDTV), simultaneous delivery of electronic program guides and other digitally encoded information, and the promise of future information, interactive or transaction services. There are also potential benefits to the terrestrial broadcaster, cable operator, Direct Broadcast Satellite (DBS) or other television transmission operator in that the consumer benefits mentioned translate into enhanced revenue opportunities.

Digital television signals can be transported over Direct Broadcast Satellite (DBS), cable, wireless cable (Multichannel Multipoint Distribution Service (MMDS), Local Multipoint Distribution Service (LMDS) [MMDS or LMDS]), terrestrial broadcast transmitters and, potentially in the future, fiber to the home, DSL, or any other broadband transmission access technology. It should be noted that many viewing households have access to more than one medium. For example, DBS households often also receive cable or terrestrial broadcast television to receive local content. (DBS now offers 'Local into local' to enable subscribers to receive their local channels, but this is a relatively recent offering so many subscribers have previously made other arrangements to receive local channels.).

In the US, there are currently three different modulation schemes used to transport DTV over these media:

- 8-VSB for terrestrial over-the-air broadcast;
- QAM for cable; and
- QPSK for satellite transmission.

Each of these requires a different approach to demodulate the signal, but there are sufficient similarities to allow receivers and receiver chip-sets to support multiple or even all modes. (Note: In support of this statement, we offer that current and future expected DTV implementations are based on digital signal processing architectures for which the signal processing for each modulation is of comparable computational power. Since the signal processing function is determined mainly by firmware, i.e. software stored in a memory chip, with no incremental hardware costs, there is minimal additional signal processing costs. We understand that there are hardware differences in that cable tuners needed to operate over a wider tuning range and provide lower distortion products versus terrestrial broadcast needs to control

longer delay multipath, but consider these hardware cost differences to balance out and therefore as immaterial.)

Current analog TVs sold in the US market support direct reception of both terrestrial broadcast signals and cable channels. These "cable-ready" sets enable the consumer to receive 'basic' cable (as opposed to scrambled "premium" cable) without an external set-top box, and to control their video system with a single remote control. However, to receive premium programming, an external set-top device or set-back decoder (sometimes called a Point of Deployment device, or POD) is needed to provide a conditional access means to decode/descramble the premium programs.

Given today's availability of cable ready analog TVs, and that Congress has mandated future TVs to be compatible with cable [1992 Cable Act, 1992; FCC, 1993c], it is likely that the DTV counterpart to analog cable-ready TVs may develop. In such a case, the popular form of DTV television receivers will be capable of receiving and demodulating non-scrambled digital or analog terrestrial signals and non-scrambled digital or analog cable channels. And with a service provider supplied external conditional access device, such cable ready TVs will also be compatible with premium (e.g. scrambled) terrestrial broadcast and cable channels in either analog or digital formats.

Figure 2-1 Alternative DTV Transmission and Reception Approaches

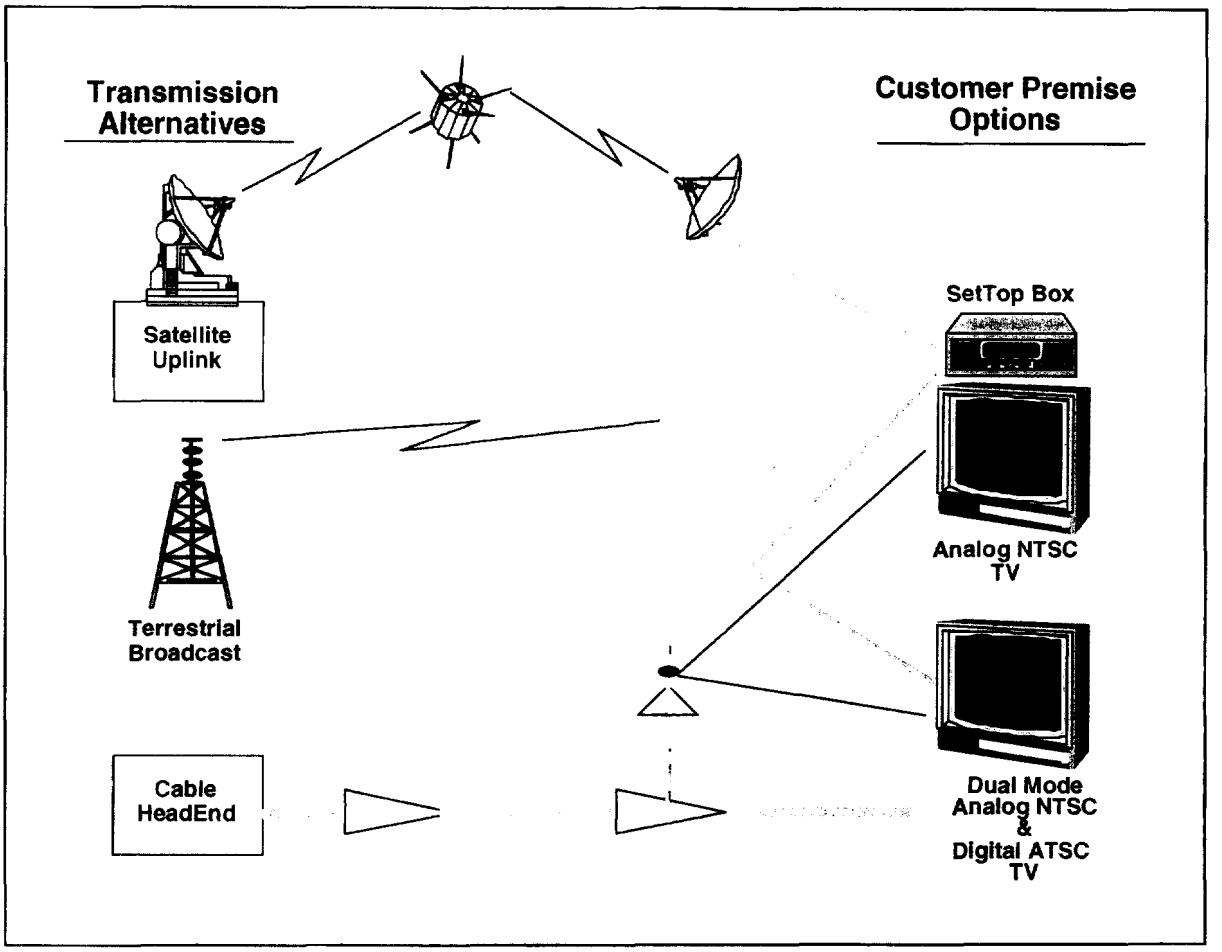


Figure 2-1 illustrates the options for transmission and reception of DTV. In particular, three alternative means of transmission are shown:

- DBS
- Terrestrial; and
- Cable.

Also illustrated are two alternative means of reception: with and without a set-top box. This study considers only the costs associated with terrestrial broadcasting of DTV with a primary focus upon a consumer TV without a set-top box. A secondary focus of the analysis is the cost of a set-top transverter capable of converting ATSC DTV to analog NTSC TV. While this study is focused on DTV, it is recognized that integrated circuits and technology developed for DBS and digital cable DTV significantly overlap terrestrial DTV technology. It is therefore expected that the development and manufacturing of digital TV receivers for DBS and cable will also drive down the costs for terrestrial DTV receivers.

2.4.1 MPEG-2 Standard

Common to ATSC terrestrial DTV, DBS, and digital cable is the MPEG-2 compression standard. Essentially, this standard breaks the analog picture frame into a matrix of vertical and horizontal picture elements or "pixels". The brightness and color of each analog pixel is "sampled" and the sample is encoded as a digital value corresponding to the brightness level and color.

Complex mathematical approaches are used to compress the digital signals and reduce the bandwidth required for transmission. For example, expressing adjacent pixels and large areas of the frame that have the same brightness/color levels in a shared representation reduces spatial redundancy. Similarly, temporal redundancy that occurs when sequential frames have common images is encoded in a manner to save bandwidth. Additionally, samples are predicted using natural order schemes based on the recognition that drastic differences between adjacent pixels seldom occur in normal images. There are different forms of MPEG-2, but the form used in ATSC is denoted as the "*Main Profile.*" It includes independent, predictive, and bi-directional frames. The cost forecasts in this study assume full compatibility with ATSC and, therefore, MPEG-2 Main Profile.

The compressed signal is "encoded" to provide error-correction redundancy and time-interleaved to spread the transmitted information in time. The latter protects against losing entire time segments when the transmission channel creates "burst errors."

As previously discussed, a single allocated spectral channel may carry multiple television channels, currently between one and ten. It follows that individual MPEG encoded programs are "multiplexed", or interleaved according to the respective bandwidth of each individual channel.

2.4.2 Overview of ATSC Formats

ATSC defines 18 distinct formats for DTV. Each format corresponds to a different number of horizontal and vertical pixels and whether the horizontal scan lines of the picture are progressive or interlaced. Consequently, each format requires a different bandwidth requirement for transmission.

Note that all digital televisions are expected to receive all 18 formats but not all will be capable of utilizing or displaying the full enhancements associated with the higher formats. In the latter case, the TV receiver will reduce the received signal to that of a lower format for display.

For the purposes of this study, the incremental costs of displaying so called *Standard Definition TV* (SDTV) of 704 x 480 interlaced picture elements (Pixels) in a 4:3 aspect ratio is considered. This SDTV format is commonly denoted *480I*. Figure 2-2 [Whitaker/NAB, DTV the Revolution in Digital Video] shows the 18 formats defined by ATSC.