GENERAL INSTRUMENT M.I.T.

American TeleVision Alliance

DigiCipher™ HDTV

A high-definition television developmental program of General Instrument Corporation and the Massachusetts Institute of Technology

DigiCipher™ HDTV System Description

f: HDTV

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American TeleVision Alliance
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1. INTRODUCTION

American TeleVision Alliance's (ATVA) DigiCipher™ System is an all digital HDTV system that can be transmitted over a single 6 MHz VHF or UHF channel. It provides full HDTV performance with virtually no visible transmission impairments due to noise, multipath, and interference. It offers high picture quality, while the complexity of the decoder is low. Furthermore, low transmitting power can be used, making it ideal for simulcast HDTV transmission using unused or taboo channels.

The DigiCipher™ HDTV System can also be used for cable and satellite transmission of HDTV. There is absolutely no satellite receive dish size penalty (compared to FM-NTSC) in the satellite delivery of DigiCipher™ HDTV. This is important for broadcast and cable as well as for DBS, since broadcast network and cable programming is typically delivered to affiliates via satellite.

To achieve full HDTV performance in a single 6 MHz bandwidth, a highly efficient, unique compression algorithm based on DCT transform coding is used. Through extensive use of computer simulation, the compression algorithm has been refined and optimized. For error free transmission of the digital data, powerful error correction coding combined with adaptive equalization is used. The DigiCipher™ HDTV system provides two distinct transmission modes, 32-QAM and 16-QAM. The mode is selectable by the broadcaster, and receivers can auto-configure to the mode being transmitted. At a carrier-to-noise ratio above 16.5 dB, essentially error free transmission can be achieved. In the 16-QAM mode, even better transmission is provided, with a threshold at 12.5 dB, and only a small sacrifice in picture quality.

We envision the 32 and 16-QAM modes coexisting within the ATV service, with some stations using 32-QAM, and others using 16-QAM. Indeed, as programming and the broadcast environment varies, a given station may switch modes. While we view the provision of both modes as integral to the system design, and a key feature, we are required to select one as the primary mode for ATTC testing. With some difficulty, we have selected 32-QAM as the primary mode, because we believe the vast majority of broadcasters, will prefer 32-QAM for its better picture quality.

However, we expect that the 16-QAM mode will be very important to those broadcasters facing co-channel spacing and transmitted power limitations. Therefore, it is important that ATTC also test the DigiCipher™ system in its 16-QAM mode, so that an important feature can be part of the public record.

This document describes the digital video and audio processing, the digital transmission, and the hardware implementation of the DigiCipher™ HDTV prototype to be delivered to ATTC for testing. It also provides an analysis of the ATV coverage area based on preliminary test data of the DigiCipher™ transmission system.

2. DIGICIPHER™ SYSTEM OVERVIEW

The DigiCipher™ HDTV system is an integrated system that can provide high definition digital video, CD-quality digital audio, data and text services over a single VHF or UHF channel. Bandwidth for an addressing signal that allows for conditional access of video, audio, and data services is also provided.

Figure 2-1 shows the overall system block diagram. At the HDTV station, the encoder accepts one high definition video and four audio signals and transmits one 32-QAM modulated data stream. The control computer can supply program related information such as program name, remaining times, and program rating. At the consumer's home, the DigiCipher™ HDTV receiver receives the 32-QAM data stream and provides video, audio, data, and text to the subscriber. On screen display can be used to display the program related information.

Figure 2-2 shows the block diagram of the encoder. The digital video encoder accepts YUV inputs with 16:9 aspect ratio and 1050-line interlace (1050/2:1) at a 59.94 field rate. The YUV signals are obtained from analog RGB inputs by low pass filtering, A/D conversion, and an RGB-to-YUV matrix. The sampling frequency is 53.65 MHz for R,G, and B. The digital video encoder implements the compression algorithm and generates a video data stream. The digital audio encoder accepts four audio inputs and generates an audio data stream. The data/text processor accepts four data channels at 9600 baud and generates a data stream. The control channel processor interfaces with the control computer and generates control data stream.

The multiplexer combines the various data streams into one data stream at 18.22 Mbps. The FEC encoder adds error correction overhead bits and provide 24.39 Mbps of data to the 32-QAM modulator. The symbol rate of the 32-QAM signal is 4.88 MHz.

Figure 2-3 shows the block diagram of the decoder. The 32-QAM demodulator receives an IF signal from the VHF/UHF tuner and provides the demodulated data at 24.39 Mbps. The demodulator has an adaptive equalizer to effectively combat multipath distortions common in VHF or UHF terrestrial transmission. The FEC decoder corrects virtually all random or burst errors and provides the error-free data to the Sync/Data selector. The Sync/Data Selector maintains overall synchronization and provides video, audio, data/text, and control data streams to appropriate processing blocks.

The DigiCipher™ HDTV system can also support 16-QAM transmission that provides lower system threshold with a slight penalty in picture quality. The lower system threshold can be used to improve the ATV coverage area and/or to reduce the station spacing. Through the use of a unique design, the DigiCipher™ system shares the same digital video/audio data processing, forward error correction, and QAM modulation/demodulation circuitries between the two operating modes. Table 2-1 summarizes the key parameters of the DigiCipher™ HDTV system.

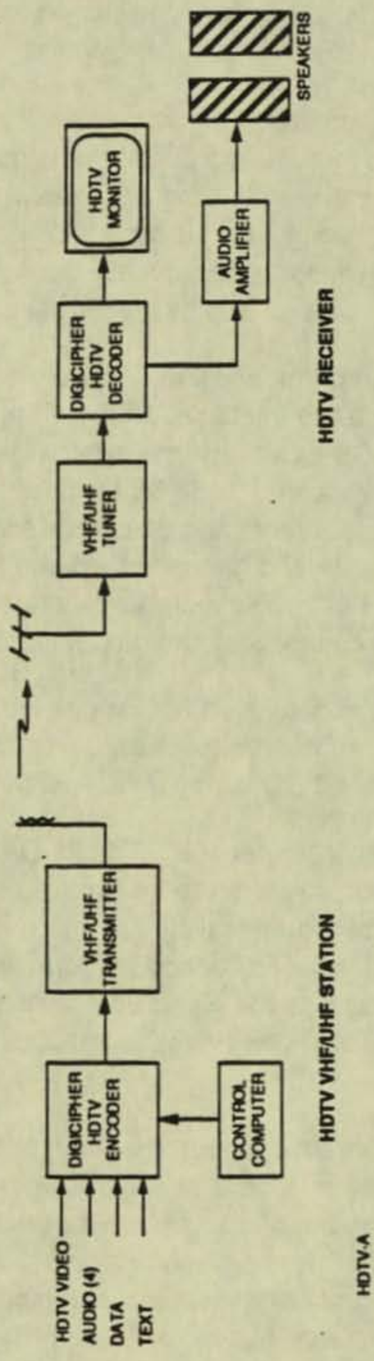
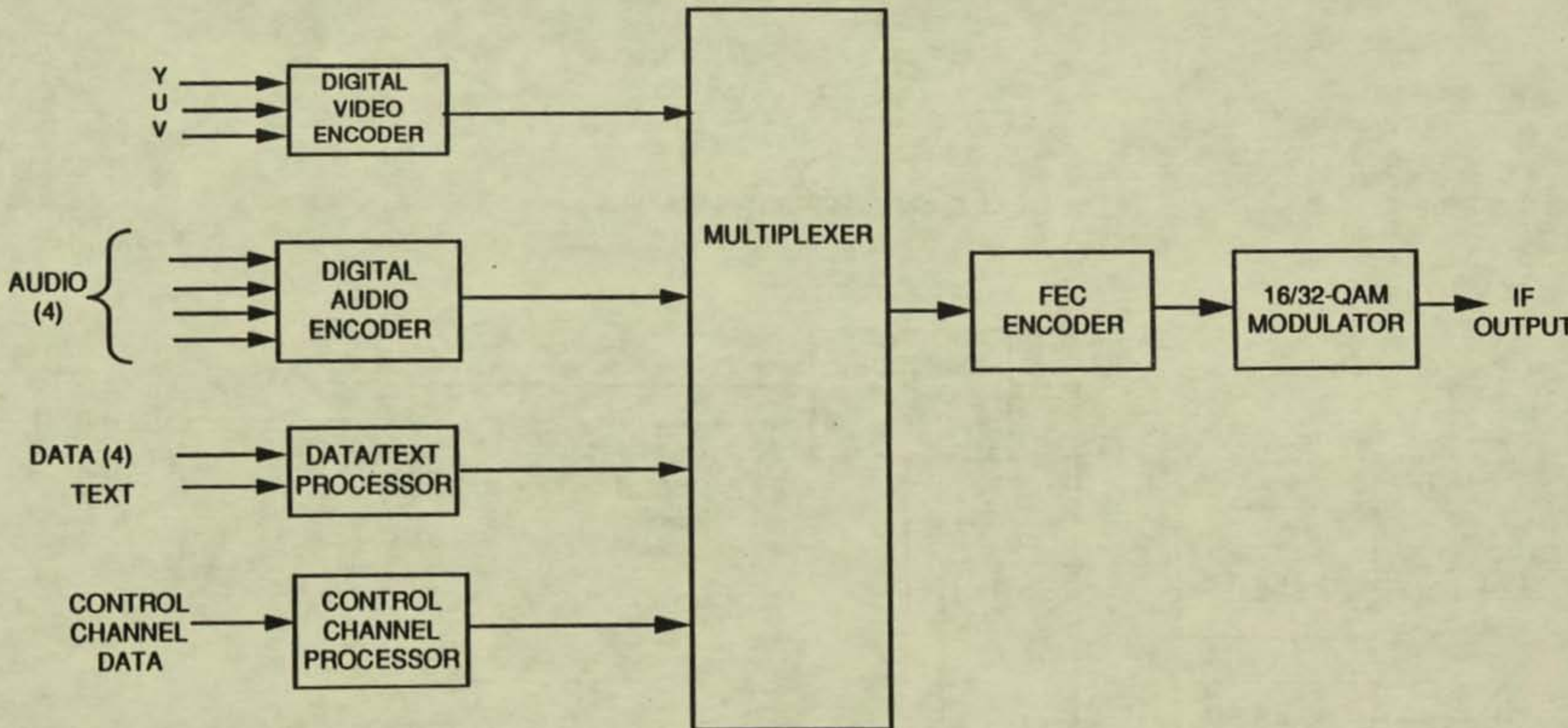
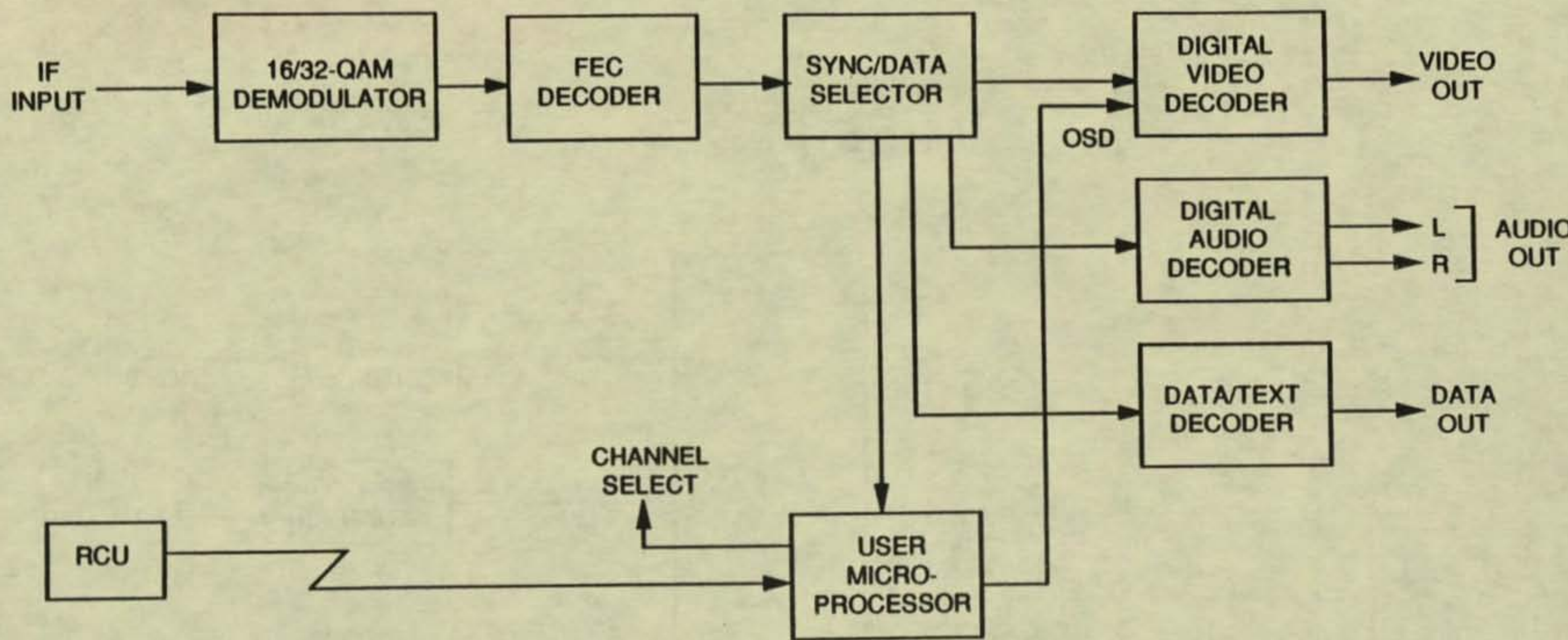


Figure 2-1. System Block Diagram



HDTV-B

Figure 2-2. Encoder Block Diagram



HDTV-C

Figure 2-3. Decoder Block Diagram

Table 2-1. DigiCipher™ System Parameters

Operating Mode	16-QAM	32-QAM
VIDEO		
Raster Format	1050/2:1 Interlaced	1050/2:1 Interlaced
Aspect Ratio	16:9	16.9
Frame Rate	29.97 Hz	29.97 Hz
Bandwidth		
Luminance	21.5 MHz	21.5 MHz
Chrominance	5.4 MHz	5.4 MHz
Active Pixels		
Luminance	960(V) x 1408(H)	960(V) x 1408(H)
Chrominance	480(V) x 352(H)	480(V) x 352(H)
Horizontal Resolution		
Static	660 Lines per Picture Height	660 Lines per Picture Height
Dynamic	660 Lines per Picture Height	660 Lines per Picture Height
Sampling Frequency	53.65 MHz	53.65 MHz
Colorimetry	SMPTE 240M	SMPTE 240M
Horizontal Line Time		
Active	26.24 μsec	26.24 μsec
Blanking	5.54 μsec	5.54 μsec
AUDIO		
Number of Channels	4	4
Bandwidth	20 kHz	20 kHz
Sampling Frequency	47.2 kHz	47.2 kHz
Dynamic Range	90 dB	90 dB
DATA		
Video Data	**12.59 Mbps**	**17.47 Mbps**
Audio Data	503 kbps	503 kbps
Async Data and Text	126 kbps	126 kbps
Control Channel Data	126 kbps	126 kbps
Total Data Rate	**13.34 Mbps**	**18.22 Mbps**
TRANSMISSION		
FEC Data	6.17 Mbps	6.17 Mbps
Data Transmission Rate	**19.51 Mbps**	**24.39 Mbps**
QAM Symbol Rate	4.88 MHz	4.88 MHz
Adaptive Equalizer Range	-2 to 24 μsec	-2 to 24 μsec
SYSTEM THRESHOLD		
Noise (C/N)	**12.5 dB**	**16.5 dB**
ATV Interference (C/I)	**12.0 dB**	**16.0 dB**
NTSC Interference (C/I)	**0.0 dB**	**5.0 dB**

NOTE: The differences in the two operating modes are emphasized in **bold** letters.

3. DIGITAL VIDEO PROCESSING

The compression process can be broken down into the following different subprocesses:

1. A/D Conversion and RGB-to-YUV Matrix
2. Chrominance Preprocessor
3. Discrete Cosine Transform (DCT)
4. Coefficient Quantization
5. Huffman (Variable Length) Coding
6. Motion Estimation and Compensation
7. Integration of Motion Compensation with Intraframe Coding
8. Adaptive Field/Frame Processing
9. Motion Picture Processing
10. Rate Buffer Control

Basic block diagrams for the encoder and the decoder video processing are shown in Figures 3-1 and 3-2 respectively.

The subsequent discussions refer to certain basic picture processing elements:

- **Pixel:** An 8 bit active video sample (luminance or chrominance). Unless otherwise indicated, the term "pixel" refers to luminance pixels. Representing an image by digitized samples is generally referred to as PCM coding.

- **Block:** An image area 8 pixels horizontally by 8 pixels vertically.

- **Superblock:** An image area 4 luminance blocks horizontally by 2 luminance blocks vertically; associated with 1 chrominance block each for U and V derived from that image area.

- **Macroblock:** An image area 11 superblocks horizontally.

These elements are described further in the appropriate sections.

3.1 A/D Conversion and RGB-to-YUV Matrix

The analog R, G, B inputs are lowpass filtered and clamped before they are digitized. Figure 3-3 shows the characteristics of the lowpass filters employed. The lowpass filters are designed to provide adequate rejection of aliasing components and other spurious signals. The clamping restores proper DC-levels during the horizontal blanking interval.

The RGB-to-YUV matrix digitally converts the RGB signal into the YUV color space. The matrix conforms to the SMPTE 240M colorimetry.

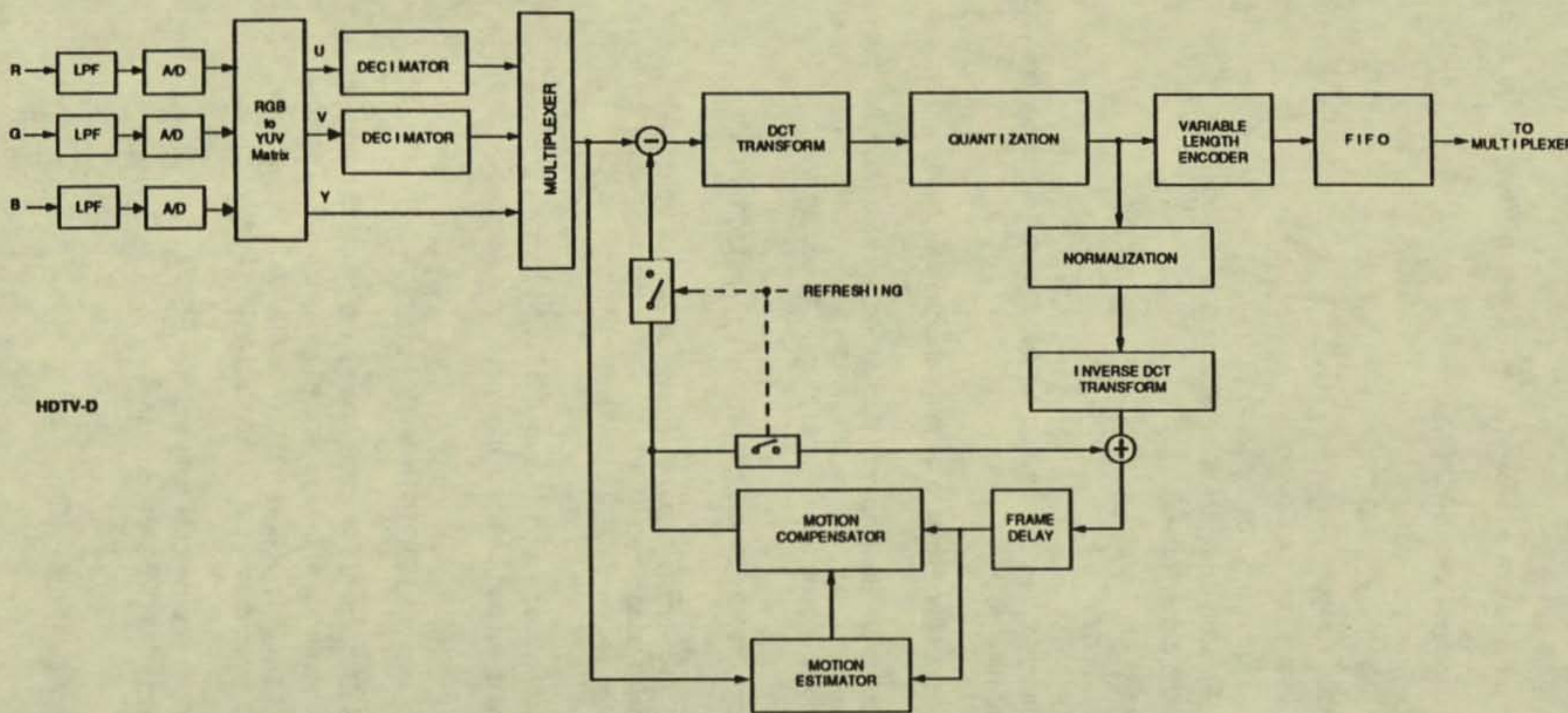


Figure 3-1. Digital Video Encoder Block Diagram

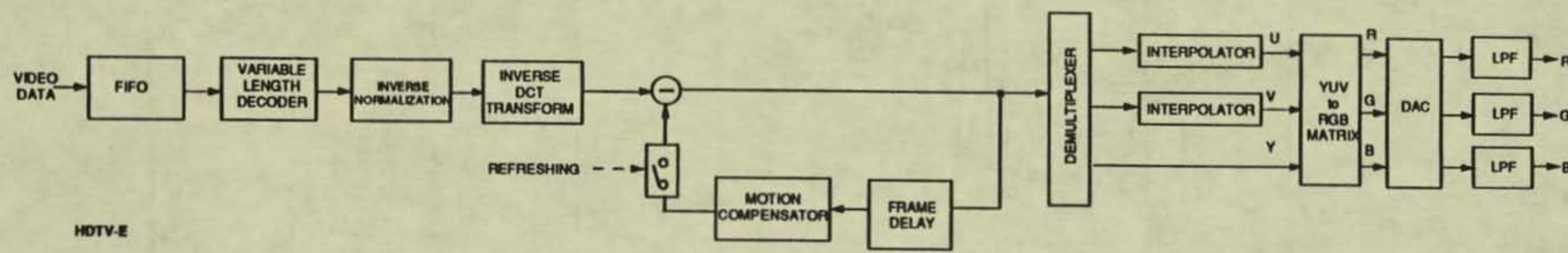


Figure 3-2. Digital Video Decoder Block Diagram

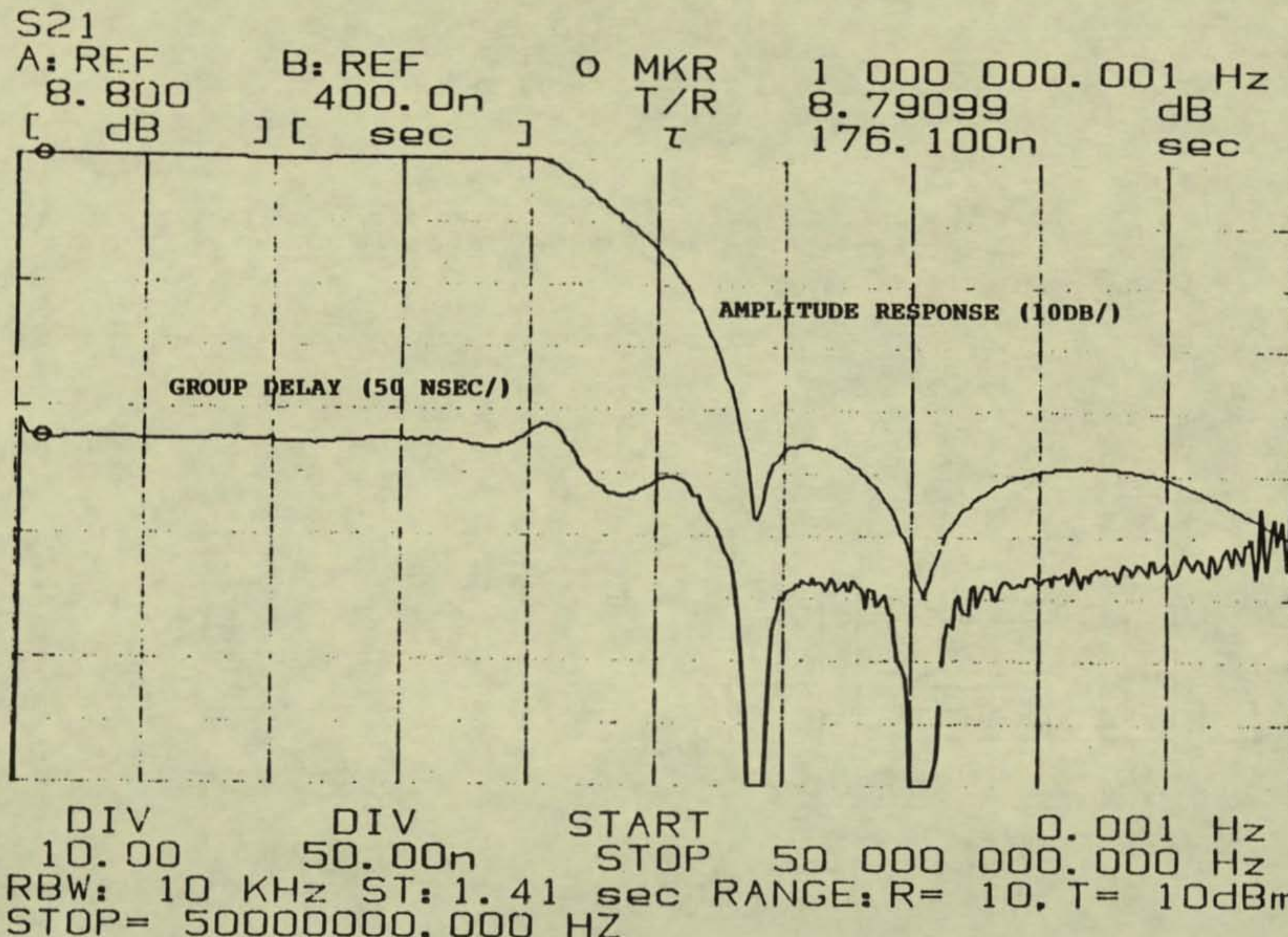


Figure 3-3. Video Lowpass Filter Characteristics

3.2 Chrominance Preprocessor

The resolution of chrominance information can be reduced relative to luminance resolution with only a slight effect on the perceived image quality. The U and V chrominance components are decimated horizontally by a factor of 4 and vertically by a factor of 2.

Horizontal decimation is performed by applying a digital FIR filter prior to subsampling. The impulse response of the FIR filter is shown in Table 3-1. Horizontal interpolation is performed at the decoder by zero-padding and apply the same filter with the gain increased by a factor of four. Vertical decimation by a factor of two is performed by discarding one of every two fields. The decoder reconstructs the interlaced signal by repeating each chrominance field twice.

Since the vertical decimation is performed across two different fields, some degradation in motion rendition occurs. In practice, however, this degradation is very difficult to detect. We are not only less sensitive to reductions in chrominance spatial resolution, but in temporal resolution as well.

The luminance signal (Y) bypasses the chrominance preprocessor, and therefore full resolution is maintained. The chrominance components are then multiplexed with the luminance component, one block at a time, and all components are then subjected to the same processing. At the decoder, the components are again separated and the chrominance signals are interpolated back to full resolution.

3.3 Discrete Cosine Transform

The Discrete Cosine Transform (DCT) transforms a block of pixels into a new block of transform coefficients. A block size of 8 x 8 has been chosen because the efficiency of the transform coding doesn't improve much while the complexity grows substantially beyond the 8 x 8 block size. The transform is applied in turn to each such block until the entire image has been transformed. At the decoder, the inverse transformation is applied to recover the original image.

If $f(i,j)$ represents pixel intensity as a function of horizontal position j and vertical position i, and $F(u,v)$ represents the value of each coefficient after transformation, then the equations for the forward and inverse transformations are

$$F(u,v)=\frac{4C(u)C(v)}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}f(i,j)\cos\frac{(2i+1)u\pi}{2N}\cos\frac{(2j+1)v\pi}{2N}$$

$$f(i,j)=\sum_{u=0}^{N-1}\sum_{v=0}^{N-1}C(u)C(v)F(u,v)\cos\frac{(2i+1)u\pi}{2N}\cos\frac{(2j+1)v\pi}{2N}$$

$$\text{where } C(w)=\begin{cases}1/\sqrt{2} & \text{for } w=0\\ 1 & \text{for } w=1,2,\cdots,N-1\end{cases}$$

where N is the horizontal and vertical dimension of the block.

There are instances when the DCT is not effective in compacting the energy into a small number of coefficients. For example, if the input signal was white noise, then the image energy

Table 3-1. Impulse Response of Horizontal Decimation/Interpolation Filter for Chrominance

COEFFICIENT INDEX	COEFFICIENT VALUE
55,56	0.2505
53,54,57,58	0.1590
51,52,59,60	0.0000
49,50,61,62	-0.0518
47,48,63,64	0.0000
45,46,65,66	0.0297
43,44,67,68	0.0000
41,42,69,70	-0.0197
39,40,71,72	0.0000
37,38,73,74	0.0140
35,36,75,76	0.0000
33,34,77,78	-0.0101
31,32,79,80	0.0000
29,30,81,82	0.0074
27,28,83,84	0.0000
25,26,85,86	-0.0054
23,24,87,88	0.0000
21,22,89,90	0.0038
19,20,91,92	0.0000
17,18,93,94	-0.0027
15,16,95,96	0.0000
13,14,97,98	0.0018
11,12,99,100	0.0000
9,10,101,102	-0.0011
7,8,103,104	0.0000
5,6,105,106	0.0007
3,4,107,108	0.0000
1,2,109,110	-0.0004

would be no less randomly distributed after transformation than it was the in the pixel domain. Under such conditions, the image becomes much more difficult to compress, and in fact, cannot be compressed without introducing artifacts of some form or another. Fortunately, under such conditions, artifacts tend to be much less conspicuous than they would be under more quiet conditions. Also, such conditions are not typical of television video. Generally a high degree of horizontal and vertical correlation exists among adjacent pixels. In the next six sections, the procedure for reducing the number of bits required to represent the DCT coefficients and the effect on the appearance of the image is described.

3.4 Coefficient Quantization

Coefficient quantization is a process that introduces small changes into the image in order to improve coding efficiency. This is done by first weighting each of the DCT coefficients and then selecting 8 bits for transmission to the decoder. Once assigned, the weights for each coefficient are fixed and are never changed. The current implementation uses the weighting matrix shown in Table 3-2. The matrix weighting coefficients represent individual scaling factors for the 8x8 DCT coefficients. As before, horizontal frequency increases from left to right and vertical frequency increases from top to bottom.

Table 3-2. Weighting Table for DCT Coefficients

16	16	19	22	26	27	29	34
16	16	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	83

Each coefficient is initially represented as a 12 bit number which is then divided by the respective weighting factor. However, additional scaling may still be necessary to achieve the desired data rate. Therefore, the weighted coefficients are next divided by a quantization factor. The quantization factor is determined by the quantization level that is periodically adjusted based on scene complexity and perceptual characteristics. The quantization level ranges from 0 to 31. Maximum precision occurs at quantization level 0 and minimum precision occurs at level 30. Level 31 is reserved and indicates to the decoder that no data will be transmitted.

After a 12 bit DCT coefficient is scaled by both the weighting factor and the quantization factor, the 8 least significant bits are selected. In almost all cases, the 4 MSB's will be 0 and therefore no information is lost. However, in some cases where both the weighting and quantization factors are small, it may be necessary to clip the resulting coefficient in order to prevent an overflow or underflow from occurring.

The quantization method described above does not apply to the DC coefficient. The 8 most significant bits of the DC coefficient are always selected, independent of the quantization level.

The subjective effect of excessively quantizing the DCT coefficients is evident, not so much within the block, but when the image is viewed as a whole. The most objectionable artifact almost always tends to be the blocking effect that arises due to the individual processing of each block. The system has been designed to prevent such artifacts from being visible at normal viewing distances (3 x picture height) and make them only occasionally visible at very close viewing distances.

3.5 Huffman Coding

Quantization improves the compressibility of an image by reducing the amplitude of the transform coefficients. In order to take advantage of the result, an algorithm for assigning a variable number of bits to these coefficients is required. At this stage, a statistical coding technique is used, which unlike the quantization process, is information preserving, and therefore, does not degrade the image.

Huffman coding is an optimum statistical coding procedure capable of approaching the theoretical entropy limit, given a priori knowledge of the probability of all possible events. The encoder can generate such probability distributions and send them to the decoder prior to the transmission of a given frame. This table is then used to derive Huffman code words where relatively short code words are assigned to events with the highest probability of occurrence. The decoder maintains an identical code book and is able to match each code word with the actual event. The DigiCipher™ system, however uses a fixed Huffman table for hardware simplicity. The Huffman table has been generated based on a wide variety of materials processed.

In order to apply Huffman coding for this application, the 8 x 8 DCT coefficients are serialized into a sequence of 64, and "amplitude/runlength" coded. Scanning the sequence of 64, an event is defined to occur each time a coefficient is encountered with an amplitude not equal to zero. A code word is then assigned indicating the amplitude of the coefficient and the number of zeros preceding it (runlength). Table 3-3 shows the length of each code word in bits. It does not include the sign bit which must be also included with each code word.

When the coefficient amplitude is greater than 16 or the number of preceding zeros is more than 15, a special code word is used to tell the decoder not to use the code book to interpret the bits that follow. Instead, the runlength is sent uncoded. The coefficient amplitude is also sent uncoded with the number of bits determined by the quantization process described previously. In addition, it is sometimes more efficient to directly code the amplitude and runlength even if it can be coded through the use of the two-dimensional table. The encoder detects these occasions and will switch to direct coding if necessary to shorten the length of the code word. A special code word is also reserved to indicate the end of a block. It is always inserted after the last non-zero coefficient. In addition, the DC coefficient is Huffman coded after it is differentially coded within a superblock. This makes use of the high correlation of DC coefficients within a macroblock and further improves the compression efficiency.

The efficiency of this coding process is heavily dependent on the order in which the coefficients are scanned. By scanning from high amplitude to low amplitude, it is possible to reduce the number of runs of zero coefficients typically to a single long run at the end of the block. The coefficients are zig-zag scanned going down first from the DC coefficient. As defined above, any long run at the end of the block would be represented efficiently by the "end of block" code word.

Table 3-3. Number of Bits Used for Two-Dimensional Huffman Code Book

	AMPLITUDE															
RUNLENGTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	2	3	5	5	6	7	7	8	8	9	9	9	10	10	10	10
1	3	5	6	8	8	9	10	11	11	12	12	13	13	14	14	14
2	4	7	8	9	11	11	12	13	14	14	15	15	16	16	17	17
3	5	8	10	11	12	13	14	15	16	16	17	18	20	19	18	19
4	6	9	11	13	14	15	16	17	18	19	20	21	21	21	22	20
5	6	10	12	13	15	16	18	18	20	20	22	22	22	22	21	22
6	7	10	13	14	16	18	19	20	22	21	22	22	22	22	22	21
7	7	11	13	15	16	17	20	20	21	22	22	21	21	18	20	22
8	8	12	14	16	18	20	20	21	22	22	22	22	22	22	22	22
9	8	13	16	18	20	20	22	22	22	22	22	22	22	22	22	22
10	9	13	17	19	20	19	18	20	22	22	22	22	22	22	22	22
11	9	13	16	16	20	21	22	21	22	22	22	22	22	22	22	22
12	9	15	18	21	22	22	22	22	22	22	22	22	22	22	22	22
13	10	16	20	22	22	22	22	22	22	22	22	22	22	22	22	22
14	10	17	20	22	22	22	22	22	22	22	22	22	22	22	22	22
15	11	18	21	22	22	22	22	22	22	22	22	22	22	22	22	22

3.6 Motion Estimation and Compensation

There is a limit to the amount of compression possible by spatial processing alone. An interframe coder, however, can benefit from temporal correlation as well as spatial correlation. A very high degree of temporal correlation exists whenever there is little movement from one frame to the next. Even if there is movement, high temporal correlation may still exist depending on the spatial characteristics of the image. If there is little spatial detail, then frame-to-frame correlation remains high even at high velocities. If the image is highly detailed, however, and contains high spatial frequencies, then even slight displacements of one pixel or less can significantly reduce the amount of correlation that exists.

In the DigiCipher™ system, we compress the signal by first predicting how the next frame will appear and then sending the difference between the prediction and the actual image. A reasonable predictor is simply the previous frame. This sort of temporal differential encoding (DPCM) will perform very well if little movement occurs or if there is little spatial detail. At other times, it will be less effective and occasionally worse than if the next frame had simply been encoded without prediction (PCM).

Motion compensation is a means of improving the performance of any temporal compression scheme when movement occurs. In order to apply motion compensation, it is first necessary to determine what has moved since the previous frame and where it has moved to. If this information is known at the decoder site, then the previous frame can be shifted or displaced in order to obtain a more accurate prediction of the next frame that has yet to be transmitted. The encoder would reproduce the same prediction as the decoder and then determine the difference between the prediction and the actual image. If the movements match the model used to estimate motion and if the motion estimates are accurate and the signal is free of noise, then this error signal would, in fact, be zero.

Displacement of the previous frame can be performed on a frame, partial frame, or pixel basis. That is, a unique displacement (motion vector) could be generated for every frame, part of a frame, or every pixel respectively. The usefulness of generating a single motion vector per frame, however, is limited since it can only model simple panning of the entire image. Ideally, a unique motion vector would be generated for each pixel. However, since motion estimation is a complex process and requires knowledge of the next frame, it can only be performed at the encoder, and the overhead involved in making this per-pixel motion information available to the decoder would be excessive. Therefore, the motion estimation is performed on a partial frame basis with the area of the portion chosen to equal a superblock. The superblock has a horizontal dimension equal to 4 DCT blocks and a vertical dimension equal to 2 DCT blocks. This sizing is compatible with the 4 times horizontal subsampling and 2 times vertical subsampling of the chrominance components, thus allowing the same motion vector to be used to displace a single chrominance DCT block.

The process of displacing portions of the previous frame in order to better predict the next frame is illustrated in Figure 3-4.

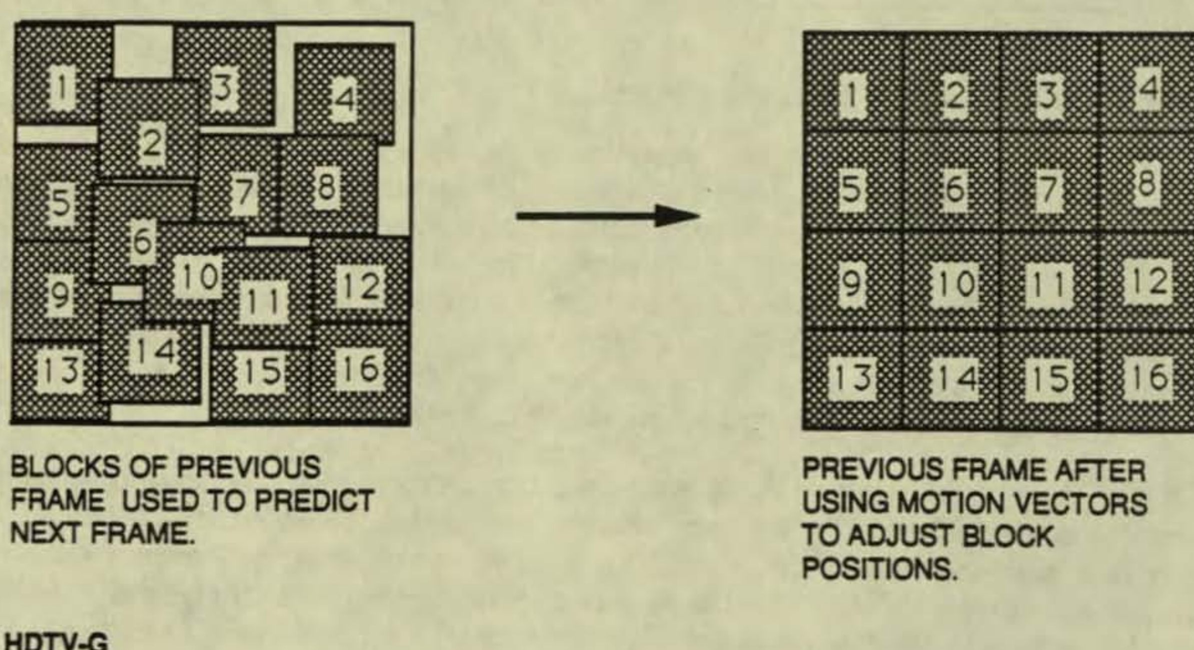


Figure 3-4. Using Motion Compensation to Predict Next Frame

The search area covered by the full current frame/previous frame search algorithm is +31/-32 pixels horizontally and +7/-8 pixels vertically. The greater horizontal tracking range is due to the increased likelihood of rapid horizontal motion. These limits allow the tracking of objects moving at 0.68 picture widths per second and nearly 0.25 picture heights per second. The overhead required to send a single motion vector to the decoder is 10 bits per superblock (approximately 0.0195 bits/pixel).

3.7 Integration of Motion Compensation with Intraframe Coding

As shown in the encoder and decoder block diagrams in Figures 3-1 and 3-2 respectively, motion compensation is easily integrated into the overall system design. Instead of transform coding the image directly, an estimate of the image is first generated using motion compensation. The difference between this estimate and the actual image is then transform coded and the transform coefficients are then normalized and statistically coded as before. The second of the two frames from which the motion estimates are derived is always the previous frame *as it appears after reconstruction by the decoder.* The encoder thus must include a model of the decoder processing.

As stated previously, a lower bit rate is occasionally possible by direct PCM coding of a block instead of using motion compensation and coding the differences. Therefore, to obtain the lowest possible bit rate, the encoder determines the number of bits required for each of the two methods and then selects the method requiring the fewest bits, on a per-block basis. The overhead required to inform the decoder of the selection is thus one bit per block. For most scenes, the motion compensation rate averages between 85% to 100%. During scene changes, however, the compensation rate can drop to less than 10%.

Differential processing in general causes a basic problem for the decoder. When a decoder is tuned to a new channel, it has no "previous frame" information. Acquisition would be delayed until at least 1 PCM version of every block was received, which would result in an unbounded acquisition time. There are two basic schemes for achieving an acceptable acquisition time:

1. Every one second, all blocks of a frame can be sent in PCM form. This technique results in a DPCM-based acquisition time component of from 0 to 1 second, evenly distributed. However, the resulting large number of channel bits due to the less efficient PCM coding is difficult for the encoder buffer to handle, and may cause visible artifacts in the reconstructed image.

2. During each 0.37 second interval, process all blocks once in PCM form on a distributed basis. This technique results in a 0.37 second DPCM-based acquisition time component, but spreads the resulting increase in channel bits uniformly over time.

The DigiCipher™ system uses the second approach. Note that 0.37 second parameter would imply a forced PCM block once every 11 frames, and there is a necessary but non-trivial reduction (about 9%) in the overall compression efficiency. The 0.37 second parameter can be varied to trade off acquisition time versus efficiency.

3.8 Adaptive Field/Frame Encoding

There are two options when processing interlaced signals. The first option is to separate each frame into its two fields and then process the two fields independently (Figure 3-5). The second option is to process the two fields as a single frame by interleaving the lines of corresponding even and odd fields (Figure 3-6).

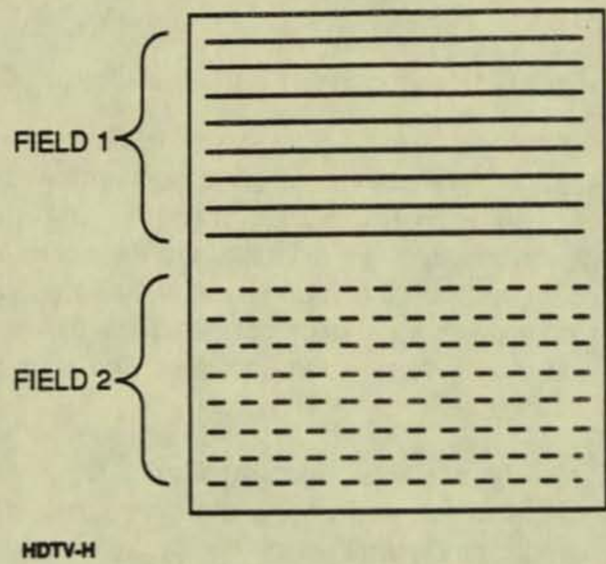


Figure 3-5. Field Processing

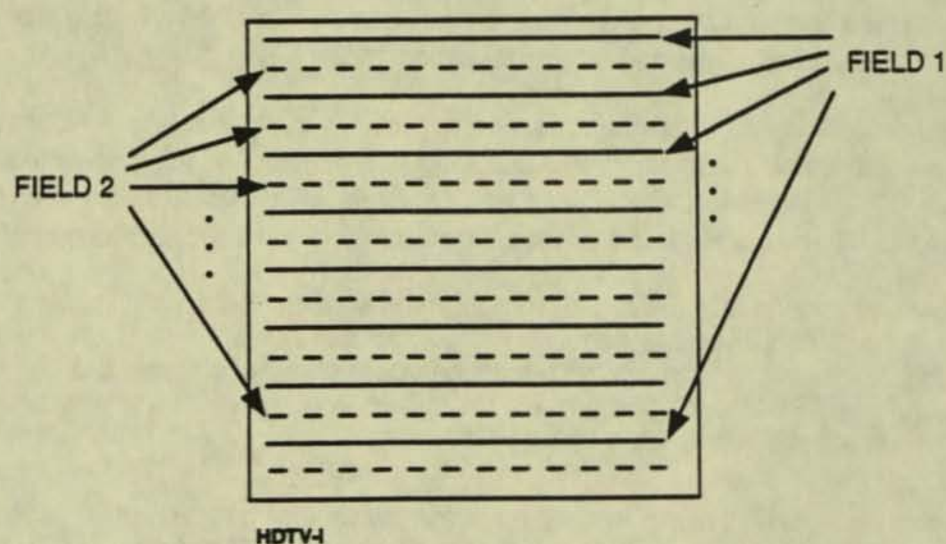


Figure 3-6. Frame Processing

Frame processing works better than field processing when there is little or no motion. Since each frame has twice as many lines or samples for a given picture height, there will be more correlation between samples and hence compressibility will be increased. Therefore, to achieve the same accuracy, field processing will require a higher bit rate, or alternatively, for equal bit rates, frame processing will achieve greater accuracy.

Similar advantages over field processing will be realized if horizontally moving features have little horizontal detail or if vertically moving features have little vertical detail. In other regions, where there is little detail of any sort, frame processing may still work better than field processing, no matter how rapidly changes occur.

Field processing generally works better than frame processing in detailed moving areas. In such cases, the interleaving of the even and odd fields would introduce spurious high vertical frequencies into the frame processing system. This would reduce the correlation between lines and therefore the effectiveness of the compression algorithm.

The DigiCipher™ HDTV System uses a novel method that has been developed to combine the advantages of both frame processing and field processing. It permits video signals to be compressed and then reconstructed with minimal degradation in motion rendition.

A selection between frame processing and field processing based on achieving minimum error has been found to be very effective. Still or slowly moving regions are rendered much more accurately than would be possible in a field-only processing system, while motion rendition is much better than would be possible in a frame-only processing system. Since the selection is made on a local basis, the system can adjust to scenes containing both moving and non-moving features.

Other simulated and less effective selection methods for the field/frame decision include simple motion detection schemes and criteria based on minimizing the number of bits used to represent the image.

Since one bit per superblock of side information is included in the encoded signal that is transmitted, decoder complexity can be significantly reduced. Field and frame processing decisions are not made at the decoder, and are instead extracted from the encoded video signal.

3.9 Motion Picture Processing

Almost all movies developed for the cinema and a significant amount of program material developed for television are initially acquired on film. Except for a few special cases, the display rate used for film is 24 frames/second, and therefore the motion rendition is significantly degraded in comparison to normal television video. Eventually, when this program material is converted to the NTSC television standard, a process called three-two pulldown is used. As shown in Figure 3-7, it involves alternating between three repetitions and two repetitions of each frame of the film.

Since the three-two pulldown process increases the number of video frames from 24 to 30 without increasing the amount of information in the signal, the first step in the source coding process is to restore the signal to its original state. Since one of every five fields is redundant, it can either be discarded, or averaged with the other identical field as shown in Figure 3-7. In the latter case, a 3 dB noise reduction results; however, its significance is questionable, since it will benefit only one of every four fields.

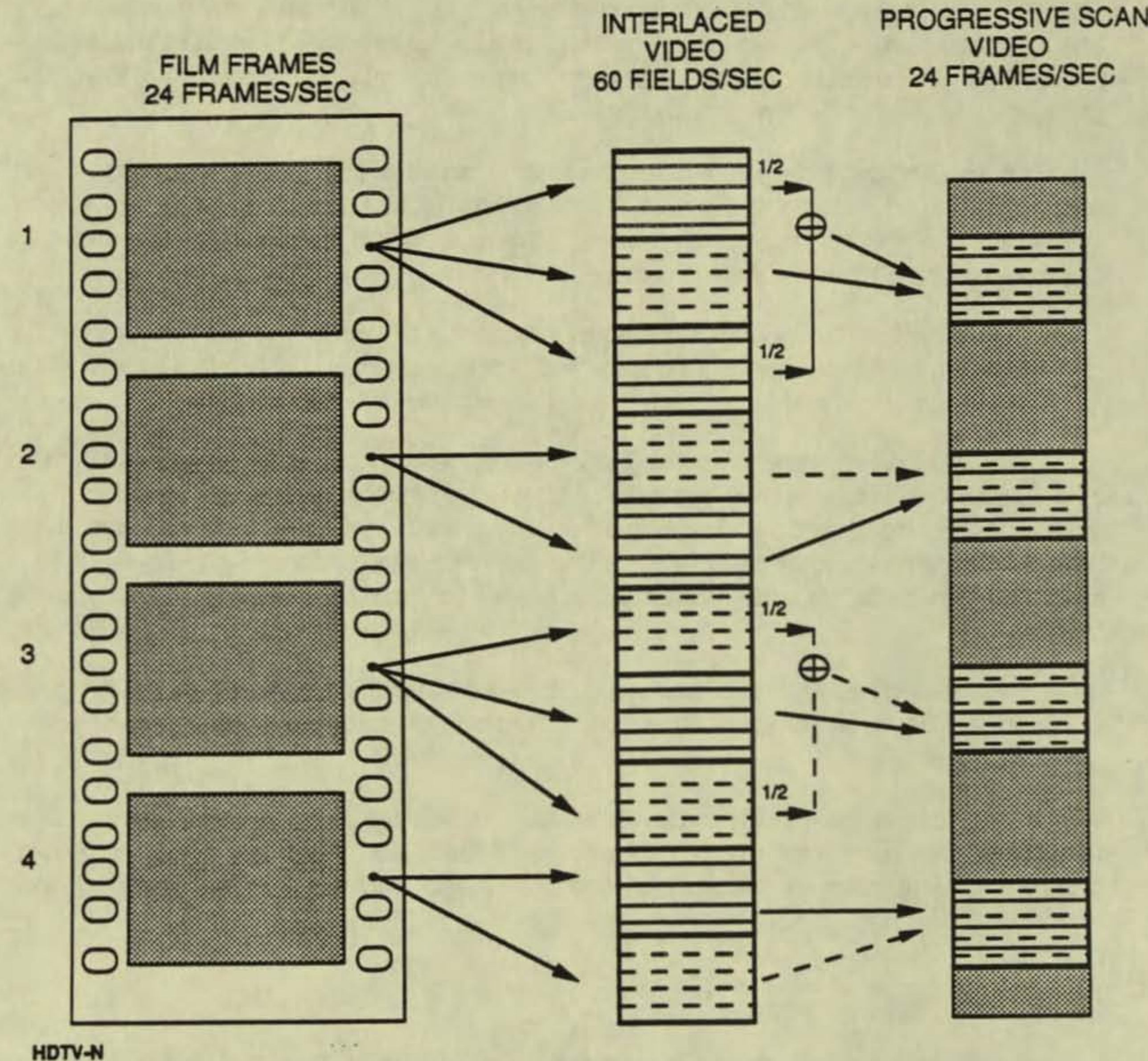


Figure 3-7. Conversion of Film to Interlaced Videoand Restoration of Progressive Scan

After the 24 frame/second signal is reconstructed at the decoder, it must be converted back to 60 fields/second before it can be displayed. This is easily accomplished by applying the three-two pulldown process once again.

The DigiCipher™ System processes material shot on film in this matter to further improve performance. Other video source material is, of course, handled without going through this process.

3.10 Rate Buffer Control

Each single channel video processing section in the encoder requires a rate buffer in order to match the variable rate of the Huffman-coded data to the fixed output rate necessary for channel transmission. This rate buffer is implemented as a one frame FIFO located after the Huffman encoder. The total storage size is large enough to handle variations of plus and minus one field.

In order to prevent the video output buffer FIFO from overflowing or underflowing, the FIFO input block rate must be continuously adjusted. This is the purpose of the multi-quantization level coding structure. As the quantization level is incremented, quantization becomes coarser, blocks are shortened, and an increase in the FIFO input block rate results. As the quantization level is decremented to a minimum level of 0, finer quantization results in longer blocks, and a reduced FIFO input block rate. This adjustment has the required effect of keeping the bit rate into the FIFO relatively constant. The status of the buffer is continuously monitored, and as long as the number of stored blocks remains within a predetermined window, the quantization level will remain unchanged. If the buffer level drops below the lower threshold or rises above the higher threshold, then the quantization level will decrement or increment respectively. Fill bits may need to be inserted into the channel in order to prevent underflows during the transmission of very simple images.

4. DIGITAL AUDIO PROCESSING

The DigiCipher™ HDTV system uses Dolby Laboratories' AC-2 digital audio system that combines highly efficient data compression with professional-quality audio transparency. It uses frequency-domain signal processing in a multiplicity of narrow bands to take full advantage of psychoacoustics and noise masking. The functions of the encoder and the decoder are described in the following. Refer to Appendix B for additional detail.

4.1 Digital Audio Encoder

Figure 4-1 shows the block diagram of the encoder. The encoder accepts two channels of analog input signals. They are lowpass filtered and synchronously quantized to 16-bit precision using dual high-quality A/D converters. The 16-bit PCM output data representing both audio channels is processed using the Dolby AC-2 algorithm at 24-bit precision and formatted along with the 1200 bps data into a single serial output data stream at 252 kbits/second.

The dynamic range of the Dolby AC-2 process exceeds that of the current A/D and D/A converter technology. For protection against A/D converter overload, independent safety limiters provide up to 10 dB of gain reduction. The limiter control signals can be linked to preserve image stability with stereo program signals.

The Dolby AC-2 process is designed to be tolerant of random data errors which may occur between encode and decode. In addition, it incorporates Reed-Solomon error protection for certain bits in the AC-2 format. This protection scheme provides sufficient protection for random bit errors to 1×10^{-5}.

4.2 Digital Audio Decoder

Figure 4-2 shows the block diagram of the decoder. The decoder accepts the 252 kbits/second AC-2 serial data stream and a clock signal. Complementary processing is performed at 24-bit precision to recover the two main audio signals which are passed to high-quality 16-bit D/A converters. The two audio signals and 1200 bps data are available as outputs on the rear panel.

Both encoder and decoder provide front panel accessible input and output level controls, system status indicators and LED calibration displays. An internally generated 1125 Hz calibration signal is provided for system alignment.

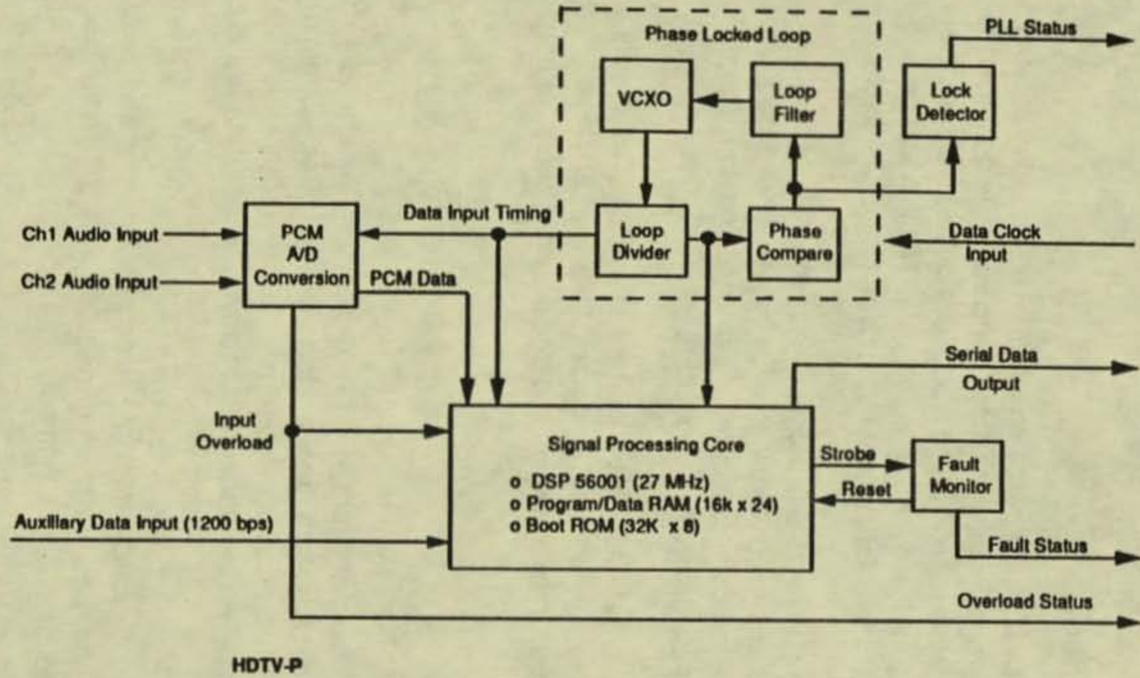
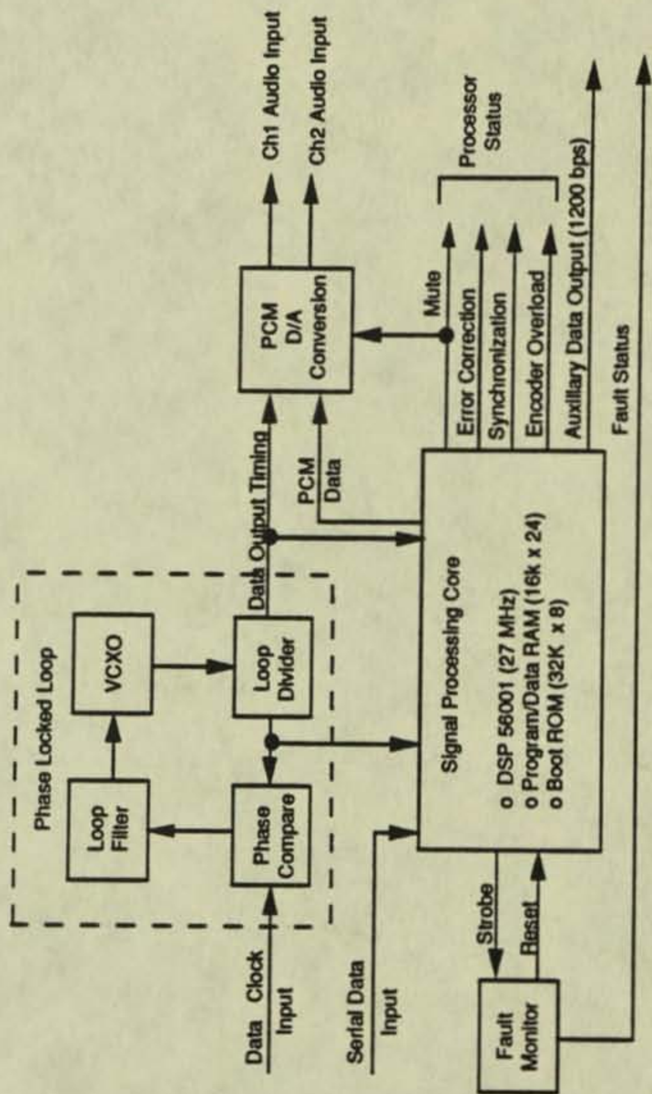


Figure 4-1. Digital Audio Encoder Block Diagram



HDTV-Q

Figure 4-2. Digital Audio Decoder Block Diagram

5. DATA PROCESSING AND DATA MULTIPLEX FORMAT

The DigiCipher™ HDTV system can allocate data capacity to support various services such as additional audio channels, "5.1" channel (left, right, left rear, right rear, center, and subwoofer) surround sound system (Dolby AC-3 system, for example), descriptive video, special audio for the hearing impaired, expander control data, program guide, closed captioning, program mode control, conditional access, and teletext. The encoder can adaptively allocate unused data capacity back to the digital video processor to optimize the video performance. The prototype DigiCipher™ HDTV system supports the data processing described as follows.

5.1 Data Channel Processing

The DigiCipher™ transmission format has 4 bits per line, (8 bits per 2 line time), assigned to data channel capacity. This allocation of 125.87 kbps is sufficient capacity for 13 9600 baud data streams. The initial DigiCipher™ design will support 4 such data streams, with the remaining capacity reserved.

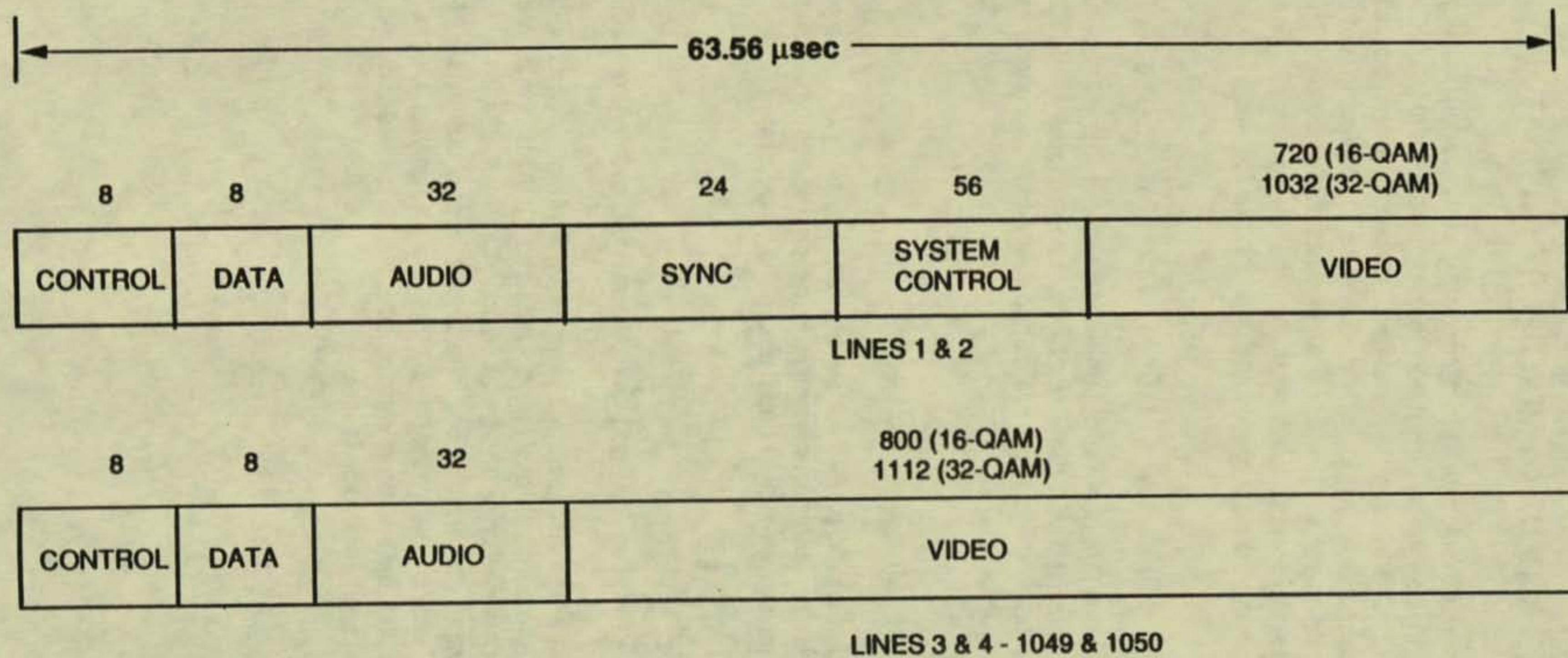
5.2 Control Channel Processing

The DigiCipher™ transmission format has 4 bits per line time, (8 bits per 2 line time) which amounts to 125.87 kbps to for the control channel (subscriber addressing). There is great flexibility allowed in message mixing within the control channel on a bit stream.

5.3 Data Multiplex Format

This section defines the data multiplex for video, audio, data, text, and control channel.

Prior to forward error coding at the encoder, each pair video line time (corresponding to one NTSC line time) includes 848 information bits for 16-QAM and 1,160 information bits for 32-QAM. Figure 5-1 shows the data transmission format. During lines 1 & 2, a 24-bit sequence is transmitted for maintaining overall synchronization. The system control contains a 24-bit control word, a 16-bit frame count, and a 16-bit NMP (next macroblock position) word. The NMP indicates the beginning position of the next macroblock and it is used during the initial acquisition or when the overall synchronization is lost.



HDTV-R

Figure 5-1. Data Multiplex Format

6. DIGITAL TRANSMISSION

Modulation and channel coding are key elements of the DigiCipher™ system. The modulation technique must be efficient in order to send the required number of information bits reliably through a single 6 MHz VHF or UHF channel. The channel coding technique must be powerful in order to maintain a very low error rate; the more compression (source coding), the more serious the effect of a single error.

Figure 6-1 shows the basic communication system blocks, including coding, modulation, pulse shaping (transmit filtering), receive filtering, demodulation, tracking, and decoding.

Adaptive equalization is employed to handle the reflections (multipath) found in typical VHF or UHF reception. Details of the DigiCipher™ digital transmission system are described in the following sections.

6.1 Forward Error Correction

The DigiCipher™ system uses concatenated trellis coding and block coding to protect against the effect of channel errors. Concatenated coding is one of the most powerful error correction techniques and it offers error free operation at low C/N and/or low C/I condition.

Figure 6-2 and Figure 6-3 show the block diagrams of the FEC encoder and the FEC decoder, respectively. A trellis decoder (rate 3/4 for 16-QAM and rate 4/5 for 32-QAM)is used for the inner code, as it supports the use of soft decisions easily. A Reed-Solomon decoder (rate 106/116, t=5 for 16-QAM and rate 145/155, t=5 for 32-QAM) is used for the outer code, as its built-in burst error correcting capability can handle burst errors produced by the trellis decoder. Interleaver #1 is used to improve the performance of the Reed-Solomon decoder by dispersing the burst errors generated by the trellis decoder. Interleaver #2 is used to combat burst or impulsive noises such as car ignition noise. It can effectively handle 3 μsec long impulse noises.

Figure 6-4 shows measured performance of the DigiCipher™ transmission system. Notice that the system threshold is approximately 12.5 dB C/N for 16-QAM and 16.5 dB C/N for 32-QAM where the noise power is measured over a 5 MHz bandwidth. At this threshold there will be one uncorrected error per minute and the video degradation is not quite perceptible because the digital video decoder almost always detects uncorrected errors and provides error concealment.

6.2 Modulation

The modulation selected for digital transmission over the VHF or UHF channel is 16/32-QAM at 4.88 Msps. The 16-QAM has extremely low threshold thus providing wider coverage while the 32-QAM provides higher video quality with 4 dB higher threshold. Consumer HDTV receivers can be easily designed to accept either signals and automatically detect the transmitting mode. Therefore, the choice between the two operating modes can be left to local broadcasters as a tradeoff between the coverage versus video quality.

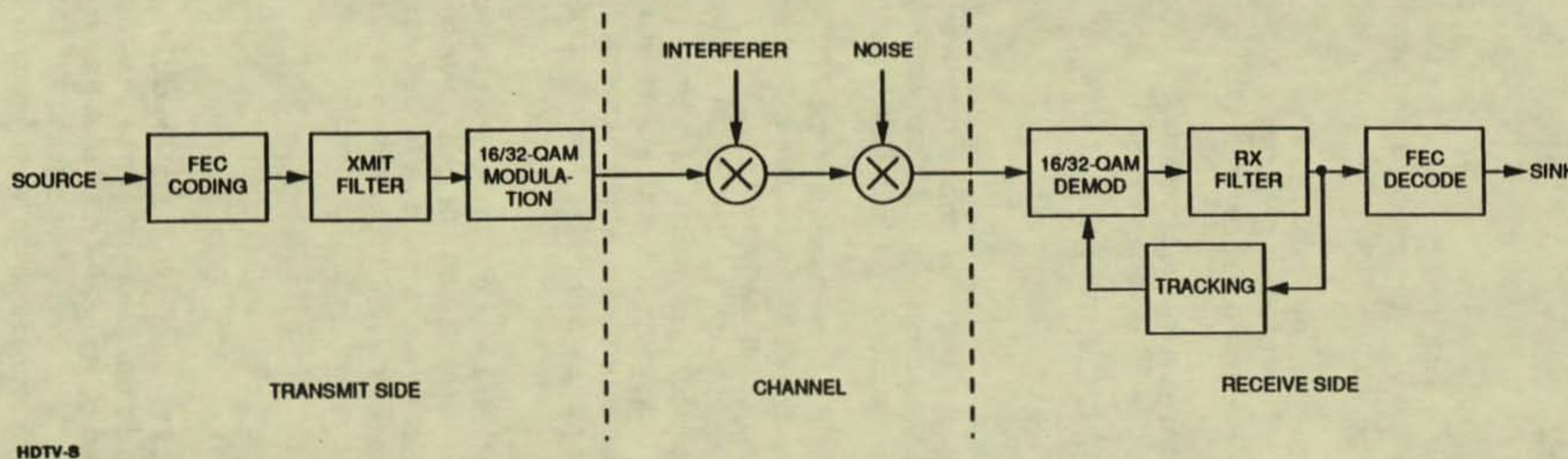


Figure 6-1. Communication System Blocks

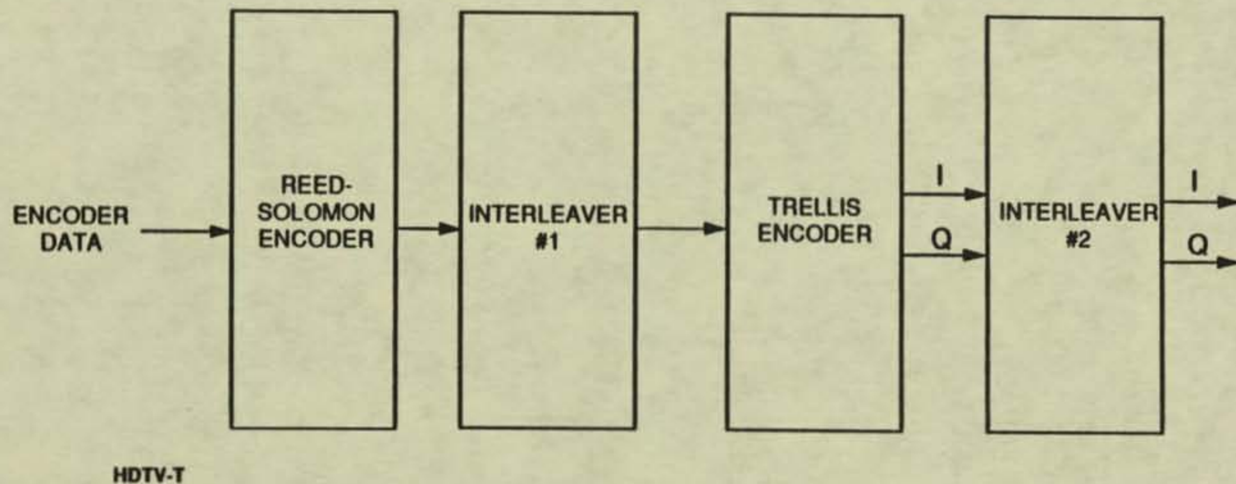


Figure 6-2. FEC Encoder

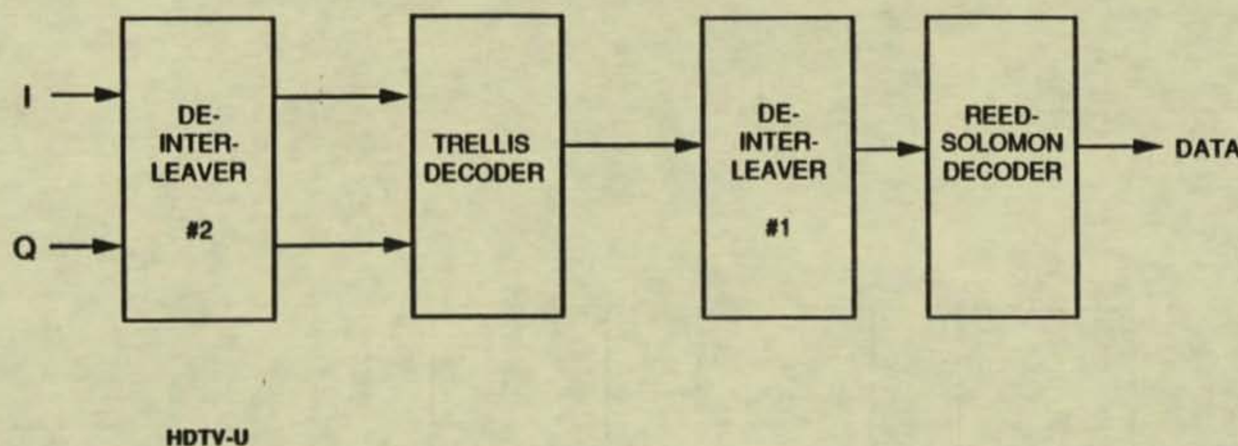
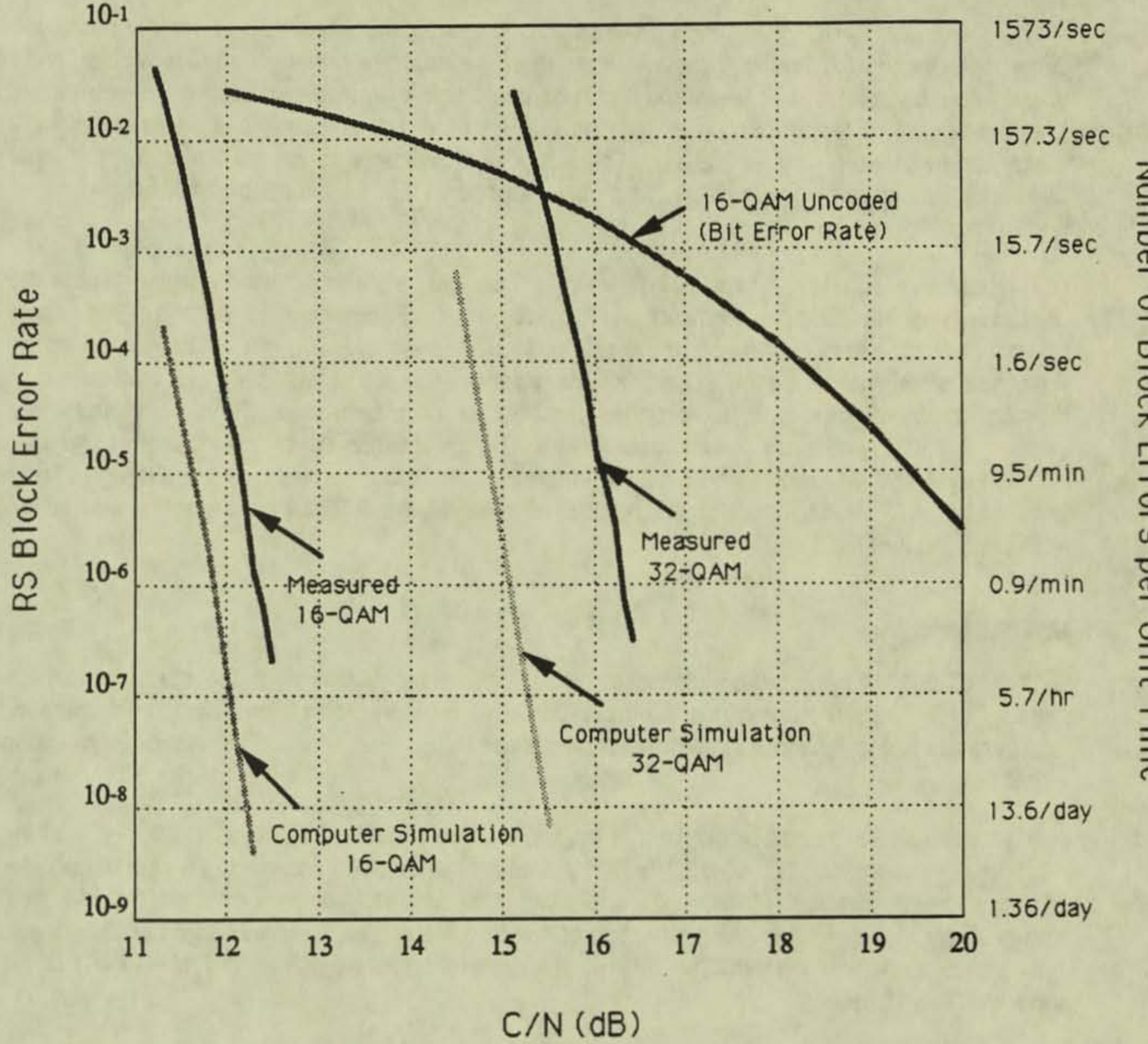


Figure 6-3. FEC Decoder



HDTV-V

Figure 6-4. Performance of DigiCipher™ Transmission System

Figure 6-5 shows the signal constellations of the QAM signal. Digital filtering with a 21% roll-off raised cosine is used to prevent adjacent channel interference. SAW filters are used to further remove spurious signals. Figure 6-6 shows the output spectrum of the encoder. Notice that the output spectrum is well contained within a 6 MHz bandwidth.

6.3 Adaptive Equalizer

The DigiCipher™ HDTV receiver uses a 256 tap adaptive equalizer to handle multipath distortions. Figure 6-7 shows the block diagram of the adaptive equalizer. The effective range of the equalizer is -2 to +24 μsec and it can handle single or multiple echoes within the range. The level of the multipath can be as high as -6 dB for close-in echoes (-2 to +4 μsec) and -12 dB for long echoes (+4 to +24 μsec). The adaptive equalizer also compensates for non-ideal frequency response or group delay distortions caused by the transmitting amplifier, antennas, and the tuner.

The adaptive equalizer uses LMS (least mean square) algorithm. It constantly adjusts the coefficients of the 256-tap complex FIR (finite impulse response) to optimize the signal constellation for the soft decision in the presence of noise, multipath, and interference. In the presence of an interfering NTSC signal, the adaptive equalizer automatically creates notch filtering at visual, color, and audio carrier frequencies as a byproduct. This contributes to a superior NTSC interference rejection capability. The system can operate almost error free at 0 dB C/I in the 16-QAM mode and 5 dB C/I in the 32-QAM mode where C is the average carrier level of the ATV signal and I is the peak sync level of the NTSC interference signal at the VHF/UHF input of the tuner.

6.4 Tuner

The 16/32-QAM demodulator does not place any special requirements on the tuner but the DigiCipher™ HDTV prototype has a double-conversion tuner. It has improved characteristics compared to a conventional single-conversion tuner in the area of spurious response rejection capabilities.

Figure 6-8 shows the block diagram of the tuner. The first IF frequency is 1200 MHz and the second IF frequency is 43.5 MHz. The first IF frequency has been chosen to be high enough for spurious free reception of all VHF and UHF frequencies, yet low enough for low cost implementation of the tuner. The selection of the 43.5 MHz IF as compared to 44 MHz is due to the availability of off-the-shelf SAW filters. The operating range of the VHF/UHF input to the tuner is -70 to -5 dBm.

The channel selection can be made by entering a two-digit number or by depressing the channel up/down key on the front panel.

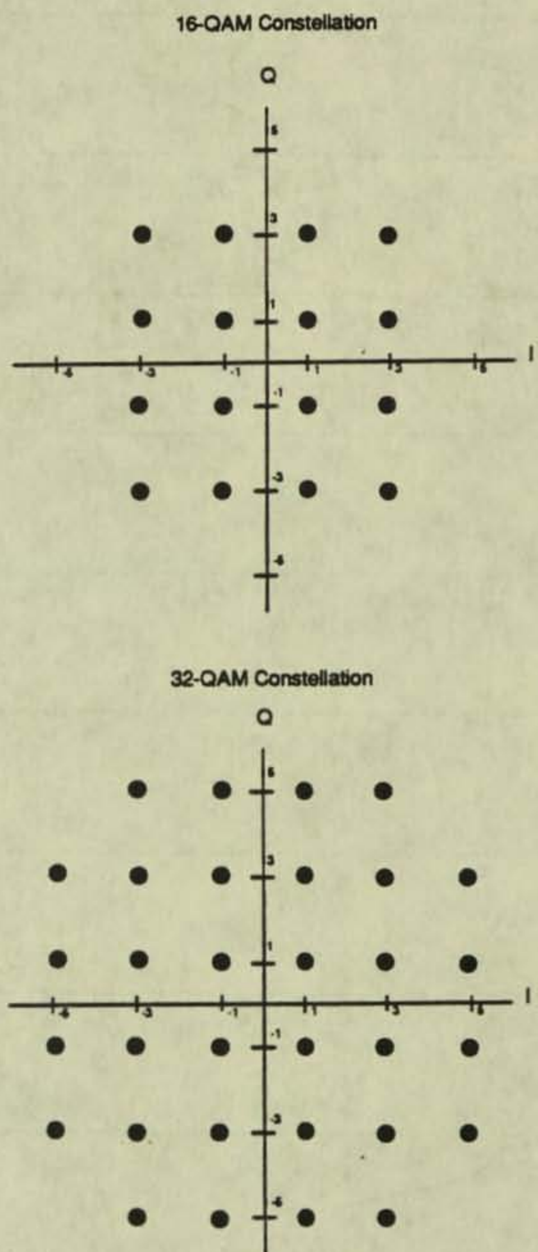


Figure 6-5. Signal Constellations of 16-QAM & 32-QAM Signals

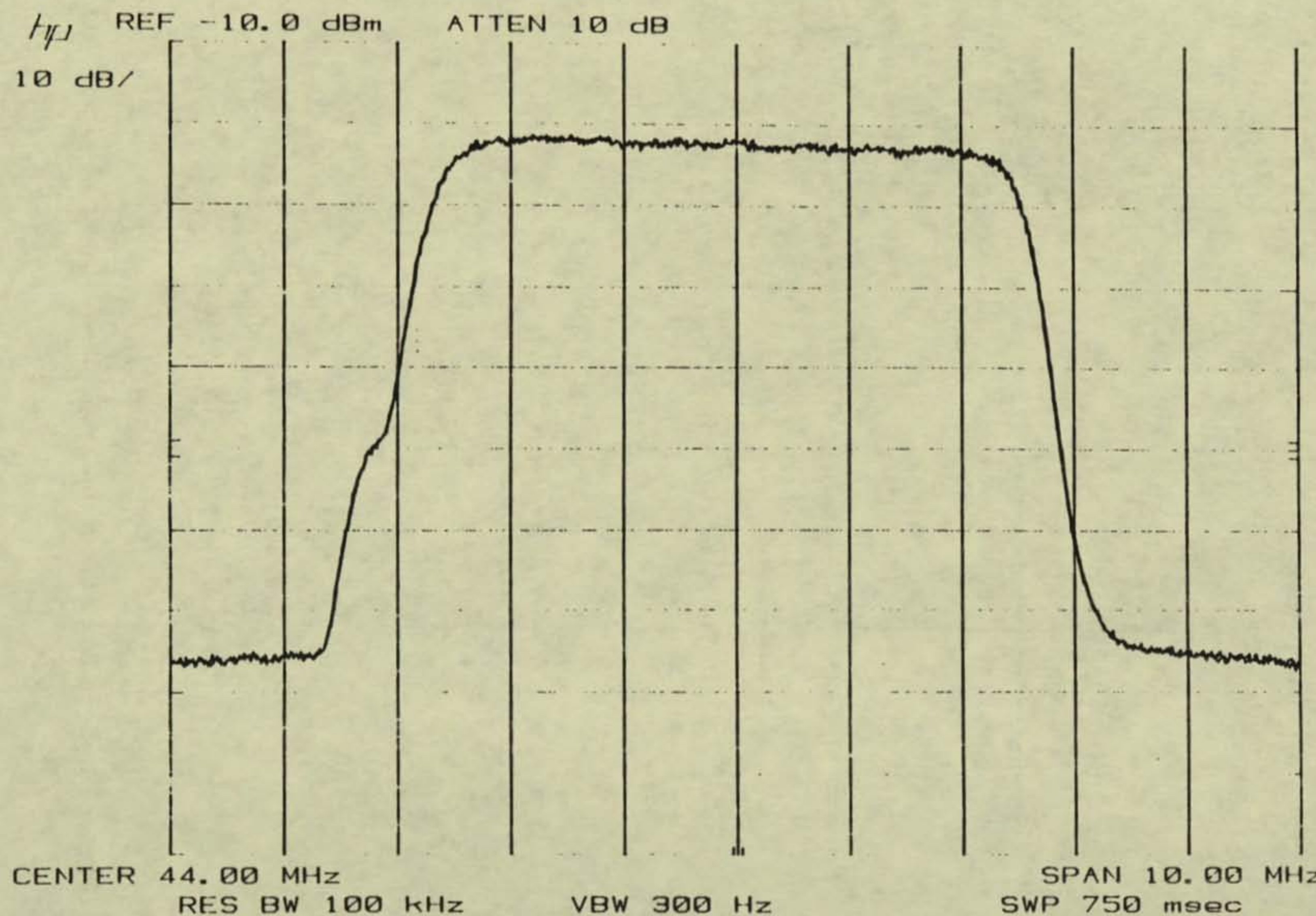


Figure 6-6. IF Output Spectrum

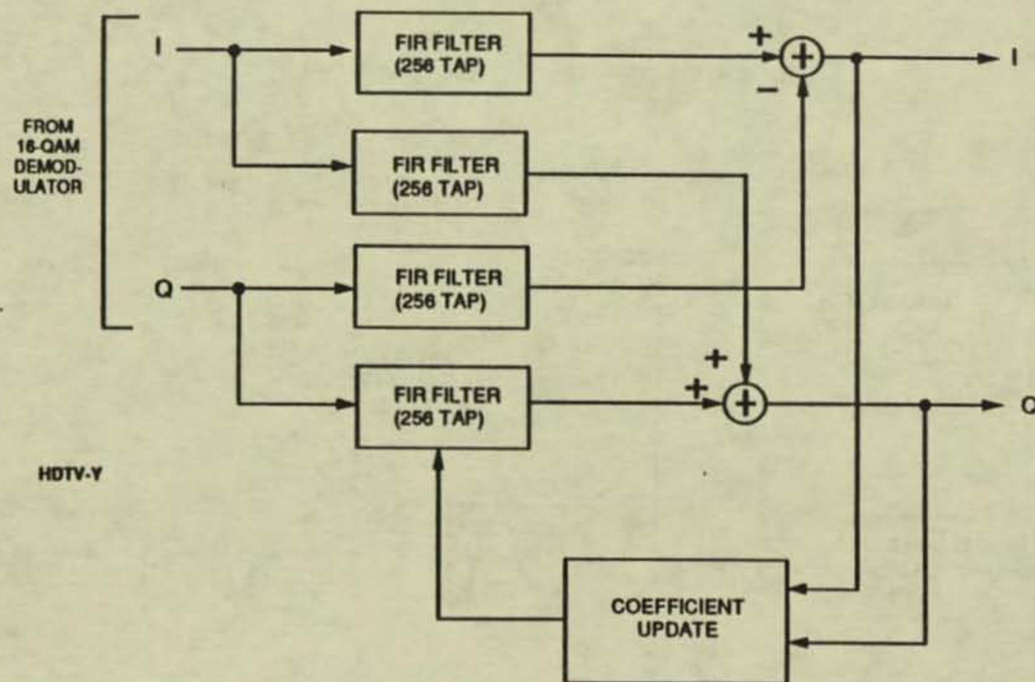


Figure 6-7. Adaptive Equalizer Block Diagram

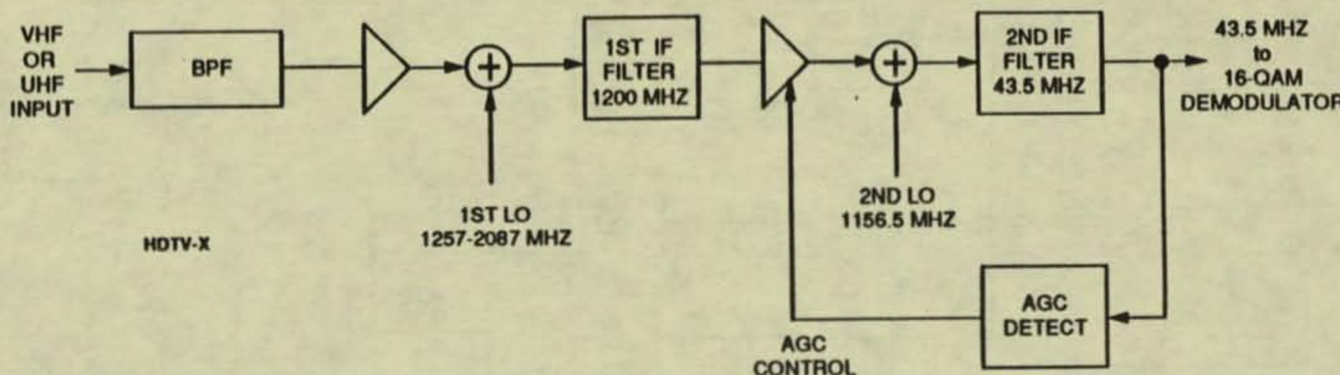


Figure 6-8. HDTV Tuner Block Diagram

6.5 Transmitting System Requirements

The DigiCipher™ system has been designed to be able to tolerate distortions that can be introduced by ATV transmitting systems. Table 6-1 shows the specifications that ATV transmitting system needs to meet for proper operation of the system in the 32-QAM mode.

The system will operate at the max tolerable limit but with additional degradation in C/N of several decibel. It is likely that the system can tolerate distortions beyond the max tolerable limit and it requires further study. Also the 16-QAM mode can tolerate a little more distortions than the 32-QAM mode. The rank indicates the importance of the parameters where rank of 1 indicates the most critical parameter and the rank of 6 indicates the least critical parameter.

Table 6-1. Transmitting System Specifications

Parameter	Specification	Max Tolerable Limit	Rank
Frequency Response (over 6 MHz):	± 1 dB	± 2 dB	4
Group Delay (over 6 MHz):	± 50 nsec	± 100 nsec	3
Amplitude Non-Linearity:	3%	5%	1
Incidental Carrier Phase Mod:	± 2 degrees	± 3 degrees	2
Output System Return Loss (over 6 MHz):	-20 dB	-10 dB	6
AC Hum:	-40 dB	-30 dB	5

7. SYNCHRONIZATION

The DigiCipher™ HDTV System has been designed to provide fast, reliable acquisition in the presence of noise, multipath, and interference. Through the use of advanced digital processing, the acquisition and synchronization time has been minimized.

7.1 Clock Synchronization

Figure 7-1 shows the block diagram of the clock/sync generator used in the encoder and the decoder. A VCXO generates a master clock at 214.6154 MHz. All the clocks used for the digital video processing and the 16/32-QAM modem are derived from the master clock. The encoder synchronizes the master clock into the 31.47 kHz horizontal sync provided externally. The decoder synchronizes the master clock into the QAM symbol rate. The phase-locked loops have been designed to minimize the clock jitter (a few nsec).

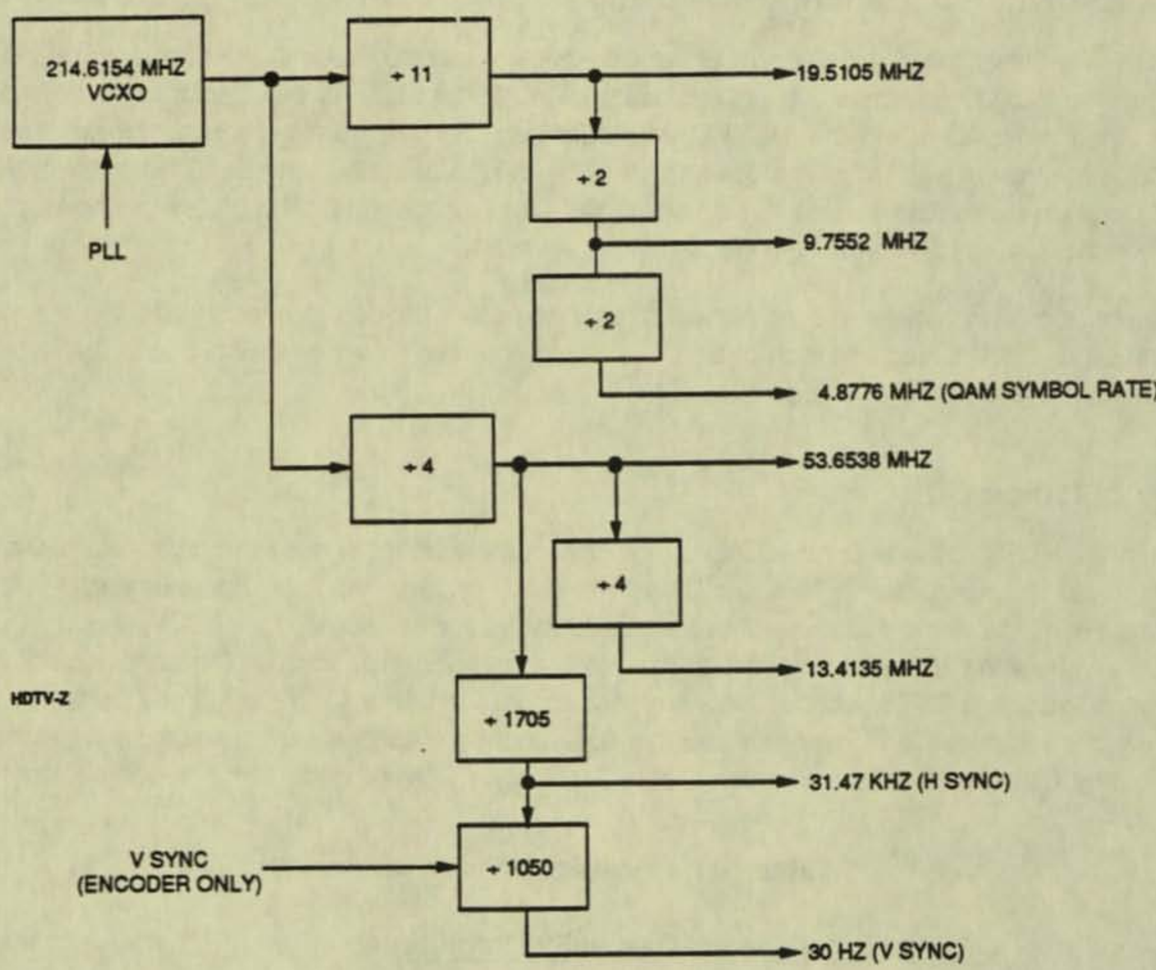
The encoder also makes use of vertical sync externally provided to synchronize the frame vertical sync. The decoder synchronizes the internal vertical sync by using the 24-bit sync generated by the encoder.

7.2 Acquisition

When the HDTV receiver is tuned into a new channel, the decoder goes through a number of synchronization processes. The DigiCipher™ HDTV system requires approximately 0.40 seconds for QAM demodulator and overall synchronization to occur, and 0.37 seconds for complete refreshing of the decoded video. Total acquisition time of the Digicipher™ HDTV system, therefore, is 0.77 seconds. However, subscribers will be able to start to see portions of the new channel video and hear the audio in 0.4 seconds. Apparent acquisition time is thus significantly faster than 0.77 seconds. Table 7-1 lists the breakdown of the synchronization process.

Table 7-1. Signal Acquisition time

QAM Demodulator and Overall Synchronization	
AGC	0.05 sec
Bit Sync	0.10 sec
Adaptive Equalizer	0.10 sec
Carrier Sync	0.10 sec
Interleaver	0.02 sec
24-bit Sync	0.03 sec
Total	0.40 sec
Digital Video Decoder	
DPCM Refreshing	0.37 sec
Total Acquisition Time	**0.77 sec**



HDTV-Z

Figure 7-1. Clock/Sync Generator

8. HARDWARE DESCRIPTION

The DigiCipher™ HDTV prototype hardware has been designed to fully comply with the ATTC interface specifications. The system consists of two 6', EMI shielded racks; one for the encoder and one for the decoder. The encoder and the decoder draw approximately 15 amps each at 120 volts AC.

8.1 Encoder

The encoder consists of 16 multi-layer printed circuit boards in a rack mountable cage. The encoder also has a power supply, a fan, 2 audio synchronizers, 2 Dolby® AC-2 digital audio encoders, video distribution amplifiers, a control panel, and an interface panel mounted in a rack as shown in Figure 8-1.

8.2 Decoder

The decoder consists of 11 multi-layer printed circuit boards in a rack mountable cage. The decoder also has a power supply, a fan, a VHF/UHF tuner, video distribution amplifiers, a control panel, and an interface panel mounted in a rack as shown in Figure 8-2.

8.3 Consumer HDTV Receiver

The Digicipher™ system has been designed to provide optimum performance while the hardware complexity is kept low. This allows the production of low cost consumer HDTV sets as well as low cost broadcasting equipment. Consumer HDTV sets can be designed using a total of 12 custom VLSIs as shown in Table 8-1. In addition, 2 Mbytes of memory are required for the implementation of the digital video decoder.

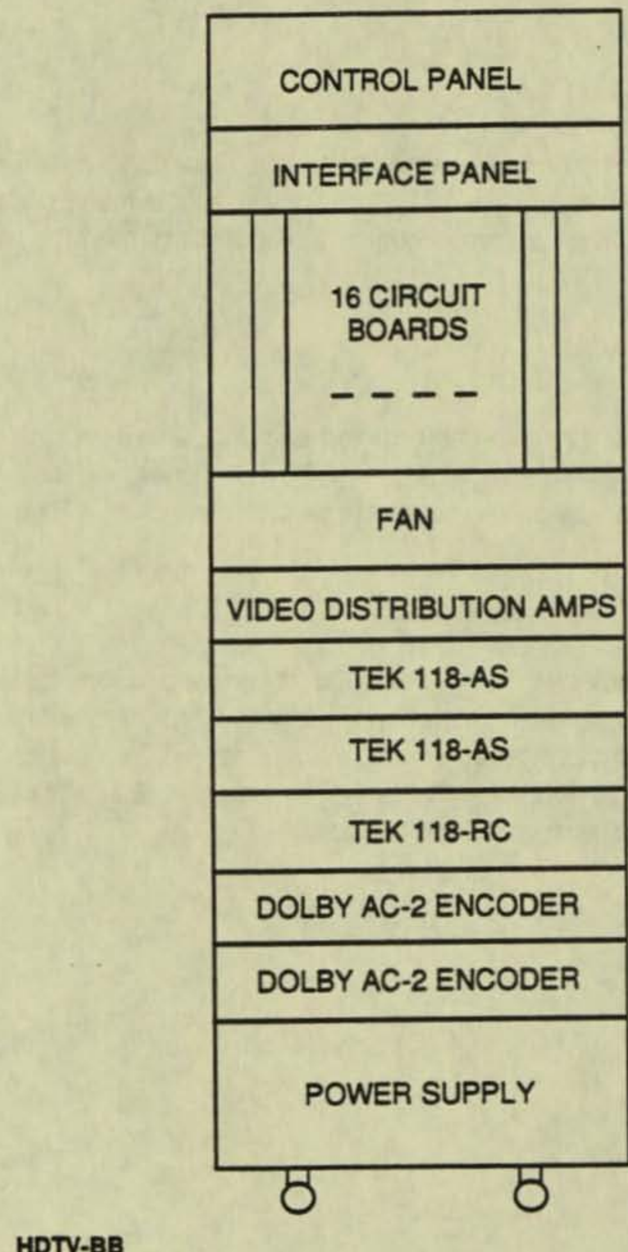


Figure 8-1. DigiCipher™ HDTV Encoder

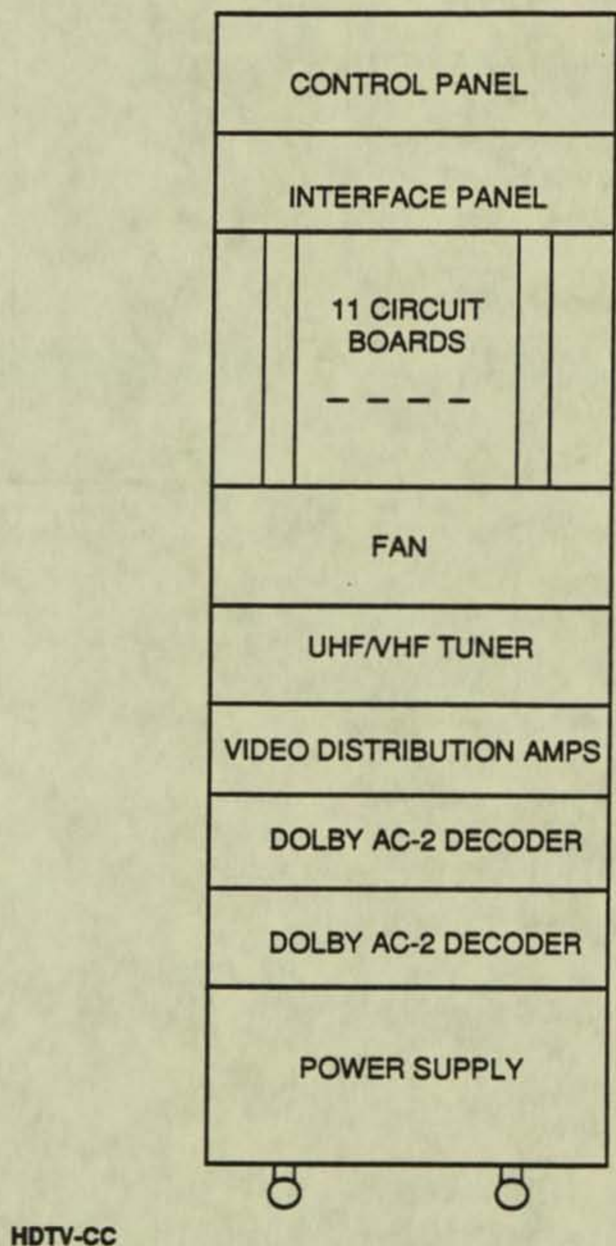


Figure 8-2. DigiCipher™ HDTV Decoder

Table 8-1. HDTV Receiver VLSI Chip Set

VLSI Chip	Qty Per HDTV Receiver
16/32-QAM Demod	1
Adaptive Equalizer	4
FEC Decoder/Sync	1
Decompression	4
Video Mux/Filter/OSD	1
Digital Audio Decoder	1
Total	**12**

9. COVERAGE AREA ANALYSIS

In this section, an analysis of the coverage area of the DigiCipher™ HDTV System is provided. The analysis is based on a set of assumptions as well as measured performance of the DigiCipher™ HDTV transmission system.

9.1 Measured Performance

NTSC Interference-Into-ATV-Service

The DigiCipher™ HDTV transmission system provides essentially error free performance at 0 dB C/I in the 16-QAM mode and 5 dB C/I in the 32-QAM mode where C is the average carrier level of the ATV signal and I is the peak sync level of NTSC interference signal, for typical NTSC signals. An HP3780A Noise & Interference Test Set was used for this measurement.[1] This superior NTSC interference rejection capability is mainly attributable to the powerful forward error correction, two levels of interleaving, and the adaptive equalizer.

ATV Interference-Into-ATV Service

ATV-to-ATV C/I performance has been measured to be 0.5 dB better than the C/N performance of the DigiCipher™ HDTV system. The difference can be attributed to the non-Gaussian nature of the QAM signal.

9.2 ATV Coverage Area Calculations

Key transmission performance parameters are provided in sections 6.1 and 9.1. PS/WP-3 has the responsibility to project coverage areas, using ATTC measurements of the parameters. Realizing the high level of interest in those projections, and that they will not be available for quite some time, we provide our own here.

Making projections is complicated by the fact that planning factors for the ATV service are not yet resolved. In order to tie our projections as closely as possible with the approach which will ultimately be used by PS/WP-3, most of our ATV planning factor assumptions are those tentatively agreed on by Study Group 11 of PS/WP-3.

In providing an ATV service, the key factors are spectrum availability, ATV service area, and the impact on current NTSC service. Consistent with our understanding of work to date in the area, we have made the following central assumptions:

1. The ATV service area should be comparable to the current NTSC service area.

[1] For proper calibration of the NTSC interference level, a CW carrier at the peak sync level of the NTSC signal has to be supplied to the I input when the HP3780A enters into the calibration mode.

2. Interference to existing NTSC service by an ATV signal should be no worse than the interference into NTSC by another NTSC signal now.

3. ATV service will be co-channel interference limited, and, in order to meet simulcast channel allocation goals, co-channel transmitters between ATV and NTSC, and ATV to ATV, may have to be as close as 100 miles.

In what follows, we first present our planning factor assumptions in two categories: 9.2.1, System Independent, presents factors which do not depend on the specifics of the ATV system. 9.2.2, System Dependent, presents factors which do depend on the performance of the specific system being analyzed.

Section 9.2.3 presents our coverage calculations. Given the demanding requirements of simulcasting, we are very pleased with the performance of the DigiCipher™ transmission system. As expected, 16-QAM performance exceeds that of 32-QAM, but the difference is not great, only about four miles in service radius.

9.2.1 System Independent Planning Factors

9.2.1.1 Transmitting Antenna Height and NTSC Effective Radiated Power

We conform to PS/WP-3's choice of 1200 feet as the UHF transmitter Height Above Average Terrain (HAAT). Assumed NTSC Effective Radiated Power (ERP) is 37 dBk.

9.2.1.2 NTSC Service Assumptions

We have used the FCC planning factors assumed for NTSC receivers for UHF grade B service:

Antenna gain: 13 dB

Antenna front-to-back (F/B) ratio: 6 dB

Downlead loss: 5 dB

Receiver noise figure: 15 dB

9.2.1.3 NTSC Carrier-to-Noise Ratio Requirements

The NTSC grade B service boundary is the locus of points for which the carrier-to-noise ratio (C/N) is 28.5 dB (peak sync to RMS noise in a 6 MHz band). This level of service is based on an F(50, 90) field, i.e., a field strength available at least 50% of locations at at least 90% of the time, for a receiving antenna height of 30 feet above ground level. F(50, 90) field strength data are derived from F(50, 50) data provided in FCC Rules (Part 73.699). For an NTSC UHF transmitter with 37 dBk peak ERP at 1200 feet HAAT, the grade B service contour is at a nominal radius of 56 miles. See Figure 9-1.

9.2.1.4 NTSC Interference Requirements

Co-channel NTSC interference is measured in terms of a carrier-to-interference (C/I) ratio. For the case of NTSC carriers employing nominal frequency offset, a 28 dB Desired/Undesired (D/U) ratio defines the acceptable limit of interference. Given the assumptions used in this study, the point at which a 28 dB D/U penetrates furthest into the NTSC service area occurs 41.5 miles from the desired NTSC transmitter, along a straight line between the desired and undesired transmitters. Beyond this point, and the line forming the locus of such points, is an area for which the D/U is less than 28 dB, and service is considered to be interference limited. See Figure 9-1.

PS/WP-3 has not determined what the NTSC reference case should be, for equivalency in determining allowable ATV co-channel interference into NTSC. After consulting with a number of involved parties, we have chosen to use NTSC nominal frequency offset as the reference, i.e., ATV co-channel interference can extend to within 41.5 miles of the NTSC transmitter, per Figure 9-1. The interference limited service area depicted in Figure 9-1 represents a worst case, as compared to ATV interference, since more closely spaced ATV transmitters cause the interference limited service area to be smaller.

9.2.1.5 ATV Service Assumptions

Planning factors for ATV are somewhat different then those for NTSC receivers shown in 9.2.1.2:

Antenna gain: 10 dB

Antenna F/B ratio: 15 dB

Downlead loss: 4 dB

Receiver noise figure: 10 dB

9.2.1.6 Definition of ATV Service

As is the case for NTSC grade B service, the perimeter for ATV service is defined using F(50,90) field, i.e., a field sufficient to serve 50% of locations 90% of the time.

9.2.2 System Dependent Planning Factors

9.2.2.1 ATV Interference Into NTSC

The nature of digital ATV interference into NTSC is markedly different from that of NTSC interference into NTSC . The impairment of a digital ATV interferer in an NTSC picture is subjectively similar to that caused by white noise. Thus co-channel ATV interference into NTSC will merely appear to add to the thermal noise level at the reception site, yielding an effective C/N value lower than that due to thermal noise alone.

For analysis purposes, we first assume that the interference limited area includes those locations within the Grade B service area for which the sum of thermal noise and ATV interference yields and effective C/N of less than or equal to 28.5 dB. This initial assumption coincides with the notion of redefining the boundary of the interference free Grade B service area based on its current thermal noise boundary of 28.5 dB C/N. However, to follow this assumption precisely to its logical conclusion, one would obtain an interference boundary based on noise summation rather than a locus of points with fixed C/I. Furthermore, in such precise analysis, the interference contour never intersects the service area circle but rather approaches it to form a narrow annular ring.

In order to be consistent with current coverage analysis practice, in which plots are made for fixed D/U ratios, we chose alternatively to set a fixed C/I value that, for practical purposes, results in nearly constant effective C/N criteria for the interference boundary. We have selected the C/I ratio of 30 dB peak sync to average interfering power as the interference criterion. It can be shown that this value results in an effective C/N value of 29 dB at the 41.5 mile point along the straight line connecting the NTSC and the ATV transmitters, and an effective C/N value of 26 dB at the intersection point with the Grade B service circle. In this regard, it should be noted that in the C/N range of 28.5 dB, 70% of television observers do not change their subjective opinion score based on this 2.5 dB C/N reduction.[2]

While it may be reasonable to choose a slightly higher C/I value than 30 dB, we believe that any such choice would differ only slightly from our current assumption and would not result in significant coverage analysis changes and conclusions.

9.2.2.2 ATV Noise Threshold Requirements

Based on measurement of the DigiCipher™ HDTV System, 12.5 DB C/N defines the 16-QAM ATV noise threshold point, while 16.5 dB defines the threshold for 32-QAM. These values are measured as average signal power to average noise power across a 5 MHz bandwidth.

9.2.2.3 NTSC Into ATV Interference Requirements

Based on measurements, the DigiCipher™ HDTV System can reject interference for C/I values of 0 dB or more, in the 16-QAM mode. The C/I threshold for the 32-QAM mode is 6 dB[3] This measure corresponds to average ATV carrier to peak NTSC interference, wherein typical case NTSC video modulation has been used.

9.2.2.4 ATV Into ATV Co-Channel Interference Requirements

Based on measurements, the ATV-ATV co-channel C/I threshold is 12 dB for the 16-QAM mode, and 16 dB for the 32-QAM mode. This measure is based on average desired ATV carrier power to average undesired ATV interference carrier power.

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[2]J. R. Cavanaugh and A.M. Lessman, "The Subjective Effect of Random Noise Spectra on 525-Line NTSC Color Television", SMPTE Journal Vol. 83; No. 10, pp. 829-835, October 1974.

[3]The C/I for the 32-QAM mode has been measured to be 5 dB but C/I of 6 dB has been used for the ATV coverage area calculations to account for the effect of noise. This effect is negligible in the 16-QAM mode.

9.2.3 Coverage Calculations

The UHF planning factors used are summarized in the Table 9-1:

Table 9-1. Link Budget Calculation Results for NTSC and ATV UHF Service

Factor	NTSC	16-QAM ATV	32-QAM ATV
Thermal Noise Level (dBμV across 75 ohms)	2.5	1.8 (5 MHz)	1.8 (5MHz)
Noise Figure (dB)	10	10	10
Line Loss (dB)	5	4	4
Antenna Gain (dB)	13	10	10
Dipole Factor (dB $meter^{-1}$)	-22	-22	-22
C/N (dB)	28.5	12.5 (5 MHz)	16.5 (5 MHz)
Local Field (dBμV/m) =Req'd F(50, 90)	55[4]	40.3	44.3

Given the required fields as specified in Table 9-1, Figure 9-2 shows an NTSC-ATV co-channel example, with transmitter spacing at 100 miles. In such a case, the ATV transmitter power is limited to 17 dBk, in order to match ATV interference intrusion into NTSC with that of an NTSC-NTSC nominal offset, at 41.5 miles from the desired transmitter. 16 and 32-QAM noise-limited service areas of 50.5 and 47 miles, respectively, are shown. These values fall just short of the reference 56 mile NTSC Grade B service contour.

The C/I interference contours for NTSC into ATV interference are also shown, and illustrate the excellent interference rejection of the DigiCipher receiver. From this figure it can be seen that DigiCipher service approaches equivalent service to NTSC at a co-channel spacing of 100 miles.

In Figure 9-3, co-channel transmitter spacing is increased to 115 miles. At that distance, ATV transmitter power may be increased to 22.5 dBk, while still matching ATV into NTSC C/I interference of 30 dB at 41.5 miles from an NTSC transmitter. At 22.5 dBk the 16-QAM noise-limited service area is 56 miles, matching the NTSC Grade B service contour reference. Also shown is the 32-QAM service area, reaching 52 miles, only four miles less than for the 16-QAM mode. Again, rejection of NTSC into ATV interference is excellent.

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[4]Corresponding to an F(50, 50) field strength of 64 dBμV/m at the NTSC Grade B boundary.

In the 32-QAM mode case, the 6 dB receiver C/I contour is shown on the side of the service area away from the NTSC transmitter. It falls just outside of the noise-limited contour. In the 16-QAM mode cases, and other 32-QAM examples, the contour falls even further outside the noise -limited service area, and is not shown.

Figure 9-4 illustrates the case where spacing is increased to permit noise-limited service for the 32-QAM mode equivalent to an NTSC grade B 128 miles.

Figure 9-5 shows an example of ATV-ATV co-channel, at 125 mile spacing. Transmitter power is 22.5 dBk, as was the case in Figure 9-3. The figure shows that ATV into ATV interference rejection is excellent, with only a modest intrusion of interference limited service into the noise-limited service area.

The examples presented here illustrate the coverage resulting from the DigiCipher system's low noise threshold and excellent interference rejection. The vast majority of broadcasters will benefit most from using the 32-QAM mode, which will provide near 16-QAM coverage, and a higher bit rate for picture quality. For those situations where co-channel requirements restrict transmitted power, a broadcaster can use 16-QAM to extend his coverage area, with a modest impact on picture quality.

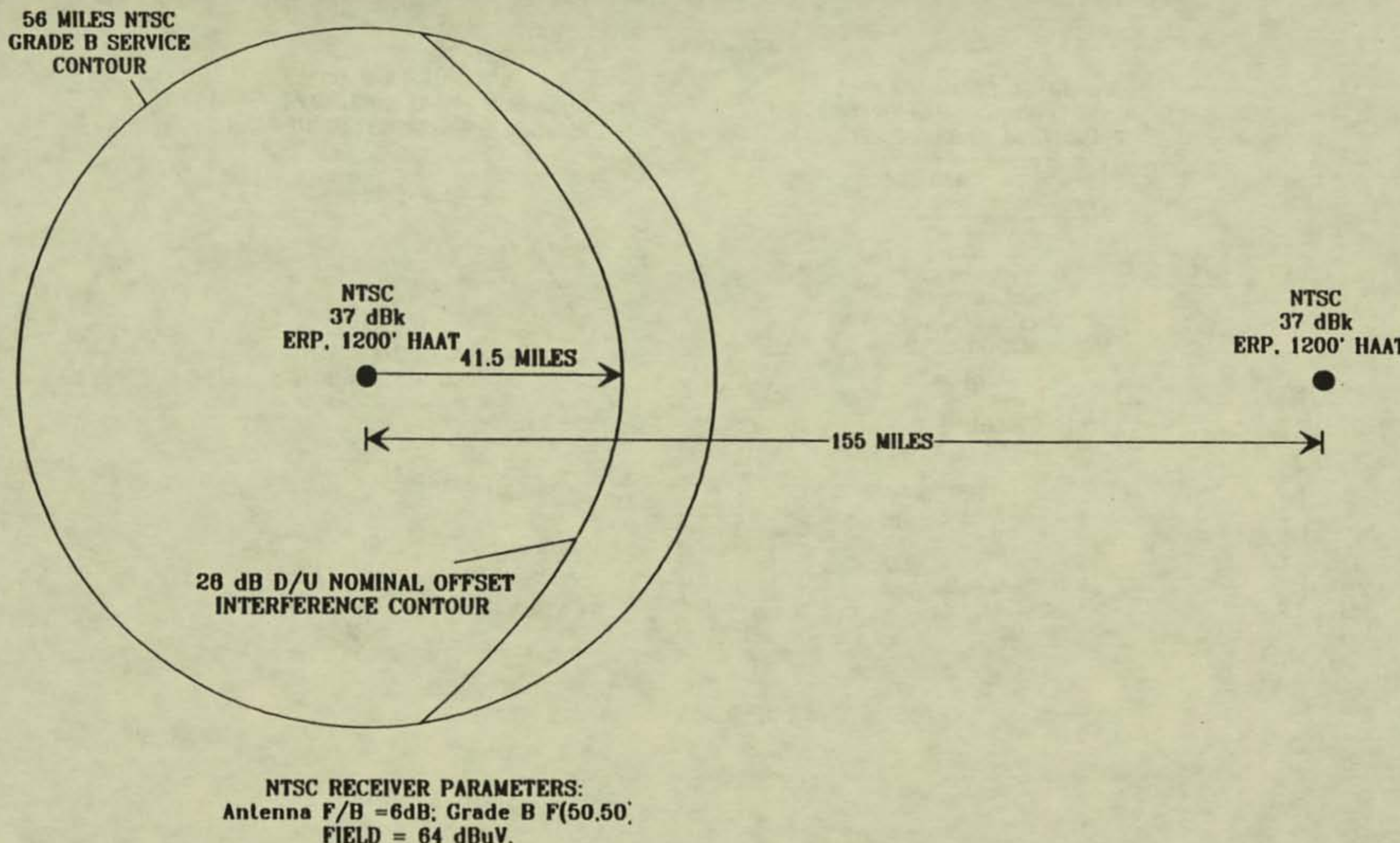

Figure 9-1. Minimum NTSC Co-Channel Separation and the Interference Boundary.

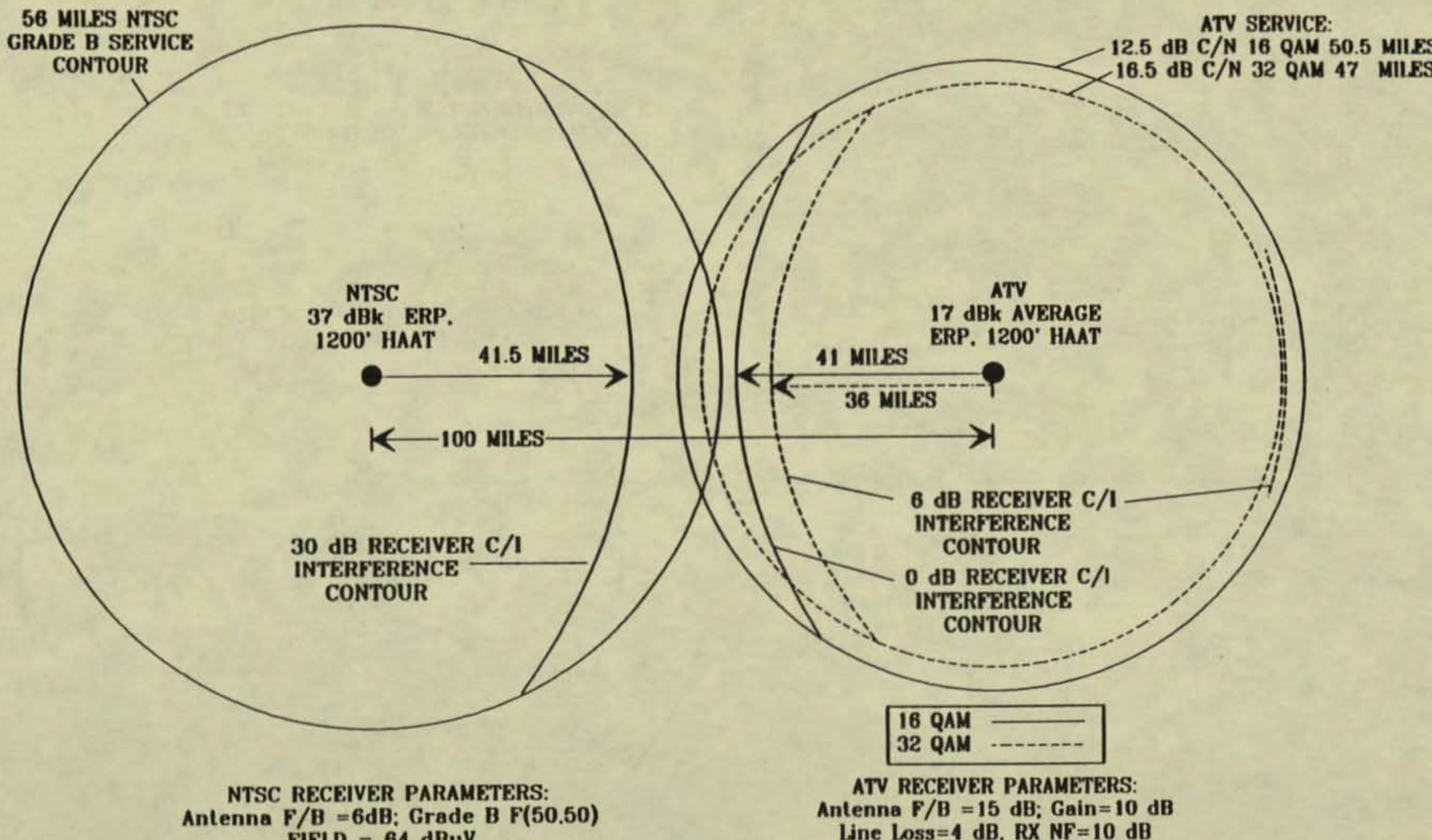

Figure 9-2. Interference Limited NTSC and ATV Service with 100 Miles Co-Channel Separation.

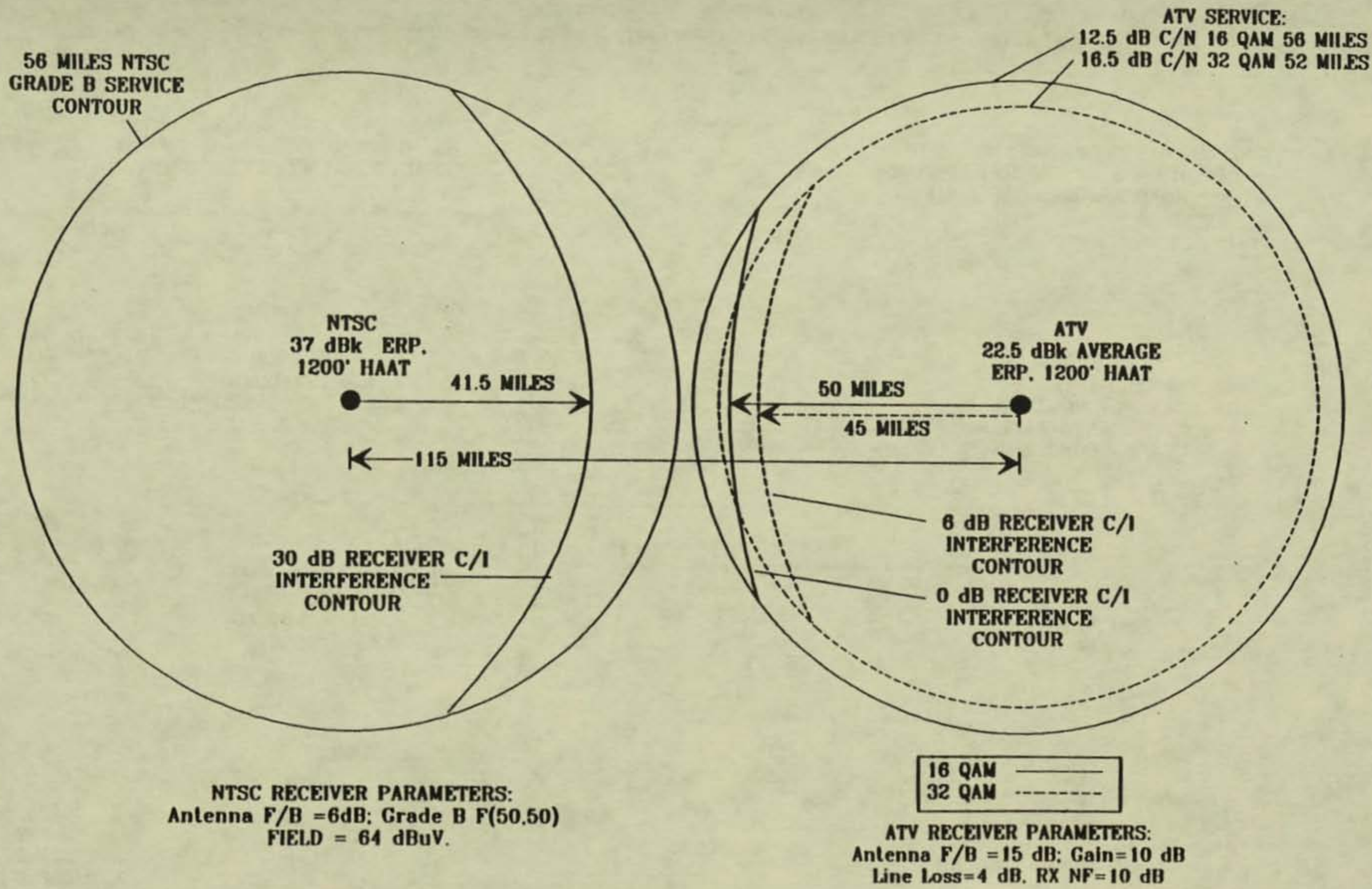

Figure 9-3. Interference Limited NTSC and ATV Service with 115 Miles Co-Channel Separation.

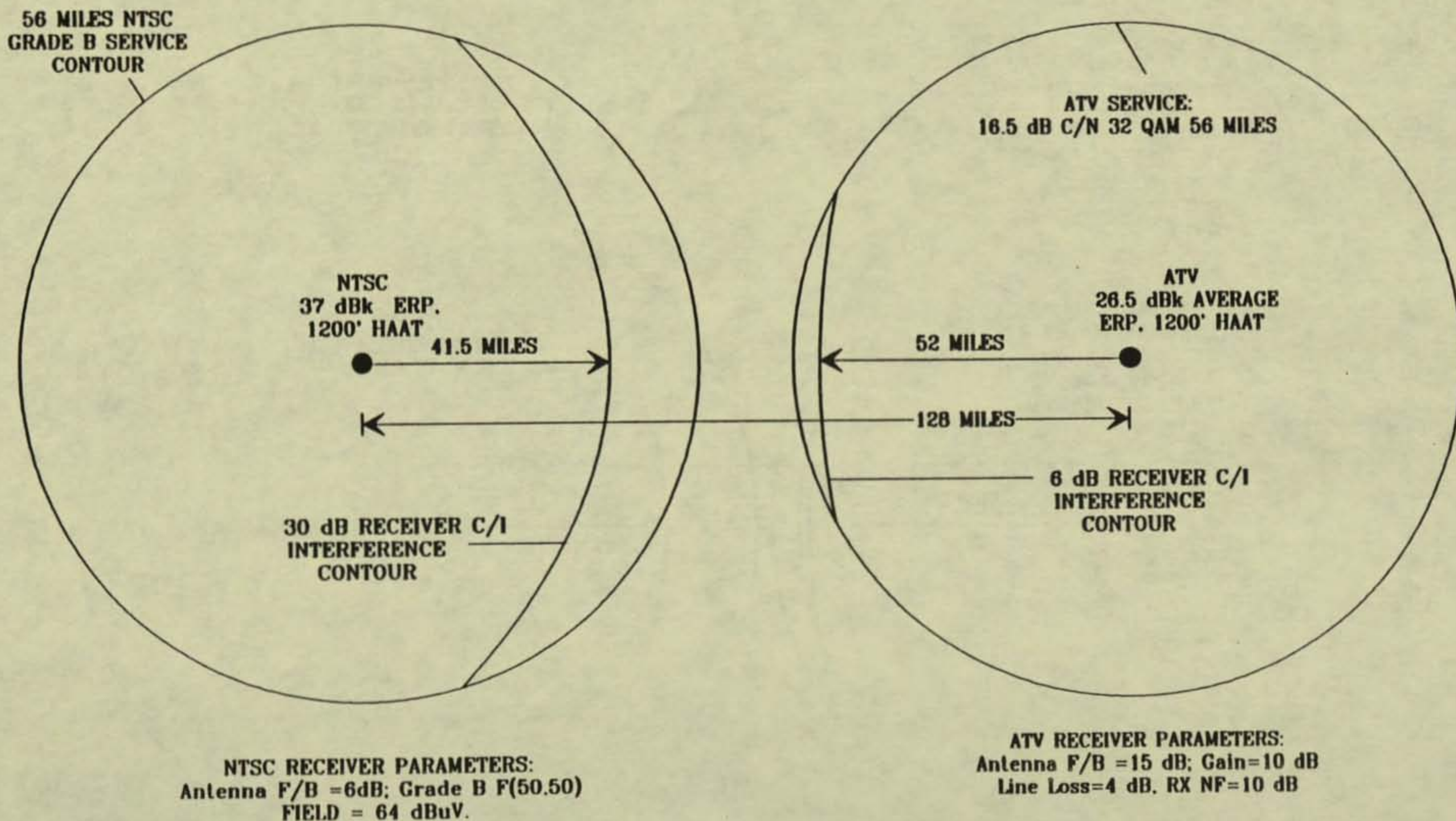

Figure 9-4. Interference Limited NTSC and 32-QAM ATV Service with 128 Miles Co-Channel Separation.

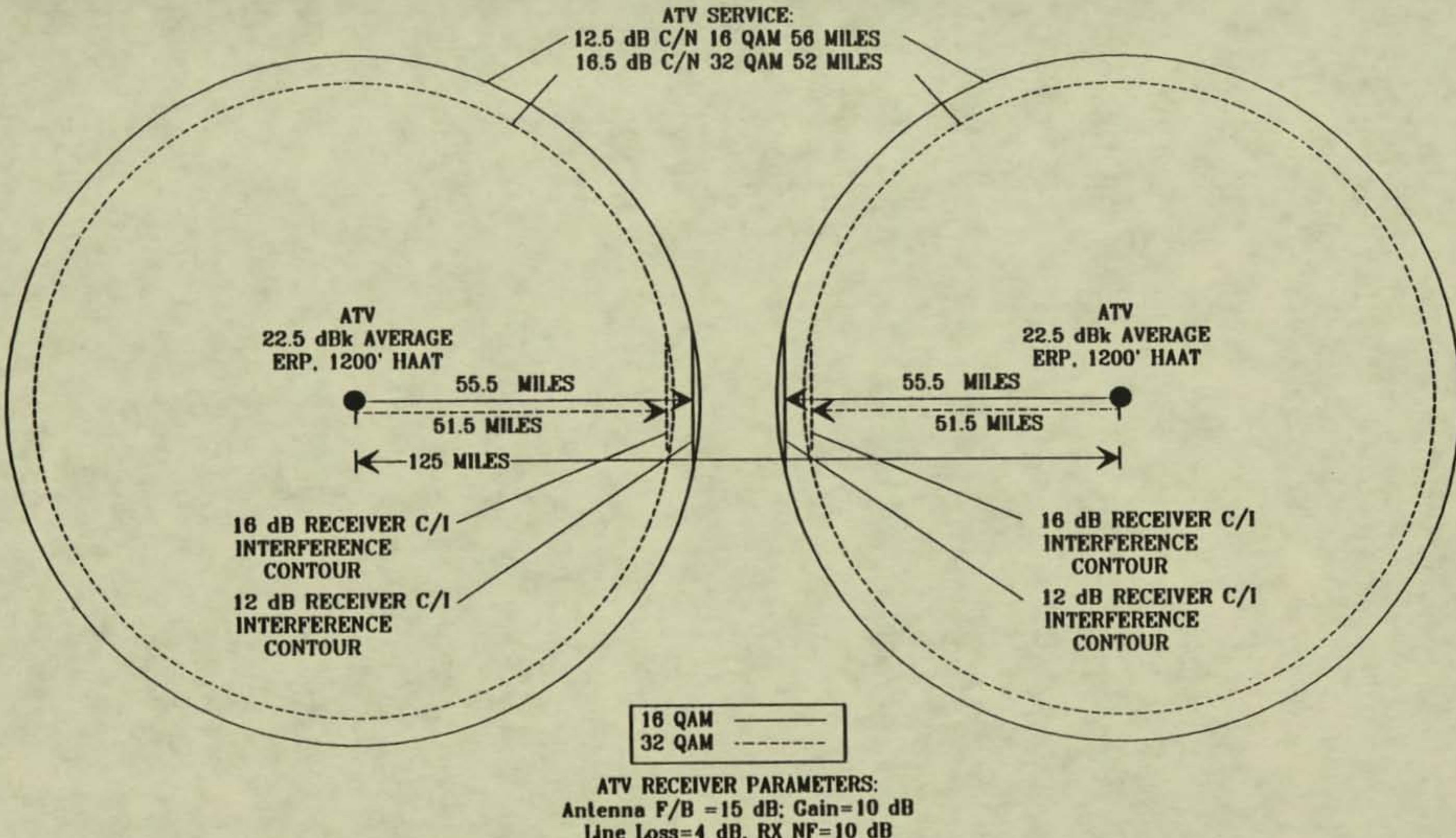

Figure 9-5. ATV-ATV Service with 125 Miles Co-Channel Separation.

10. ALTERNATE MEDIA DISTRIBUTION

10.1 Cable Transmission

The DigiCipher™ HDTV System is completely cable transmission compatible. The DigiCipher™ HDTV signal can be placed in a 6 MHz cable channel adjacent to other DigiCipher™ HDTV signals or NTSC VSB-AM signals. Features of the DigiCipher™ HDTV System for cable applications include:

- Pass through of satellite or broadcaster delivered signals to the cable subscriber without signal decompression and recompression at the cable headend.

- Lower power requirements than VSB-AM NTSC will result in an unimpaired HDTV signal delivered to the subscriber with all of the advantages of lower system power loading

- Channel transmission compatibility with the DigiCipher™ multi-channel NTSC system allows reception/access control of both signals with the same cable converter.

10.2 Satellite Transmission

The DigiCipher™ HDTV System can be transmitted over C-band or Ku-band satellite channels using QPSK modulation.

The system can support both FSS and BSS satellite transponders. The threshold C/N is 7.5 dB measured over a 24 MHz bandwidth, therefore the DigiCipher™ HDTV System allows the use of smaller dish size compared to other analog or hybrid HDTV systems.

10.3 Other Terrestrial Distribution

Since the DigiCipher™ HDTV System is an all-digital system, it can be readily applied to other transmission media such as microwave distribution service (MDS), multi-channel MDS (MMDS) and fiberoptic cables (FO).

An inherent characteristic of the all-digital system is that the HDTV service is free from transmission artifacts caused by various transmission media. Also, the complexity of the interface equipment between various transmission media is substantially lower.

10.4 VCR and Video Disc Recorders

All-digital recording and playback of HDTV signals using the signal format of the DigiCipher™ HDTV System is within the reach of current technology for consumer use since the total data rate is less than 20 Mbps. The cost and performance benefits of digital recording will be significant compared to analog recording.

11. REFERENCES

1. W. K. Pratt, Digital Image Processing, John Wiley and Sons, Inc., New York, NY, 1978.

2. S. Ericson, "Fixed and Adaptive Predictors for Hybrid Predictive/Transform Coding," IEEE Trans., on Comm., Vol. CQM-33, No. 12, December 1985.

3. W. Chen and W. K. Pratt, "Scene Adaptive Coder," IEEE Trans. on Comm., Vol. Com-32, No. 3, March 1984.

4. A. Fernandez, R. Ansari, D. J. Gall and C. T. Chen, "HDTV Subband/DCT Coding: Analysis of System Complexity," IEEE Globecom Proceedings, 343.1.1 - 343.1.4, 1990.

5. K. Feher, Advanced Digital Communications, Prentice-Hall, Inc. Englewood Cliff, NY, 1987.

6. V. Phargave, D. Haccoun, R. Matyas, P. Nuspl, Digital Communications by Satellite, John Wiley and Sons, Inc. New York, NY 1981.

7. W. Paik, "DigiCipher™ - All Digital, Channel Compatible, HDTV Broadcast System," IEEE Trans. on Broadcasting, Vol. 36, No. 4, December 1990.

8. Jerrold GT Catalog, pp. 2-6, Jerrold Electronics Corporation, Horsham, PA, 1976.

Appendix A. List of Clock and Carrier Frequencies Used in the Prototype HDTV System.

DIGITAL VIDEO ENCODER/DECODER

Master Oscillator	214.6154 MHz
A/D & D/A Sampling Clock	53.6538 MHz
Digital Video Processing Clock	13.4135 MHz
H Sync	31.47 KHz
V Sync	29.97

DIGITAL AUDIO ENCODER/DECODER

DSP CLOCK	27 MHz
Master Oscillator	12.0839 MHz
A/D & D/A Sampling Clock	47.2 KHz
Digital Audio Data Clock	251.75 KHz

DATA INTERFACE

Master Oscillator	18.525 MHz
Digital Data Board Rate	9600 Baud

DIGITAL MODULATOR/DEMODULATOR

QAM Symbol Rate	4.8776 MHz
2 x Symbol Rate	9.7553 MHz
4 x Symbol Rate	19.5105 MHz
Local Oscillator	44 MHz (mod)/43.5 MHz (demod)

TUNER

1st IF	1200 MHz $\pm$3 MHz
2nd IF	43.5 MHz $\pm$3 MHz
1st LO	1257 - 2087 MHz
2nd LO	1156.5 MHz

Appendix B. Technical Description of Dolby AC-2 System

SEE ATTACHED DESCRIPTION

AC-2: A FAMILY OF LOW COMPLEXITY TRANSFORM BASED MUSIC CODERS

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ABSTRACT

Two high-quality data rate reduction music coders from a family of TDAC transform based coders are discussed. An overview of the psychoacoustic principals used in their design is given and their limitations discussed. The use of psychoacoustics and DSP technology are combined to yield a low complexity approach to music coding. Issues of complexity, word length requirements, and memory usage are examined for both general-purpose DSP and custom IC implementations.

0. INTRODUCTION

The use of data rate reduction coders for digital audio applications shows great promise for a large variety of storage and transmission applications. Since Compact Disc digital audio employs a data rate greater than 1.4 Mbits/sec., this type of digital audio has been limited only to areas that can maintain a high data rate. Fortunately, the development of high quality data rate reduction technology for music applications has changed this situation. Now lower data rates may be used for audio in radio and television broadcast, computer hard disk storage, and telephone line connections. This paper will describe two coders from the Dolby AC-2 family, developed for different applications, that have the desired characteristics of data rate reduction, excellent sound quality, and computational simplicity.

The need to reduce the data rate for the practical application of digital audio into many areas has resulted in much work in the field of data rate reduction for music, as typified by Brandenburg et al. [1990], Johnston [1988], Schroeder et al. [1987], Stoll and Dehery [1990], Davidson et al. [1990], and Fielder [1989]. The fundamental approach of these techniques is to divide the audible frequency range into sub-bands which approximate auditory critical bands. Crucial elements in the design of these coders are the bit allocation and quantization schemes in which perceptually relevant sub-bands are identified, and the appropriate fraction of the available bit rate assigned to their representation. Many of these algorithms require a great deal of processing power to perform the frequency division and quantization operations (e.g., multiple DSP chip implementations for a single audio channel). Furthermore, they all extrapolate published models of human hearing and masking to a broader class of signals than those upon which the models were based.

This paper builds on the work described by Davidson et al. [1990] and Fielder [1989] which described 15 kHz bandwidth coders with resultant data rates between 128 and 192 kbits/sec. per channel. The two coders described here have 20 kHz bandwidth, require less than one programmable DSP chip to implement one stereo pair, and possess excellent sound quality. In particular, one coder, which will be called the low-delay coder, achieves excellent subjective and objective quality at 4:1 compression, exhibits robust tandem coding performance (i.e., where a number of encode/decode processes occur in series) and has a coding/decoding delay less than 9 msec. This low-delay feature is essential for applications requiring that announcers monitor their own coded voice signals. The other coder trades coding delay for a lower bit-rate (6:1 compression) and will be called the moderate delay coder. The coding systems described here can be applied for either 44.1 k or 48 ksamples/sec., however the remaining discussions will center on 48 ksample/sec. results.

A general overview of the psychoacoustics of masking as it effects the design of data rate reduction music coder technology will be given. Next, the details of the two coding systems resulting from this psychoacoustic examination will also be presented. Issues of implementation will also be discussed and the use of 24-bit and 16-bit DSP chips will be examined and processor speed/memory requirements determined. The use of custom DSP chips will also be considered. It will be shown that the two systems described are quite low in complexity while at the same time providing excellent sound quality.

1. APPLICATION OF PSYCHOACOUSTIC MODELS TO CODER DESIGN

The basis of all good rate reduction music coders is the application of the psychophysics of the human auditory system. As a result, a discussion of the present state of knowledge in this area is essential for the understanding of coders of this type. Masking effects for simple signals will be extended to the development of the filter bank design and quantization technology used in music coders. It will be seen that the targeted application will greatly influence the way the psychoacoustic principals are utilized. Next, these principles will be extended to more complex signals and discussed for AC-2 coding. An indication of the effectiveness of the AC-2 coding system in controlling the amount and frequency characteristics of the errors due to the reduction of word-lengths for data rate reduction will be given by a spectral comparison between both coder's performance and frequency characteristics of auditory masking.

1.1 Critical-Band Model of Hearing

Central to the development of a workable model of the auditory system is the critical-band concept and its relationship to the masking characteristics of the ear. The critical-band model of the human auditory system was first developed by Fletcher [1940] to explain why masking experiments showed that signals covering a frequency range less than a certain threshold bandwidth produced the same masking and detection properties as other signals with smaller bandwidths. The fundamental approximation is that the ear acts as a multi-channel real-time analyzer with varying sensitivities and bandwidths throughout the audio range. Despite the intrinsic simplicity of the model, it has been shown to be very enduring. Effective data rate reduction coders for music rely heavily on this model.

The critical-bandwidth represents the minimum frequency bandwidth resolvable for masked signals. For example, the masking of a low level error signal caused by a larger level tone nearby in frequency is maximal and continues at a constant level until the frequency separation between them exceeds this bandwidth. Detection of a signal component takes place based on the entire energy within a critical-bandwidth, whether it is tonal in nature, noise-like, or a combination of the two. Later workers have further refined this concept; Zwicker et al. [1957] examined this resolution bandwidth via various detection and masking experiments. Later Zwicker [1961] established 24 fixed critical-bands over the 20 Hz - 15 kHz frequency range.

1.2 The Use of Single Tone Masking Curves

Information on the masking effect of signal components is available primarily for single tones or bands of noise. As a result, coder design depends greatly on principles derived from these simple masking experiments. These typically generate masking curves of single high level component masking the presence of another smaller component and are quite useful because they can be used to derive an upper bound on the levels of permissible error signals due to the data rate reduction process. Since the masking effect varies significantly depending on whether the large level component or masker is tone-like or noise-like in character, the more demanding situation of sinewave masking curves are shown in Figures 1, 2, and 3. The figures present various 1/3 octave hearing thresholds when subjects are subjected to various levels of 100 Hz, 500 Hz, and 4 kHz sinewave maskers, as described by Fielder [1987]. For more information on the variation of the masking effect for tonal or noise signals, see Ehmer [1959].

The most appropriate way to examine masking phenomena is to perform a spectrum analysis based on critical-bandwidths. Since critical-band analyzers are not common, a good approximation can be made with the use of 1/3 octave bands; see Fielder [1987] for further details. These spectral analyses of masking are then used as a basis for the design of the coder filter bank structures and the methods to reduce the bit rate via word-length reduction.

The first observation from Figures 1-3 is that masking is generally greatest at the masker's frequency. This indicates that the coder design should concentrate error energy directly adjacent to the signal frequency. The next property the figures have in common is that the masking effect slowly decreases with increasing frequency separation, if the smaller signal is higher in frequency than the masker. The masking effect for signals at a 70 dB acoustic level may extend only a few octaves upward in frequency while higher level situations may produce six upward octaves of significant masking.

Looking at masking of signals lower in frequency than the masker shows a very different situation. For these signals, the masking effect falls off much more quickly. This is particularly evident for frequencies between 500 Hz - 2 kHz when evaluated in a dB per Hz fall-off from the masker frequency; in this frequency region the slope can be as steep as 100 dB per 350 Hz below 500 Hz (i.e. 90 dB/octave) and drop as deep as 40 dB within 1/2 octave. This rapid decrease in masking for components lower in frequency than the masker has significant consequences in coder design, and has been one of the primary reasons that data rate reductions of 4:1 or greater have awaited the practical availability of powerful DSP architectures which can practically implement the necessary complementary filter structures with sharp frequency characteristics that are suitable for music coders.

The differences in the masking characteristics versus frequency are also significant. In Figure 1 the masked threshold falls off only for frequencies above 100 Hz. The upward frequency fall-off in masking above 100 Hz is rapid on a dB per Hz basis, with a slope that is as much as 100 dB per 400 Hz. In the case of 100 Hz masking curves, it is important to note that a ratio of as much as 100 dB may be necessary between the 100 Hz masker and a resultant error component, if the error is to be inaudible. This means that any filter bank used by a rate reduction coder is most effective if its ultimate attenuation spans this 100 dB range. The masking curves of 100 Hz are typical for masking situations for maskers at or below 200 Hz.

The masking curves for 500 Hz, depicted in Figure 2, show a different situation. In this case there is a rapid reduction of downward frequency masking of up to 100 dB per 360 Hz, while having a much slower reduction at higher frequencies. In addition, high sound levels between 90-110 dB cause a very large masking effect at the second harmonic, causing the masking effect to be significantly extended upward in frequency. These 500 Hz curves are typical for the masking properties of midrange signals in the 500 Hz - 2 kHz region. Although not shown, at 2 kHz the slope of the masking curves have only 1/2 - 1/3 the slope of masking curves at 500 Hz, but the total fall-off has increased to 60 dB.

Figure 3 shows masking that is typical for high frequency signals. Masking for lower frequency error components falls off fast but not as fast a dB per rate as in the case of midrange signals. However, the total may exceed 70 dB for maskers at 8 kHz and above. As in the case of midrange signals, upward frequency masking reduces slowly with frequency but covers a more extended frequency range.

1.3 Temporal Masking and Time vs. Frequency Trade-Off

Sinewave masking experiments and the shape of masking curves derived from them indicate the requirements for the filter bank of a low bit rate coder under steady-state signals. Another requirement is the accommodation of human auditory characteristics during transient events. Although the frequency resolution for steady state sinewave signals is extremely sharp, the characteristics of auditory masking for transient events involves time resolutions on the order of a few milliseconds. The temporal characteristics of masking are important because the filter banks used for data rate reduction coders can disperse error signals in time. This spreading occurs because of the fundamental trade-off between temporal and frequency resolution of filters. For this reason, filter bank design typically involves a trade-off between these conflicting goals.

Just as in the case of the frequency characteristics of auditory masking under steady state signal conditions, there is a basic asymmetry in the characteristics of temporal masking. The masking of small signal components occurring during in time before a masker (i.e. backward masking) is substantially less than the forward masking effect in which the same small signals occur after the masker. Backward masking remains strong for about 4 milliseconds and disappears for time separations larger than 10's of milliseconds, while forward masking lasts approximately ten times as long. For further information on the temporal masking characteristics of the ear, see Carterette and Friedman [1978]. The temporal resolution characteristics of a filter bank used for data rate reduction of music signals should maximize the masking effect so that the largest data rate reduction induced errors are tolerated by the ear. Since a transient event can occur anywhere within the effective time window of a particular filter, this argues strongly for filter banks with time resolutions less than 4 milliseconds.

1.4 Filter Bank Design and Auditory Masking

The filter bank of a coder is the primary element that allows rate reduction to occur with minimal audible consequences. It does that by confining the error temporally and spectrally in such a way as to allow the greatest errors to occur. This spectral and temporal confinement must satisfy the following conditions. First, the ideal filter bank should have a frequency selectivity less than one critical band in any part of the audio band, have a fall-off rate of 100 dB per 360 Hz, with an ultimate rejection of 100 dB, and finally, have a temporal spreading effect of less than 4 msec. A filter bank which is easy and efficient to implement is also desirable. Unfortunately, the attainment of all the previously mentioned goals is extremely difficult and a compromise is necessary. As a result, further discussion will concentrate on the compromises and results for the low and moderate time delay AC-2 coders.

The design of the AC-2 coding technology is strongly influenced by the desire to keep the implementation as low in complexity as possible, while preserving coder effectiveness. For this reason, the AC-2 coders use Time Domain Aliasing Cancellation (TDAC), as developed by Princen and Bradley [1986]. This transform has the computational complexity advantages of an FFT and has excellent frequency selectivity characteristics. Unfortunately, the resultant filter bank is constant bandwidth, rather than having the varying bandwidths of the auditory system. This disadvantage of the TDAC can be overcome by approximating the nonuniform bandwidths of the human auditory system by grouping transform coefficients together to form sub-bands with bandwidths approximately that of the auditory system.

Consider first the TDAC filter bank for the moderate time delay coder, useful in applications where a low data rate is more important than low time delay. In this case the transform length is chosen to be 512 samples, which is found to be the best compromise between frequency and temporal selectivity. The resultant filter bank has a frequency selectivity that is sufficient for most of the audio band, while at the same time having a time resolution on the order of 10 msec. This compromise is acceptable since limitations in the temporal or spectral resolution are minor and can be greatly improved by a quantization process that allocates additional data to mitigate the increased audibility of errors during transient circumstances.

The other AC-2 coder is targeted for applications were low time delay is important, such as disk based storage applications requiring fine time resolution editing or for broadcast applications where an announcer may listen to the transmitted signal as a verification of proper system operation. Monitoring of the transmitted voice signal is problematic for the announcer if the time delay is too long, because it interferes with the cognitive process of speaking. The time delay at which speech difficulties begin to occur is not well defined, but 10 msec. appears to be a reasonable compromise, see Gilchrist [1990] for more details. The transform block length for this coder is set at 128 samples by this requirement and the resultant encode/decode delay is 8 msec.

This restriction in the block length has important consequences in the coder design because it moves the filter bank temporal- frequency resolution trade-off away from the optimal compromise. As a result, the frequency resolution is inadequate for masking the error signals for frequencies below 3 kHz. Insufficient frequency selectivity translates to either reduced audio quality or increased data rate. For this reason, this coder uses a higher data rate of 192 kbits/sec per channel. The time resolution of the system is 2.7 msec. and the resultant coder has excellent performance under transient conditions.

The loss of frequency selectivity to satisfy time resolution or computational complexity issues is very important in coder design. Figure 4 demonstrates this point by comparing the filter bank selectivity of three filter banks used in music coders to that of a masking curve for a 100 dB S.P.L. 1 kHz sinewave. This masking curve for 1 kHz was chosen since it is nearly a worst case for the selectivity requirements of a single tone situation. Both filter banks used in the two AC-2 coder are shown, and in addition, a typical uniform bandwidth sub-band filter band, having 750 Hz bandwidth, is included.

Examination of Figure 4 shows that none of the filter banks presented have ideal frequency selectivity when compared to this most demanding requirement of the human auditory system. The consequences of this fact is that all the coders implemented with these filter banks must either have a higher data rate than ideal or have lower sound quality. Inspection of this figure shows that the moderate delay version of AC-2 has the selectivity closest to that required, implying that little additional data rate is required to preserve sound quality. Next in selectivity is the uniform sub-band filter; the sharpness of the filter roll-off is excellent but it has the limitation that the filter's bandwidth is too wide for low frequency and midrange signals. This lack of frequency selectivity will result in quantization error that is spread over a wide frequency range (i.e. 550-1500 Hz) and must be accommodated by an increase in data rate. This increase in data rate results in an additional word-length requirement because the overall level of the error must be lowered until all of its spectrum lies below the masking curve. Finally, the short time delay AC-2 filter bank frequency selectivity is considered. In this case, additional data rate is seen to be required to mitigate the insufficient frequency selectivity of the low time delay filter bank. This, along with the desire for excellent multi-generation sound quality results in a data rate for this coder of 192 kbits/sec.

In conclusion, the examination of sinewave masking shows that the frequency selectivity of the moderate delay AC-2 is somewhat less than the worst case condition of 1 kHz masking. This indicates that its computationally efficient filter bank does not significantly limit the performance. The low time delay AC-2 coder selectivity is examined and shown to be too broad for use in the lowest possible data rate system. Fortunately, this increase in data rate is modest because the selectivity of the human auditory system is poorer than this filter bank over most of the audio band (i.e. 4 kHz - 20 kHz). One additional benefit of the short time delay AC-2 coder is that it possesses a temporal resolution substantially below that at which either forward or backward masking effects occur. The disadvantage of having too wide a filter bank bandwidth was demonstrated by the 750 Hz sub-band filter example.

1.5 Extension to Complex Signals

The use of simple stimuli masking models has determined the basic requirements of frequency and time resolution. This is done because there is not a widely accepted model of hearing for more complex signals. Unfortunately, real music signals are complex, so coder design must extend these simple masking models to the complex conditions of music signals. In the case of the AC-2 coding systems, simple stimuli masking principles are extended in a very conservative manner. Although many coding systems adaptively allocate most of the available data rate in a signal dependent manner to produce errors that are just below predicted masking, this was found to be an unnecessarily aggressive approach for applications with data rates at or above 128 kbits/sec.

The conservative approach of the AC-2 coder family is as follows: The appropriate TDAC transform filter bank is first combined with a trial quantization process that has a fixed number of bits assigned to each band, which are adjusted to simultaneously satisfy the masking requirements of simple and complex signals. Once this fixed allocation scheme is properly adjusted for optimal audible effect, a modest amount of the data responsible for this representation of the audio signal is removed and replaced by a smaller amount of adaptively allocated data, resulting in 20% or less data of this type. The advantage of the largely non-adaptive nature of most of the data is that problems in the extension of simple masking models are not nearly as serious as in the case of coders that have a more adaptive allocation strategy. This prevents serious audible mistakes from occurring: in fact the audible performances of the AC-2 coders without any adaptive bits are quite good.

This method of extension to more complex signals is evaluated and optimized by both objective and subjective means. This includes comparison of computed noise spectra with psychoacoustic masking threshold data, and conducting A:B listening tests. Subjects are asked to evaluate signals coded by hardware in real-time to facilitate exposing the coder to a wide variety of instrumental, vocal, and synthetic audio signals.

Although coder performance is more rigorously evaluated using complex music signals, many important features are revealed by the sinewave error spectrum. Figures 5 and 6 are a comparison of both coder's 1 kHz error spectra with a 100 dB S.P.L., 1 kHz masking curve. The moderate delay AC-2 coder results are shown in Figure 5 and those of the low delay AC-2 coder in Figure 6. Both figures give an indication of the worst case performance of the coder because the 1 kHz auditory selectivity is the most severe. These comparisons assume a consumer playback sound level at 108 dB peak acoustic level, being limited by the maximum loudness capabilities of typical home loudspeakers and amplifiers. In both figures, the error spectra are shown for coder operation with, and without, the adaptively allocated portion of the data. Both coding systems are interfaced to 16-bit ADC's and DAC's so the noise of the conversion process also is present.

Examination of Figure 5 shows that the error signal and converter noise under normal operation is just at or below audibility. The error spectra above 2.5 kHz for both situations are limited by the ADC/DAC noise floors and indicative of the 91 dB dynamic range of typical 16-bit conversion systems. The frequency region below 2.5 kHz is a result of coder operation and a significant deviation from an ADC/DAC noise floor results. In this region, the 1 kHz error spectrum under normal operation is substantially below the masked threshold curve, except for frequencies between 400 Hz - 700 Hz, where the error spectrum is comparable to the masked threshold. This indicates that a slight modulation noise may be audible, although in practice this has not been heard. The error spectrum shown without the adaptive portion of the data shows that modulation noise is now quite audible since the error spectrum is significantly above the masked threshold in the frequency range of 400 Hz - 1200 Hz. The generation of audible modulation noise indicates that the adaptive bit allocation process is necessary to preserve excellent sound quality. Notice that the error spectrum falls off less rapidly than that of the downward frequency portion of the 1 kHz masking curve.

This is exactly as predicted by the earlier discussion of the requirements of filter bank selectivity.

Figure 6 shows the same comparison for the low time delay AC-2 coder. In this case, the audio performance is essentially noise-free in normal operation, but limited by modulation noise without the adaptively allocated bits. This time the coder dependent part of the spectrum extends to 5 kHz and the extension of the range where the coder affects the noise spectrum is due to the more gradual frequency selectivity of the low time delay filter bank. Similar to the case of the moderate delay AC-2 coder, the normal operation spectrum slightly exceeds the masked threshold curve in the region of 400-600 Hz, indicating the presence of a small amount of masking noise. As before, actual listening tests determine that no modulation noise is audible. The use of adaptive bits is shown to be important since the situation with no adaptively allocated bits indicates the presence of substantial modulation noise. In this case, the error spectrum exceeds the masked threshold by 25 dB at 500 Hz.

2. AC-2 CODING ALGORITHM

In Section 1, some of the groundwork for audio coder design was established. In this section, we build upon this presentation by exploring the AC-2 coding algorithm in more detail. The description generally applies to all members of the AC-2 family; differences between the low and moderate delay versions are described where appropriate.

Figure 7 presents the block diagram of a generic AC-2 digital audio encoder. In the first stage of processing, PCM audio is buffered into frames of length N samples. Each new frame overlaps the previous one by 50%, i.e., the first N/2 samples in each frame are comprised of the last N/2 samples from the previous and present one. Consequently, each input sample is contained within exactly two consecutive frames. Next, the buffered samples are multiplied by a window function to reduce the effect of frame boundary discontinuities on the spectral estimate provided by the transform. The window also significantly improves the frequency analysis properties of the encoder.

The time-to-frequency domain transformation is based on evenly- stacked TDAC, consisting of alternating Modified Discrete Cosine (MDCT) and Modified Discrete Sine (MDST) transforms. A crucial advantage of this approach is that 50% frame overlap is achieved without increasing the required bit-rate. In a critically- sampled analysis technique such as TDAC, exactly N unique nonzero transform coefficients are generated on the average in an interval of time representing N input PCM samples. In TDAC, each MDCT or MDST transform of frame size N generates only N/2 unique nonzero transform coefficients, so critical sampling is achieved with 50% frame overlap. Any nonzero overlap used with conventional transforms (such as the DFT or standard DCT) precludes critical sampling, since each N-point transform generates N unique nonzero transform coefficients. Additionally, several memory and computation-efficient techniques are available for implementing the MDCT and MDST transforms.

TDAC is applied to model the auditory system by grouping adjacent transform coefficients into sub-bands for further decomposition and analysis. The number of coefficients per sub-band is computed a priori to approximate the nonuniform critical-bands. Transform coefficients within one sub-band are converted to a frequency block floating-point representation, with one or more mantissas per exponent, depending upon the sub-band center frequency. Each exponent represents the quantized peak log-amplitude for its associated sub-band. The exponents collectively provide an estimate of the log-spectral envelope for the current audio frame, computed on a critical-band frequency scale.

From a psychoacoustic perspective, the log-spectral envelope provides an ideal framework for estimating which sub-bands of a given audio frame are perceptually most relevant, and for ranking them in relative order of importance for dynamic bit allocation. Furthermore, the nonuniform frequency division scheme offers key advantages compared to one based on uniform-width filter banks. Accordingly, the AC-2 frequency division scheme reduces the need both for relying upon a complex masking model, and for using a second, higher-resolution filter bank in the encoder.

The dynamic bit allocation routine is completely feed-forward in nature and is constrained to produce a constant bit-rate as required for transmission applications. Bits are allocated in accordance with a set of deterministic rules derived from conservative use of single-tone masking curves. A portion of the routine employs a water-filling procedure in which sub-bands are ranked and allocated bits on a band-by-band basis.

The allocation routine provides step-size information for an adaptive quantizer. Each sub-band mantissa is quantized to a bit resolution defined by the sum of a fixed allocation and a dynamic allocation. The total fixed allocation for one frame outweighs the dynamic allocation in approximately a 4:1 ratio. For a given level of error protection overhead, this approach was found to provide more robust coding and error performance, since the number of most-significant mantissa bits is known a priori in the decoder. In the final stage of the encoder, exponents are multiplexed and interleaved with mantissa bits for transmission to the decoder. Optional error correction codes may be added at this step. The amount of overhead information reserved for error control coding can be adjusted to give greater or lesser protection depending upon channel error performance for a given application.

Serial bitstream formats can be optimized for the application. In the DP501/DP502 digital audio encoder/decoder products employing AC-2, two independent channels are interleaved in a regular pattern of alternating 16-bit segments. This format allows for straightforward demultiplexing of the encoder bitstream into separate channels, and for recombining monophonic bitstreams from different encoder units. Provision is also made for the insertion of a 1200 bit/s auxiliary data stream, algorithm identification bits, ADC overload status, and other information.

In the AC-2 decoder, shown in Figure 8, the input bitstream is demultiplexed and errors, if any, are corrected. The received log spectral envelope is processed in a stage identical to the encoder bit allocation routine, which generates step-size information for the adaptive inverse quantizer. The fixed and dynamically-allocated portions of each mantissa are concatenated to regenerate compressed transform coefficients. A sub-band block floating-point expander then linearizes the compressed transform coefficients and passes them to an inverse MDCT/MDST transform stage. After the inverse transformation, a window identical to that used in the encoder is used to post-multiply the reconstructed time-domain samples for each frame. Adjacent windowed frames are overlapped by 50% and then added together to reconstruct the PCM output.

Total coding/decoding time delay is determined by the frame size N, the manner in which frames are processed, and the processor speed. In the low-delay coder, input frames are processed one-by-one, resulting in a theoretical minimum total coding and transmission delay of 2.5N samples when employing infinitely-fast encoder and decoder processors. In actual practice, the delay increases to about 3N samples for fully-utilized (finite-speed) encoder and decoder processors. With a frame size of N = 128 samples and a sample rate of 48 kHz, a delay of 8 msec. is obtained. In the moderate-delay coder, two successive frames from one channel are buffered and processed jointly. In this case, the total delay when using fully-utilized processors is about 4N samples, which results in less than 45 msec. of delay at a sampling rate of 48 kHz and with N = 512.

3. HARDWARE IMPLEMENTATION

All coders within the AC-2 family have been optimized for very low hardware implementation cost. By today's standards, cost is ultimately measured by the die size and package cost of a custom VLSI implementation. Accordingly, the cost equation must not only include such traditional complexity measures as multiply-add count and RAM/ROM memory usage, but regularity of computation and minimum word-length requirements as well. Considerable attention has been given to structuring the computations in AC-2 to minimize VLSI implementation cost and simultaneously achieve the audio performance objectives. At a sampling rate of 48 kHz, the total number of multiplies and adds per second in a stereo AC-2 encoder is about 2.7 million. The decoder complexity is slightly lower. This compares to calculations by Reader [1991], estimating a total of about 35 million multiplies and adds per second for a straightforward implementation of a current generation sub-band encoder, and 16 million multiplies and adds per second in the decoder.

The low computational complexity can be attributed to several factors. First, the computational structures employed are highly regular in nature. Second, an efficient technique has been found for implementing the evenly-stacked TDAC transform by combining a core FFT routine with pre-twiddle and post-twiddle operations. Third, the nonuniform frequency division stage and log spectral energy representation enables the use of a low-complexity dynamic bit allocation routine. Finally, the use of functions which are inefficiently implemented on programmable DSPs or in custom-ICs, such as logarithms, square roots, and divides, have been found unnecessary. The only functions required are multiply, add, integer left/right shift, normalize, and compare.

3.1 General-Purpose Programmable DSPs

Programmable DSPs provide a flexible and expedient path to real-time algorithm development, and as such provide an attractive means for a first implementation. An early embodiment of AC-2 based on the Fourier transform was implemented using six Texas Instruments TMS32010s by Fielder [1989]. This work subsequently led to an implementation employing TDAC and based on the Motorola DSP56001, as detailed by Davidson et al. [1990]. In the latter case, a single 27 MHz chip could either encode or decode two independent channels. Recent improvements in software run-time efficiency have reduced this speed requirement to 20 MHz.

3.1.1 24-Bit Fixed-Point

Since it's inception in 1987, the Motorola DSP56001 has proven to be a capable platform for implementation of a wide variety of audio processing algorithms. This general trend has been supported by several audio compression implementations, including AC-2. The DSP56001's 24-bit data path, flexible addressing modes, and dual-accumulator arithmetic logic unit (ALU) are keys to its successful application in audio.

In particular for AC-2, we found that the 24-bit word-length was sufficient for all arithmetic tasks. Furthermore, no elaborate scaling or rounding procedures were required. The dynamic range of the implementation, as measured from PCM input to output, is 108 dB. This figure greatly exceeds the theoretically-achievable dynamic range of 16-bit ADC and DAC converters, and is commensurate with next-generation 18 and 20-bit converter technologies.

One of the more time-intensive processing blocks of those shown in Figures 7 and 8 is the inverse transform, which requires about 18% of the total DSP processing time. Surprisingly, however, the most time-intensive tasks are bit multiplexing and demultiplexing. This indicates that a custom IC could save significant ALU resources compared to a DSP if dedicated logic performed the multiplexing and demultiplexing. This topic is discussed further in Section 3.2.

3.1.2 16-Bit Fixed-Point

A study was made to determine the feasibility of implementing an AC-2 decoder on a 16-bit DSP chip. The motivation for this work was to identify a lower-cost platform for the implementation of an AC-2 decoder, while maintaining the flexibility of a programmable DSP. Our results indicate that current generation 16-bit DSPs, such as the Texas Instruments TMS320C5x, Analog Devices ADSP-2105, and Motorola DSP56116, are sufficiently powerful to implement a single-chip stereo encoder or decoder.

An analysis of finite word-length effects was conducted in part by modifying the real-time AC-2 DSP56001 software to emulate a reduced word-length processor. The data word-length was selected on-the-fly with switches. Coefficient word-lengths could also be varied. This approach allowed us to independently adjust, and jointly minimize, the data and coefficient word-lengths in each processing stage of the coder. The real-time variable word-length simulation served as a valuable tool for rapid objective and subjective evaluation of finite precision arithmetic effects.

Figure 9 presents a plot of the spectral error between an original and a coded 100 dB S.P.L., 100 Hz sinewave as processed by both 24-bit and a 16-bit ALUs in the decoder. Results from the moderate-delay decoder are shown since arithmetic round-off noise in the inverse transform is highest for long frame lengths; round-off noise in the low-delay coder is more than 6 dB lower. The idle channel noise produced by 16-bit ADC and DAC converters is included to show when the coder is limited by the conversion process. The low frequency sinewave represents a demanding test signal since minimal masking of the 4 to 6 kHz region occurs, where the ear's hearing threshold is low.

At frequencies below 500 Hz, noise introduced by transform coefficient quantization dominates arithmetic round-off noise. This region is perceptually insignificant because both noise curves are below the masking curve. Above 2 kHz, round-off noise for the 16-bit ALU significantly exceeds the masking curve, indicating that 16-bit single-precision (SP) arithmetic is inadequate.

Most of the noise shown in Figure 9 is generated during the inverse FFT computation of the inverse MDCT/MDST transform computation. Therefore, conventional techniques for reducing round-off error in fixed-point FFTs apply, such as those described by Meyer [1989]. We found that the combination of dynamic scaling between IFFT stages, optimal rounding, and optimal placement of quantizers in the butterfly produced a significant, but still insufficient, reduction in round-off noise. Furthermore, such techniques may impose a three-fold increase in IFFT butterfly computation time within a general-purpose DSP.

Based on these results, a preferred approach is to employ an extended-precision (EP) scheme based on 16 x 32-bit multiplies, which for many 16-bit DSPs results in a fixed two-fold increase in butterfly computation time, and provides a digital noise floor which is more than 40 dB lower than that obtainable with 24-bit SP multiplies. All other processing stages of the decoder can be implemented with 16-bit SP arithmetic. The minimum required DSP clock speed using 16-bit EP is only about 18% higher than the equivalent rating for a 24-bit fixed-point or 32-bit floating-point device.

3.2 Full-Custom VLSI

In order for an audio processor to be utilized in high volume applications, the device cost must usually be low. Since programmable DSP chips frequently contain more hardware logic than required for a given application, we have considered the design of a special-purpose VLSI architecture for implementing an AC-2 decoder. The architecture is capable of implementing any of the coders in the AC-2 family with one IC.

The architecture consists of three sections: a bit demultiplexer, a quantizer step-size control, and an inverse transform and reconstruction processor. The chip inputs are a serial bitstream and data clock, and the output is one or more 20-bit PCM digital audio channels. The bit demultiplexer performs such functions as data de-scrambling and bit de-interleaving. The demultiplexer directs the unpacked exponent data to the quantizer step size control, and the unpacked fixed and adaptive mantissa bits to a dedicated state machine/barrel shifter. The quantizer step size control, composed of a simple programmable microcontroller, processes incoming exponents and directs the state machine and barrel shifter to concatenate fixed and adaptive transform coefficient mantissa bits. The reconstruction processor performs either an IMDCT or IMDST, producing one frame of PCM samples. These samples are then windowed and overlap/added with the previous windowed block of PCM data to reconstruct audio samples. Since the multiply-add rate of the audio synthesis stage is quite low, a bit-serial multiplier has been employed. The serial multiplier requires significantly less chip area than a single-cycle array multiplier of the same word-length.

4. CONCLUSIONS

Adaptive transform coding of audio signals with AC-2 technology offers a high-quality, low complexity approach for data rate reduction of professional grade audio. Two 20 kHz bandwidth examples of the AC-2 coding family have been discussed, providing 4:1 and 6:1 bit-rate compression at low and moderate time delays, respectively. The excellent sound quality and computational ease of implementation of the AC-2 technology make it a natural candidate for broadcast, computer multimedia, and digital storage applications. The 128 kbits/sec. data rate of the moderate delay coder make it very appropriate for Digital Audio Broadcast and High Definition Television applications. The low delay coder is optimized for music material contribution applications (i.e. studio to transmitter and contribution quality links) requiring excellent multi-generational sound quality and a time delay acceptable for off-air monitoring during voice announcing.

The performance of these systems has been quantified by examination of simple stimuli masking models which have been the driving force shaping the design of the employed filter bank structures. Sinewave masking models have been used because a comprehensive and complete model for complex signals is not widely agreed upon. As a result, extension of the simple models is necessary for the design of practical coding systems. It was shown that the AC-2 family used a conservative extension process which resulted a relatively small amount of adaptively allocated data. As a consequence, these coder techniques were robust with respect to difficult program material. Other benefits created by this approach were a relative insensitivity to the effects of data-stream errors and low computational complexity.

Issues of computational complexity and practical implementation were discussed in some detail. It was shown that the AC-2 coder family is straightforward to implement at 128 and 192 kbits/sec. In particular, implementation of a stereo encoder or decoder was readily accomplished in one 20 MHz Motorola DSP56001. It was also shown that a practical modification of the frequency division algorithm permitted the realization of full fidelity realizations on 16-bit fixed-point DSP chips. A custom approach was also presented. It was shown that the AC-2 algorithms lend themselves well to dedicated chip hardware because of their reliance on simple shift operations and a low-complexity bit allocation strategy.

In conclusion, the AC-2 coder family represents one of the most cost effective solutions to very high-quality music coding applications at a 4:1 to 6:1 compression ratio. Although only two coders with data rates of 128 and 192 kbits/sec. were discussed, this technology can be applied to other sample rates, lower data rates (i.e. 64 kbits/sec.), and other signal bandwidths as well.

5. REFERENCES

K. Brandenburg, H. Gerhaeuser, D. Seitzer, and T. Sporer, "Transform Coding of High-Quality Digital Audio at Low Bit Rates: Algorithms and Implementation," Proc. of IEEE Intl. Conf. on Comm., Atlanta, pp. 932-936, April 1990.

E. C. Carterette and M. P. Friedman, Handbook of Perception, pp. 305-319, Academic Press Inc., New York, 1978.

G. Davidson, L. Fielder, and M. Antill, "Low-Complexity Transform Coder for Satellite Link Applications," presented at the 89th Convention of the Audio Engineering Society, preprint 2966, Sept. 1990.

R. H. Ehmer, "Masking of Tones vs. Noise Bands," J. of the Audio Eng. Soc., vol. 31, pp. 1253-1256, Sept. 1959.

L. D. Fielder, "Evaluation of the Audible Distortion and Noise Produced by Digital Audio Converters," J. Audio Eng. Soc., vol. 35, pp. 517-535, July/August 1987.

L. D. Fielder, "Low-complexity Transform Coder for Music Applications," presented at the IEEE ASSP Workshop on Appl. of Sig. Proc. to Audio and Acous., New Paltz, New York, session 2- 1, Oct. 1989.

H. Fletcher, "Auditory Patterns," Reviews of Modern Physics, vol. 12, pp. 47-65, Jan. 1940.
N. H. C. Gilchrist, "Delay in Broadcasting Operations,"
presented at the 90th Convention of the Audio Engineering Society, preprint 3033, Feb. 1991.

J. D. Johnston, "Transform Coding of Audio Signals Using Perceptual Noise Criteria," IEEE J. on Sel. Areas in Comm., vol. JSAC-6, no. 2, pp. 314-323, Feb. 1988.

R. Meyer, "Error Analysis and Comparison of FFT Implementation Structures," Proc of IEEE Conf. on Acous, Speech and Sig. Proc., Glasgow, pp. 888-891, 1989.

J. P. Princen and A. B. Bradley, "Analysis/Synthesis Filter Bank Design Based on Time-domain Aliasing Cancellation," IEEE Trans. on Acous., Speech, and Sig. Proc., vol. ASSP-34, no. 5, pp. 1153-1161, Oct. 1986.

C. Reader, "Comments on Audio CD and Analysis of Audio Complexity," ISO/MPEG Document ISO/IEC/JTC1/SC2/WG11/MPEG91/082, May 20, 1991.

E. F. Schroeder, H. J. Platte, and D. Krahe, "MSC: Stereo Audio Coding with CD-Quality and 256 kbits/sec," IEEE Trans. on Cons. Elec., vol. CE-33, no. 4, pp. 512-519, Nov. 1987.

G. Stoll and Y. F. Dehery, "High-Quality Audio Bit-Rate Reduction System Family for Different Applications," Proc. of IEEE Intl. Conf. on Comm., Atlanta, pp. 937-941, April 1990.

E. Zwicker, "Subdivision of the Audible Frequency Range into Critical Bands," J. of the Acous. Soc. of Am., vol. 33, no. 2, p. 248, Feb. 1961.

E. Zwicker, G. Flottorp, and S. S. Stevens, "Critical Band Width in Loudness Summation," J. Acous. Soc. of Am. vol. 29, pp. 548- 557, May 1957.

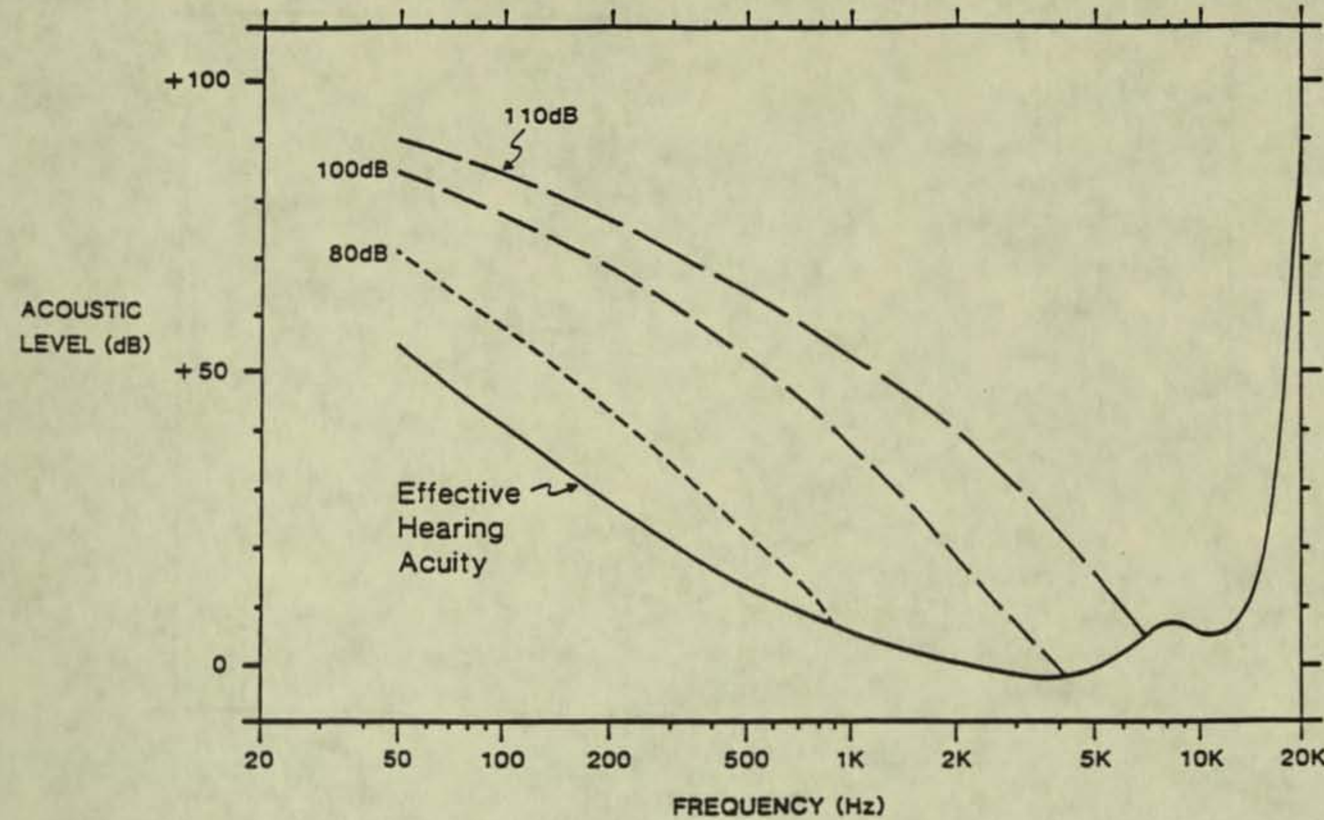

Fig. 1. 100 Hz Masked Threshold Curves (0 dB = 20 micropascals)

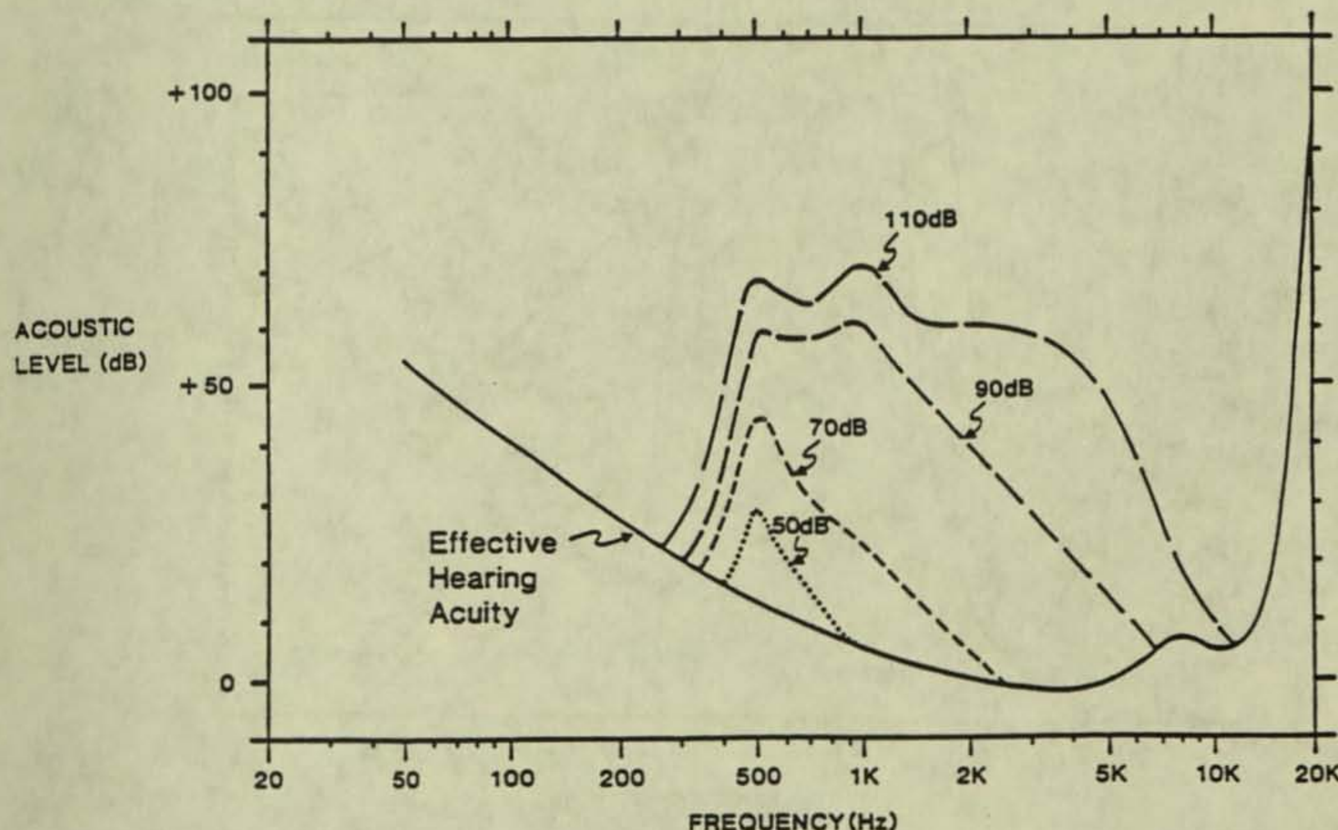

Fig. 2. 500 Hz Masked Threshold Curves (0 dB = 20 micropascals)

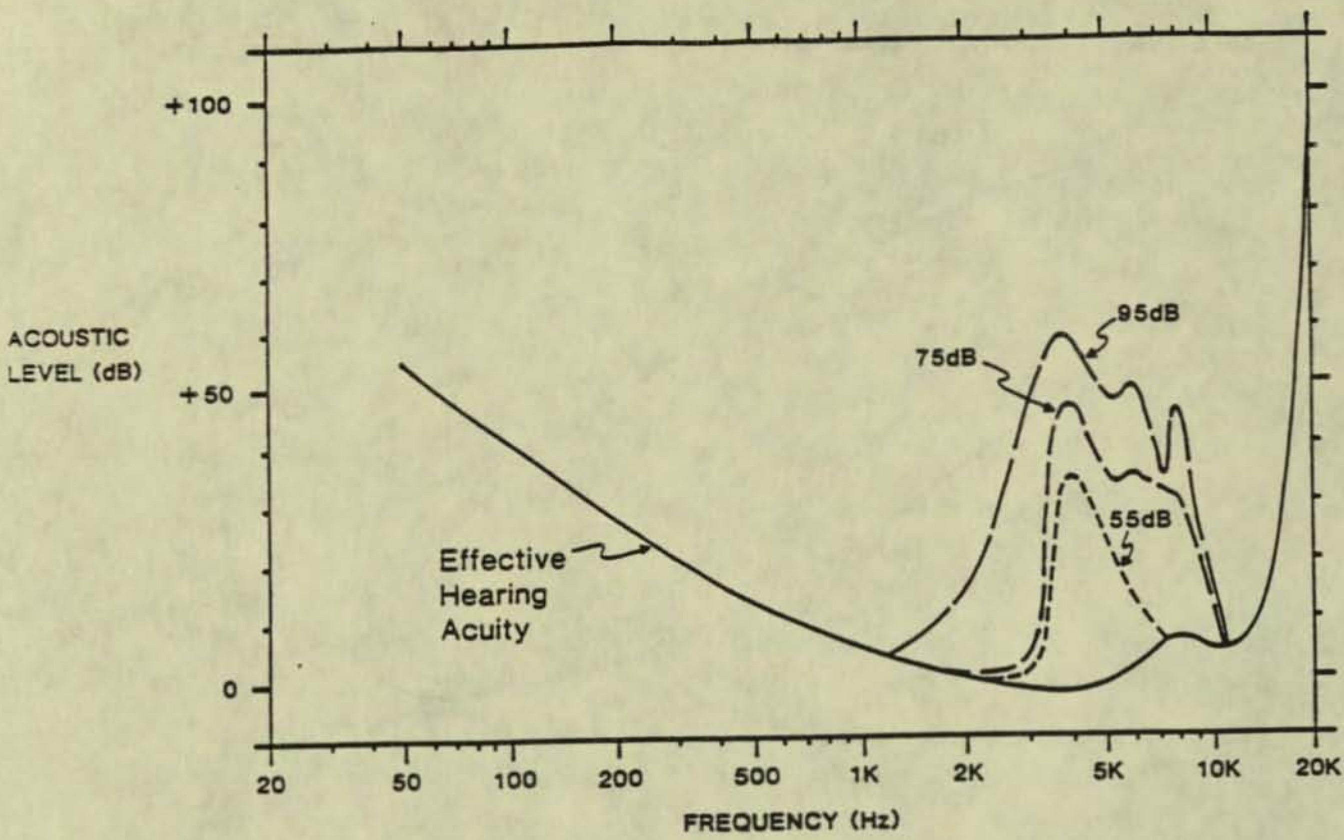

Fig. 3 4 kHz Masked Threshold Curves (0 dB = 20 micropascals)

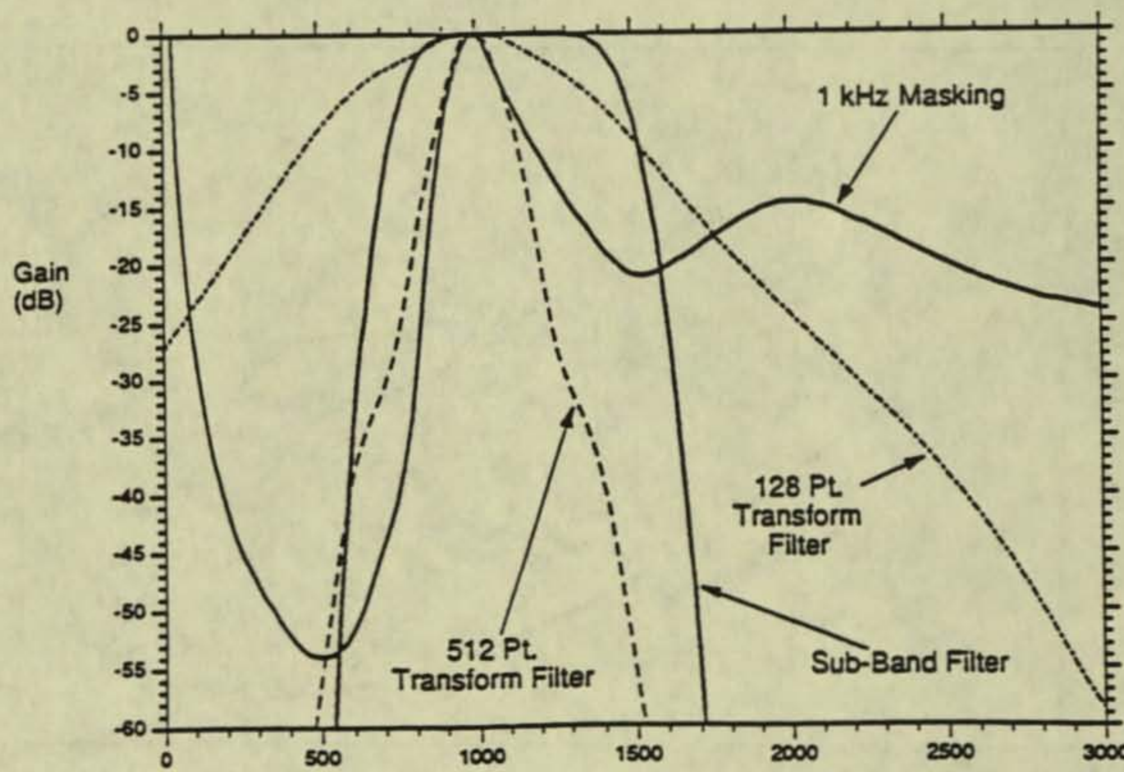

Fig. 4 Comparison Between Various Filter Banks and 1 kHz Human Auditory selectivities

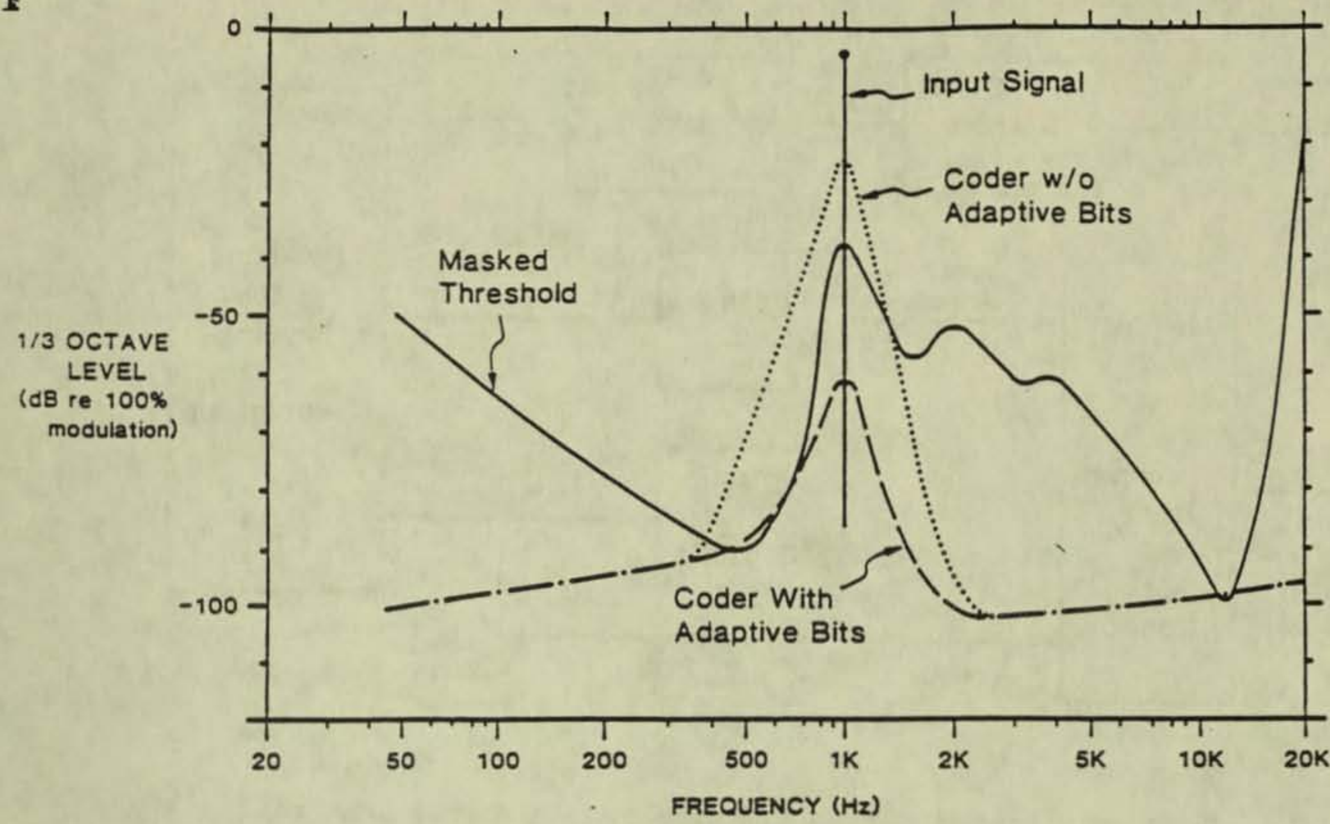

Fig. 5 Moderate Time Delay AC-2 Coder Performance with the Application of a 1 kHz Sinewave

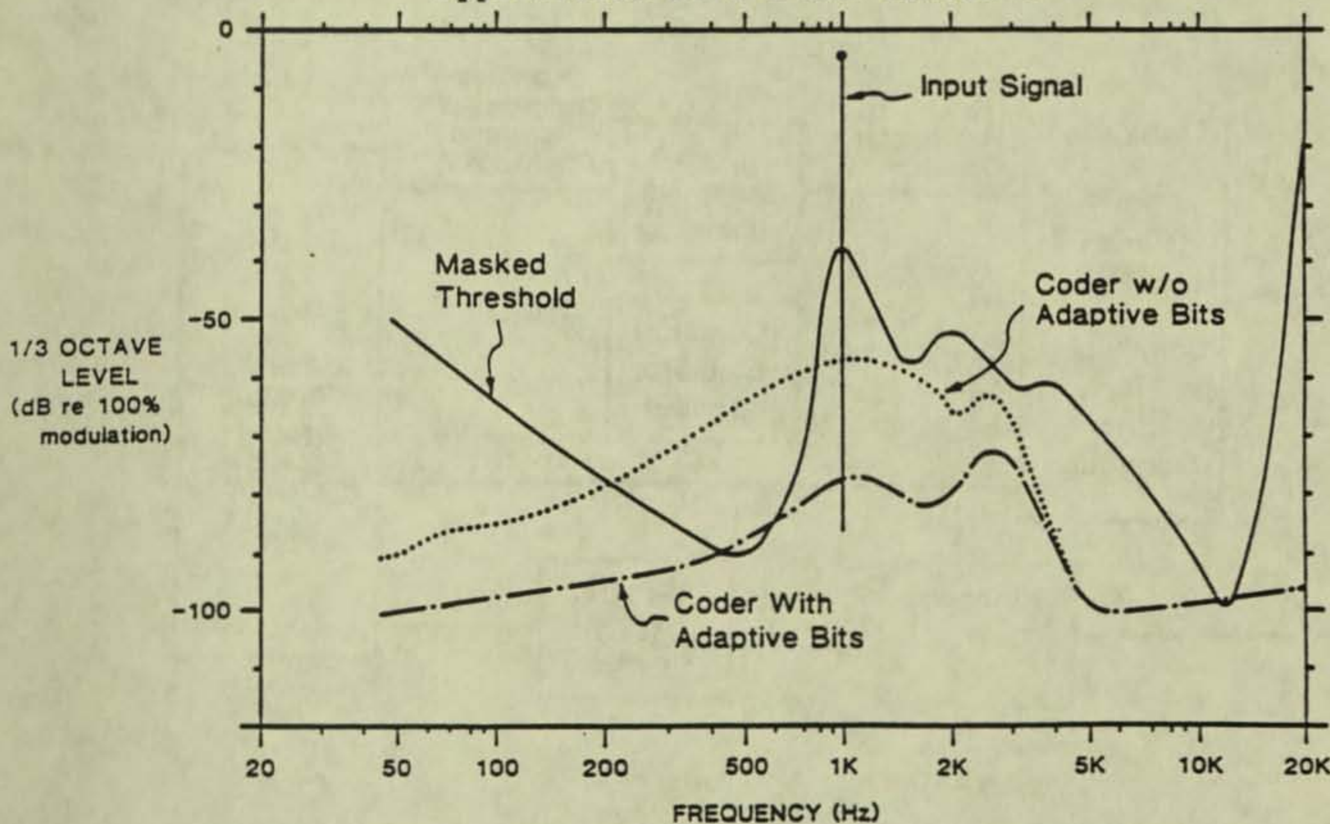

Fig. 6 Low Time Delay AC-2 Coder Performance with the Application of a 1 kHz Sinewave

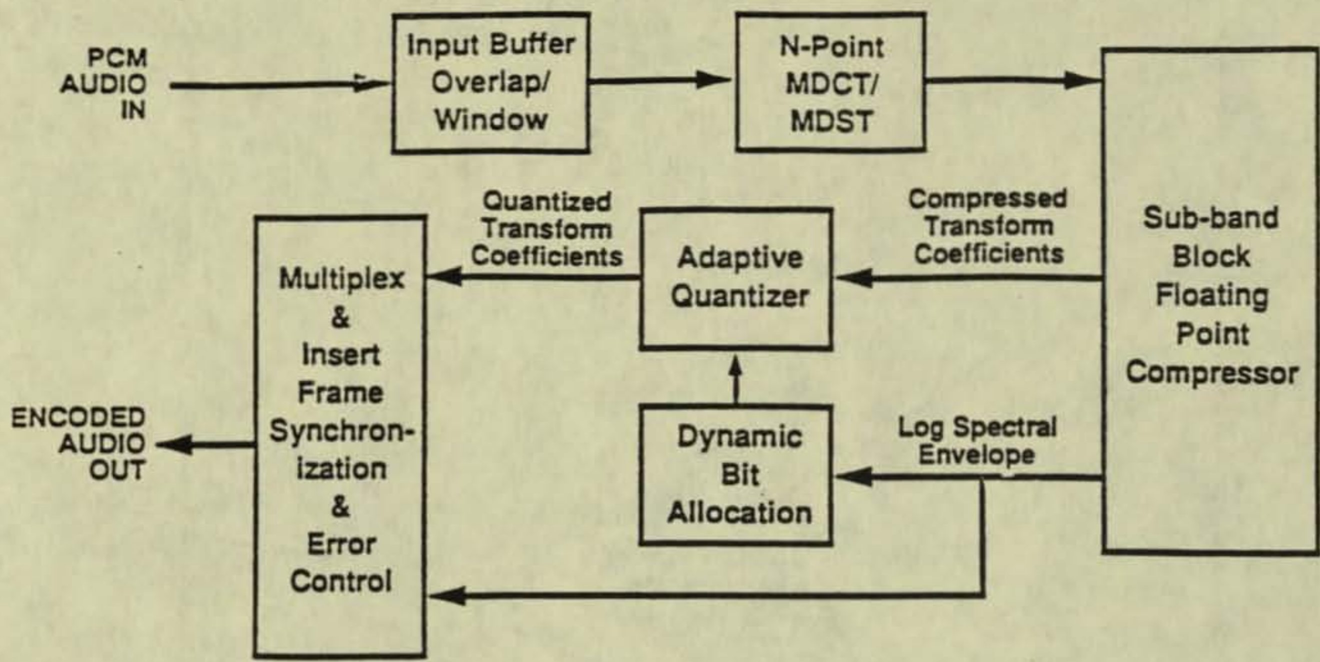

Fig. 7 AC-2 Digital Audio Encoder Family Block Diagram

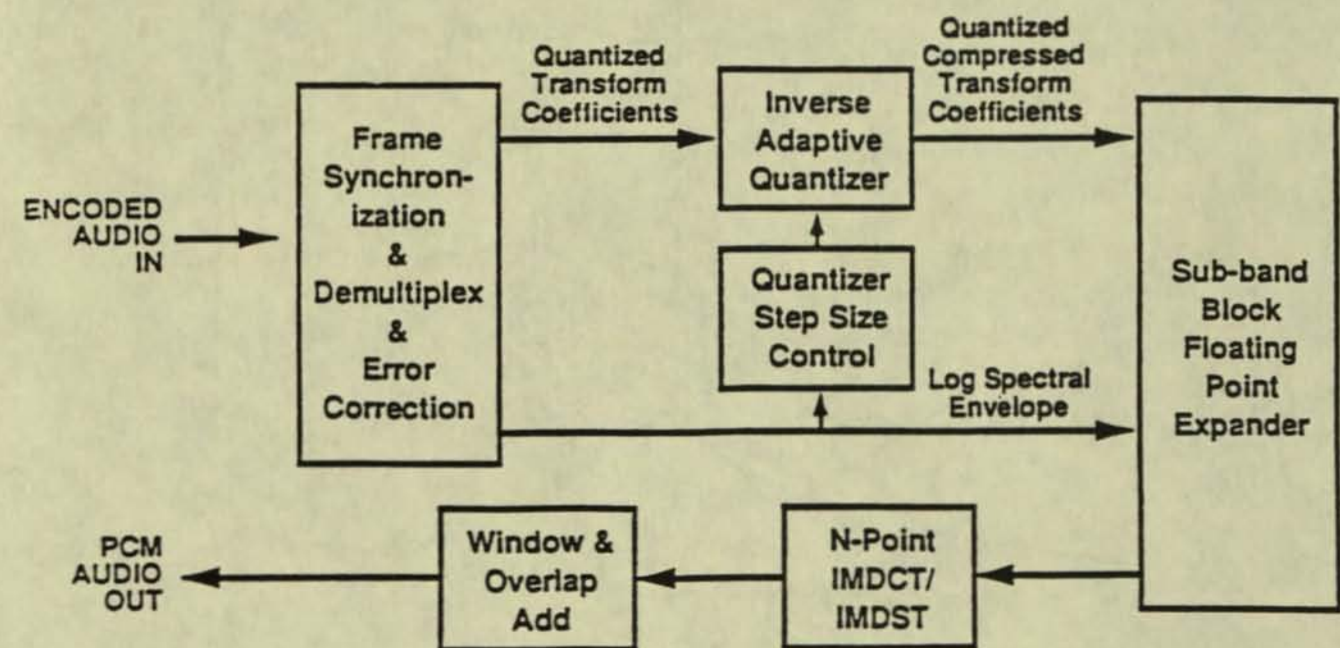

Fig. 8 AC-2 Digital Audio Decoder Family Block Diagram

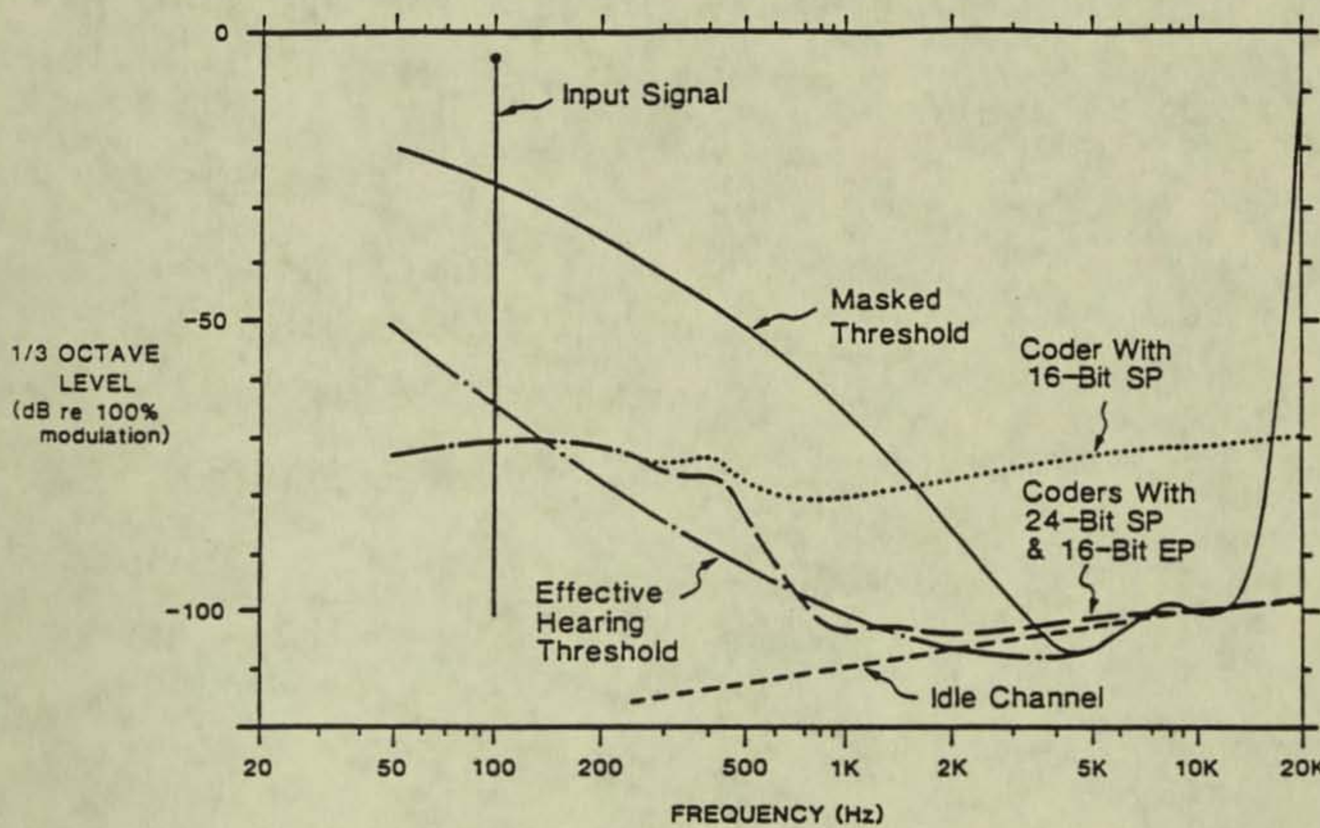

Fig. 9 Comparison of Filter Bank Arithmetic Noise of Single Precision (SP) 16-Bit Arithmetic Versus Extended Precision (EP) 16-Bit and Single Precision 24-Bit Arithmetic

From: RDVAX::GEROVAC "Branko J. Gerovac 16-Apr-1993 0906" 16-APR-1993 09:11:2
6.61
To: FULLER,GANNON,LIPP
CC: GEROVAC
Subj: HDTV update (for CSPP mtg)

f: HDTV

Sam and Tom/

HDTV activities are continuing along three parallel directions: (1) the formal FCC testing and selection process, (2) the backroom discussions on a "grand alliance" among the 4 digital HDTV proponents, and (3) emerging activities related to a national information infrastructure.

FCC Process

Because the first round of testing did not show any one system to be superior and since all 4 digital system proponents proposed improvements, a second round of testing was recommended. (See attachment on FCC testing/selection.) Testing was to start in mid-March, but people realized this was optimistic. Start of testing was delayed twice, now to the beginning of May (and may be delayed again till June).

This round of testing was to include interoperability testing. Gary Demos, consulting for Apple, was pulling this together. However, it appears that adequate interoperability testing will not be possible. The FCC's testing lab was originally set up assuming analog systems. Therefore, there are not the hooks in the testbed to extract digital signals (or rather to do so without significant schedule delay). (See attached draft memo on Interoperability Testing. Please do not distribute.)

The resulting lack of interoperability testing can form the basis of a later challenge to the FCC decision.

Grand Alliance

The backroom discussions on a grand alliance of the 4 digital systems has been on-again off-again for the past 2 months. The delays in the formal process make a grand alliance more enticing to the proponents.

In recent private discussions I've had with several of the people involved, it appears that the alliance is fairly close. The two sticky points are interlace vs progressive image transmission and MPEG vs proprietary image compression. It looks like an MPEG compliant scheme without B-frames might resolve one issue. That leaves interlace vs progressive. Unclear what will happen.

Other Activities

Somewhat because of the delays in the FCC process, simply because the technology is becoming available, and to some degree because of the broader interest in a national information infrastructure, many other activities (e.g., alliances, initiatives) are pushing on digital television. (See attached new items.)

Let me know if you'd like to discuss any of this further. I can be reached at home this weekend, 617-489-5927.

/Branko

Attachments: FCC ATV Testing/Selection Criteria/Results
Recent News Items

Draft Memo on Interoperability Testing

Attachment: FCC ATV Testing/Selection Criteria/Results

The abbreviated system names used below are:

DigiCipher -- General Instrument, interlace scan system
DSC-HDTV -- AT&T/Zenith
AD-HDTV -- ATRC (Sarnoff, Philips, Thomson, NBC)
CCDC -- MIT/GI, progressive scan system

Selection Criteria

Here is a quick review of the 10 primary selection criteria (in 3 categories) and the results that were reviewed during the meeting:

Spectrum Utilization

1. Service Area -- the effective area in which an HDTV station could be received. The desire is that an HDTV station would have at least the same service area as its companion NTSC station.

2. Accommodation Percentage -- the percentage of existing NTSC stations that can be accommodated with an additional HDTV channel (independent of the resulting service area.

All 4 digital systems provided full accommodation and all produced very similar results in service area. In a few major markets (e.g., Los Angeles, New York), it was difficult to provide the same service area for HDTV as its companion NTSC station. The simulation that produced these results was a worst case analysis. Actual (rather than simulated) allocation analysis would likely yield better results. Also, all proponents have proposed improvements to their systems that will improve spectrum utilization.

Economics

3. Cost to Broadcasters -- the cost ranging from simple pass-through of a network generated HDTV signal (e.g., transmission equipment) to the outfitting of a complete HDTV production studio (e.g., cameras, VTRs, etc.).

4. Cost to Alternative Media

5. Cost to Consumers -- the cost of manufacturing an HDTV receiver.

There was no significant difference among the 5 proponent systems in costs to consumers or broadcasters.

Technology

6. Video/Audio Quality -- subjective testing of perceived quality and objective performance testing.

   All 4 digital systems produced good video quality. The two interlace systems (DigiCipher, AD-HDTV) were generally better than the two progressive systems (DSC-HDTV, CCDC). However, there were implementation errors in the tested systems, and there seemed to be problems with the source material. Note that on one test with computer generated source material, the progressive systems were better than the interlace systems which showed typical interline flicker problems.

CCDC uses a MIT designed audio system. DigiCipher and DSC-HDTV use Dolby AC-2/AC-3. AD-HDTV uses MPEG's Musicam. The CCDC objective audio tests results were better than the other 3 systems. The subjective audio tests showed considerable variability, therefore were inconclusive.

7. Transmission Robustness -- the ability of the transmission to maintain useful picture, sound, and data in the presence of interference (e.g., co-channel, adjacent channel,...) and impairments (e.g., noise, multipath,...).

   All 4 digital systems performed well. DSC-HDTV and CCDC showed better results than DigiCipher and AD-HDTV. Some of the results depend on receiver implementation, and are not inherent in the system design. AD-HDTV's poorer receiver implementation was apparent in their results. All proponents will submit improved implementations and additional system refinements for the next round of testing.

8. Scope of Services and Features -- services and features not covered elsewhere in the selection criteria, e.g., ancillary data capacity, reallocation of data stream,...

9. Extensibility -- the ability to support and incorporate future functionality as technology advances.

10. Interoperability -- the suitability of the system to support alternative transmission media (satellite, cable, packet networks), transcoding (with NTSC, film, other video formats), integration with computers and digital technology (interactive systems), use of headers/descriptors, and scalability.

    For many of the comparisons the digital systems were comparable.

    Only AD-HDTV had its final proposal for a packetized data structure and headers and descriptors fully implemented at the time the system was tested by ATTC, and it received the highest rating on these characteristics. All 4 digital proponents now recognize the importance, and have implemented or commit to implement both a flexible packetized data transport structure and universal headers/descriptors for the next round of testing.

    Progressive scan and square pixels are recognized as important to interoperability with computers, and further, are considered beneficial to creating synergy between terrestrial HDTV and national information initiatives. Only DSC-HDTV and CCDC are progressive scan and square pixel systems. AD-HDTV provides some degree of progressive-scan square-pixel transmission with a potential migration path. And, DigiCipher claims a possible option for progressive scan transmission. The migration paths need to be fully documented and analyzed for suitability in addressing these needs.

    None of the systems achieved the desirable degree of scalability at the transmission data stream that would permit trade-offs in "bandwidth on demand" network environments and useful subsampling of the data stream. There are no effective proposals coming forward at this time for scalability.

Note that on most measures, the digital systems performed well but not significantly differently. After the next round of testing they will be even closer. The one major distinguishing characteristic remaining is progressive versus interlace scan (and the interplay of national information infrastructure and entertainment media).

Attachment: Recent News Items

SUBJECT: ^HOUSE CHAIRMAN ASKS FCC FOR HDTV INVESTIGATION@
SOURCE: Reuters via First! by INDIVIDUAL, Inc.
DATE: April 14, 1993
INDEX: [2]

WASHINGTON, The Reuters Business Report (U.S.) via First! : The chairman of a House subcommittee asked the Federal Communications Commission Wednesday to investigate the economic impact of setting a technical standard for high definition television.

''What impact will the setting of an HDTV standard have on the consumer-electronics and high-technology industries here and around the world? How many jobs are likely to be created and in which industries?'' Rep. Edward Markey, D-Mass., asked in suggesting issues the FCC should consider.

Markey, chairman of the Telecommunications and Finance subcommittee, made the request to FCC Chairman James Quello. The FCC is considering an industry-wide standard for high definition television sets, which provide movie-quality pictures.

Markey said the FCC should chose an HDTV standard that would allow television sets to link with computers.

''Choosing a standard of maximum interoperability could, in the not too distant future, ensure that every television set has the ability to interact with intelligent machines, thus helping to bring the information age to a broader range of consumers,'' Markey wrote.

''It could, at the same time, broaden the market for related information products and software, industries in which U.S. companies have traditionally prospered,'' he said.

SUBJECT: AT&T SWITCH CHOSEN FOR TIME WARNER'S "ELECTRONIC SUPERHIGHWAY"
SOURCE: Business Wire via First! by INDIVIDUAL, Inc.
DATE: April 14, 1993
INDEX: [3]

STAMFORD, Conn.--(BUSINESS WIRE) via First! -- Time Warner Cable has selected a highly sophisticated switching system manufactuered by AT&T as a key component of its Full Service Network, the electronic superhighway to be constructed this year in the Orlando, Fla., area.

In making the announcement, Joseph J. Collins, chairman and CEO of Time Warner Cable, said, "This next-generation AT&T switching system is by far the most sophisticated equipment of its kind.

"We are very pleased that its first commercial use to transmit video signals will be in our ground-breaking Full Service Network in Orlando. Our ability to create the first switched television system using this AT&T technology will change forever the way people use the medium, allowing the convergence of television, computers and telecommunications. Our discussions with AT&T on the switching system and other aspects of the Full Service Network have been very helpful as we work toward completion of the initial phase of construction."

"We're obviously pleased that Time Warner has chosen our ATM switch for the Orlando system," said William J. Marx Jr., president, AT&T Network Systems. "We believe that the deployment of this kind of technology will revolutionize the way consumers interact with information, entertainment and basic communications."

Time Warner Cable's Full Service Network, announced in January, will combine fiber optic cable with digital switching, storage and video compression technologies to provide a broad array of services including video-on-demand, interactive games, distance learning, full-motion video interactive shopping, personal communications services and high-speed data transfer.

The AT&T switch selected for the system is the GCNS-2000, an Asynchronous Transmission Mode (ATM) switch developed by AT&T Network Systems, AT&T's largest manufacturing unit. ATM is a next-generation fast-packet technology capable of relaying voice, data and images at multi-gigabit speeds.

The GCNS-2000 moves information at up to 20 gigabits per second. At this capacity, it would be the equivalent of transmitting 1,600 copies of the novel "Moby Dick" in one second. In addition to providing data networking services, the switch is specifically designed to work in an end-to-end video system offered by service providers to consumers so they can order and retrieve movies and other video services from program providers, video "libraries," mass data bases or other programming sources.

The ATM switch will operate in the first phase of the Full Service Network that will be available to 10,000 homes in the Orlando area by early 1994.

Time Warner Cable serves approximately 500,000 homes in Central Florida. Time Warner Cable, a division of Time Warner Entertainment, is the nation's second-largest cable television operator, with 7.1 million customers in 36 states.

AT&T Network Systems is one of the world's largest manufacturers and providers of network telecommunications equipment, offering communications service providers virtually everything they need to build and operate their networks. AT&T provides communications services, equipment and computer systems to consumers, businesses and communications companies around the world.

CONTACT: Time Warner Cable, Stamford | Mike Luftman, 203/328-0613 | or | AT&T Network Systems | Pat Stortz, 201/606-2478 | Kevin Beagley, 201/606-2587

[04-14-93 at 14:23 EDT, Business Wire, File: b0414142.600]

SUBJECT: SEGA, TIME WARNER AND TCI JOINT VENTURE TO BRING VIDEO GAMES TO CABLE TV
SOURCE: Business Wire via First! by INDIVIDUAL, Inc.
DATE: April 14, 1993
INDEX: [4]

NEW YORK--(BUSINESS WIRE) via First! -- Sega of America Inc., Time Warner Entertainment Co. L.P. and Telecommunications Inc. Wednesday announced plans to form a joint venture to develop and market "The Sega Channel," offering Sega Genesis owners access to a large library of video games via cable television.

The Sega Channel -- to be priced in the range of most pay-cable subscription services -- will be launched in test markets this fall. The service could be available to all U.S. cable system operators by early 1994.

Sega Channel subscribers will choose from a wide selection of popular games, previews and soon-to-be-released titles, gameplay tips, news, contests and promotions. The programming will be updated monthly to keep it exciting and new for avid gamers.

To receive the Sega Channel, subscribers will get a special tuner/decoder cartridge. The tuner/decoder plugs in the Sega Genesis cartridge slot and attaches to the television cable. A menu appears on the television screen, allowing the subscriber to easily select any game, preview or other program material. The selected game is available in minutes, and plays identically to the cartridge version.

"Everybody comes out ahead with the Sega Channel," said Tom Kalinske, Sega president and chief executive officer. "The consumer gets an extraordinary value -- a well-stocked and constantly updated library of games for a low monthly fee. Once subscribers and their friends enjoy a game or preview, they'll be more likely to buy the packaged version -- so retail sales will increase.

"Our intellectual property licensors, developers and third-party publishers will gain a new source of revenue. And Sega, Time Warner and TCI will have begun working together on new ways to deliver mass-market, interactive entertainment in the radically evolving telecommunications infrastructure of tomorrow."

Additionally, Kalinske estimates that there will be 12 million to 14 million Genesis homes in the United States by the end of 1993.

Sega's partners in the proposed joint venture are the two largest cable system operators. Time Warner was among the first to market a premium cable service.

"The Sega Channel delivers the equivalent of games-on-demand via today's standard analog cable," said Larry Romrell, senior vice president of TCI. "Virtually every cable operator will be able to offer this exciting high-tech service, now, without waiting for the new digital cable technologies.

"At the same time, this development signals the beginning of an explosion of interactive programming for our developing broad-band networks."

"We welcome the opportunity to explore an innovative pay cable business which delivers top-quality video games to the home," said Geoff Holmes, Time Warner senior vice president of technology. "Along with our partners, we intend to make The Sega Channel as much of a breakthrough in the interactive video marketplace as HBO was in the early days of cable."

Sega of America is a wholly owned subsidiary of $2.8 billion Sega Enterprises Ltd., Japan. Sega is a worldwide leader in arcade and home entertainment systems.

TCI is the world's largest cable company. It serves 10.2 million subscribers in 49 states and has operations in nine foreign countries.

Time Warner Inc. is the world's leading media and entertainment company, with interests in magazine and book publishing, recorded music and music publishing, filmed entertainment, cable television and cable television programming.

CONTACT: Sega of America Inc., Redwood City, Calif. | Ellen Beth Van Buskirk, 415/802-1436 | or | TCI, Littleton, Colo. | Lela Cocoros, 303/267-5273 | or | Time Warner, New York | Edward Adler, 212/484-6630

[04-14-93 at 17:30 EDT, Business Wire, File: b0414173.200]

SUBJECT: SILICON GRAPHICS "IN TALKS WITH TIME WARNER"
SOURCE: Computergram via First! by INDIVIDUAL, Inc.
DATE: April 14, 1993
INDEX: [5]

Computergram via First! -- Silicon Graphics Inc, Mountain View, is not commenting on a report in the New York Times that it is considering teaming up with Time Warner Inc to develop hardware for interactive television. The paper said the companies were discussing building an inexpensive computer derived from the three-dimensional Silicon Graphics R4000 64-bit RISC-based Iris machines used by movie studios to create special effects, which would attach to television sets and make possible a variety of interactive games and other applications. The talks are also said to involve video servers at the transmission end. The cable television industry is said to be leery of handing over a standard to a third party such as Microsoft Corp, which has teamed up with Intel Corp to develop a set-top control box based on the 80386 and Windows; the 80386 is also regarded as underpowered for graphics work.

SUBJECT: LSI LOGIC AND PHILIPS CONSUMER ELECTRONICS ANNOUNCE COOPERATIVE DEVELOPMENT OF ICS FOR USE IN COMPRESSED DIGITAL VIDEO BROADCAST APPLICATIONS
SOURCE: Business Wire via First! by INDIVIDUAL, Inc.
DATE: April 12, 1993
INDEX: [1]

MILPITAS, Calif.--(BUSINESS WIRE) via First! -- LSI Logic Corp. and Philips Consumer Electronics Co. (PCEC) Monday announced they are collaborating on several IC development projects aimed at compressed digital video broadcast applications.

Philips, a leading U.S. supplier of color televisions and other consumer electronics products provides system expertise, while LSI Logic, a leader in Application Specific Integrated Circuits (ASIC) technology, offers its experience in developing VLSI circuits for digital signal processing, video compression, error correction and demodulation.

Commenting on the relationship, Peng Ang, vice president and general manager for LSI Logic's DSP Division, said: ''We feel it is critical that LSI Logic work with a leading system partner in developing products of this complexity. Philips is a natural choice since it has extensive experience in the television market and has made significant investments in research and development for the digital TV market. LSI Logic and Philips already enjoy a significant business relationship in Europe.''

Both companies feel that adherence to emerging international standards will be key to the success of digital TV and both are active on the MPEG standards committee. Philips is also a member of the Advanced Television Research Consortium (ATRC), which is proposing a digital HDTV system based on the MPEG standard.

According to Brian Smith, senior director responsible for ditigal TV at Philips, they chose to work with LSI Logic because of its broad expertise in system-level integration. ''We believe that LSI Logic has unique and wide-ranging capability in this emerging new consumer electronics technology.

''Coupled with LSI Logic's leading position in ASIC methodology, this offers a coherent forward integration path necessary to achieve cost effective solutions in large volume applications.''

LSI Logic and Philips have worked together for more than a year designing a number of digital demultiplexing and video/audio processing ICs for upcoming Philips digital receiver applications. The two companies plan to develop future products for the digital TV industry which involves nearly all video transmission and pre-recorded media.

LSI Logic Corp. (NYSE:LSI) is a Fortune 500 supplier of high-performance semiconductors with operations in the United States, Europe, Japan, The Pacific Rim and Canada.

The company manufactures and markets application-specific integrated circuits (ASICs), 32-bit MIPS and SPARC RISC microprocessors, electronic imaging and digital signal-processing ICs, as well as chipsets and graphics products for IBM-compatible personal computers. The company also develops and sells software used to design integrated circuits.

LSI Logic applies this leading-edge technology to fast-growing vertical markets such as internetworking. LSI Logic is headquartered at 1551 McCarthy Blvd., Milpitas, CA 95035. The main phone number is 408/433-8000.

Philips Consumer Electronics Co. (PCEC), based in Knoxville, Tenn., is a division of North American Philips Corp. PCEC manufactures and markets Philips, Magnavox, Sylvania and Philco audio, video and related products and services.

PCEC designs and manufactures all of its color TVs sold in the United States and is the second largest U.S. TV producer, incorporating the industry's highest level of local content. PCEC employs nearly 7,000 U.S. personnel including 250 engineers and more than 2,000 individuals in manufacturing.

Note to Editors:

The LSI logotype is a registered trademark of LSI Logic Corp.

Reader inquiries (''bingo'' responses) should be directed to Literature Distribution, LSI Logic Corp., MS-D102, 1551 McCarthy Blvd., Milpitas, CA 95035.

CONTACT: LSI Corp., Milpitas | Carey Mitchell, 408/433-7175 (media) | Simon Dolan, 408/433-7593 (technical) | Philips Consumer Electronics, Knoxville | Jon Kasle, 615/521-3274

[04-12-93 at 07:00 EDT, Business Wire, File: b0412070.000]

SUBJECT: IBM RESEARCH ACCELERATES ENTERTAINMENT INDUSTRY TECHNOLOGY
SOURCE: Business Wire via First! by INDIVIDUAL, Inc.
DATE: April 12, 1993
INDEX: [2]

YORKTOWN HEIGHTS, N.Y.--(BUSINESS WIRE) via First! -- IBM Research Monday boosted the thrust of its supercomputer-strength POWER Visualization System (PVS) in pivotal entertainment industry technologies -- announcing integrated digital video(a) and audio input/output and factor MDEC(b) digital video and audio compression, the availability of additional industry software and a software development pact with a major Hollywood innovator.

These strides by IBM Research are aimed at developing an all-digital, resolution-independent production and post-production environment that will revolutionize the way movies, network television and cable programs, video and music products are made and distributed.

Movies and video-on-demand, interactive home programming, software-generated movie sets and characters, more realistic theme park attractions and exhibits--all of these are taking shape as digital technology permeates the entertainment industry.

Such techniques will eventually replace photochemical and optical processes used today, creating production efficiencies as well as new artistic possibilities by shortening the time between creative impulse and finished product.

"The digital transformation of the entertainment industry presents an exciting growth opportunity for the computer industry and promises an era of dazzling, increasingly varied and more accessible film, video and electronic attractions," said Abe Peled, IBM Research vice president, systems and software.

Today's announcements include:

- The POWER Visualization System Digital Video I/O Facility, designed to supply PVS with an efficient way to capture and record digital video and audio in real-time for compositing, processing or compression. Users control the process with an intuitive on-screen graphical user interface consisting of familiar buttons, sliders and status displays. PVS is one of the only general-purpose computer systems with integrated real-time digital video I/O.

- The Digital Compression Facility for PVS, which can furnish high quality MPEG-1 compression of digital video and audio input. It is designed to radically shorten the process -- from days to hours -- of encoding digital movies for rapid decompression in applications such as video-on-demand and CD-ROM recording.

- An agreement with Boss Film to develop new, advanced software tools for essential film processing tasks such as compositing, blending images, color correction and erasing wire "prop" images from special effects.

- Two leading special effects firms - Information International Inc., and Discreet Logic Inc., have fashioned applications for IBM's POWER Visualization System - Information International's ARKImage tm 2D production and post-production system and Discreet Logic's film and video production system, DANTE. tm

- Multiple SCSI-2 channel support, permitting PVS greater access to a wider variety of disk, tape and other input/output devices supported by this broadly used standard.

The Compression Facility is the first result of IBM's technical collaboration with Laser-Pacific Media Corp. announced earlier the year. "We and IBM Research have taken the first step toward creating our industry's future Motion Picture and electronic Laboratory," said Leon Silverman, Laser-Pacific executive vice president.

The IBM POWER Visualization System operates 10 to 50 times faster than a workstation. It offers an all-digital processing and storage system that can encompass any format or resolution and run virtually any proprietary imaging software users wish to employ. PVS has made significant strides in the entertainment industry, placing systems at Boss Film Studios, The Trumbull Co., Pacific Title and Art Studio, Laser-Pacific Media Corp. and R/Greenberg Associates.

Enhancements announced today, plus a number of technology demonstrations and entertainment industry applications will debut at next weeks' NAB '93 (National Association of Broadcasters) convention in Las Vegas, April 18-22, 1993.

These will include applications such as the Alias PowerTracer, Pixar Photorealistic RenderMan and Wavefront Visualizer Server and COMPOSER Compositing Server. There will also be a technology demonstration of the Ultimate Cinefusion Compositing Tool.

Prices and availability of the new PVS offerings will be announced there.

(a) Refers to CCIR-601, which is a digital video format standard of

CCIR, the International Radio Consultative Committee, (b) Moving Pictures Experts Group.

tm Trademarks and Registered Trademarks,

DANTE is a Trademark of Information International Inc.

Alias PowerTracer is a Trademark of Alias Research nc.

Wavefront Visualizer Server and COMPOSER

Compositing Server are Trademarks of Wavefront Technologies Inc.

Ultimatte is a registered Trademark of Ultimatte Corp. and

Cinefusion is a Trademark of Ultimatte Corp.

Technical Information

IBM Research today quickened the pace of evolution in the entertainment industry with two advanced, integrated tools that provide a true end-to-end solution for digital video input/output and MPEG-1 digital compression, based on its POWER Visualization System (PVS).

Both enhancements are designed to meet increasing production and creativity needs in the entertainment industry spurred by demand for more spectacular and complex video and film effects, as well as from more efficient and cost-effective recording, delivery and archiving of video material.

Technologies are converging in the computer, consumer and entertainment industries - enabling Hollywood, cable companies and TV producers to pursue new efficiencies and move away from photochemical/electronic processes - toward an all-digital production/post-production "world." Today's announcements underscore the POWER Visualization Systems' role as a technology leader in the genesis of that all-digital environment.

The POWER Visualization System provides a responsive, real-time workspace for the creative mind. It output can stream to standard video display devices and storage as fast as it entered -- up to 30 frames per second. Creative input and output are handled and recorded at high speed in industry-standard formats -- 8 and 10-bit digital video and audio. Included software provides direct control of data capture and recording -- the XVTR control program, built on the familiar X-Windows/Motif user interface. XVTR provides an on-screen VTR (VideoTape Recorder) "console" users can control with buttons status displays and sliders just as they would any real hardware device -- providing a convenient single point of control for multiple input and output video recorders and other devices.

Precise timing of output is provided by a standard "Genlock" signal.

XVTR can create control windows for each of multiple VTRs, all of which can be assigned user-customized controls.

Hundreds of gigabytes -- enough to store entire movies in digital form -- can be accessed from high-speed parallel RAID (Redundant Array of Inexpensive Disks) drives using up to six 100 million character-per-second HIPPI (High Performance Parallel Interface) channels or four to sixteen SCSI-2 channels. Each SCSI-2 channel can provide a data transfer rate of 20 megabytes per second.

A bothersome bottleneck for the industry is data compression -- necessary for economic digital image handling and future distribution schemes, such a video-on-demand. Current MPEG compression technology is slow and expensive on workstations, but executes significantly faster on the PVS Digital

Compressions Facility, which furnishes high-speed MPEG-1 compression of digital video and audio input. It is able to import large volumes of digital video and audio input via the Video I/O facility and export compressed output rapidly to a LAN for video-on-demand applications or to EXABYTE tapes for archival storage.

The new Compression Facility announced today can compress digital video at a rate of 7 to 9 frames per second -- approximately one-fourth real-time, or a compression ratio of 4 to 1. This compares with 200 to 1 to 1,000 to 1 compression rates for other software-based techniques. Like the Video I/O facility, the Digital Compression Facility for PVS presents users with the familiar X-Windows/Motif user interface.

Users can ''tune'' their compression algorithms while viewing the resulting output and write special software routines that enhance its quality. The Compression Facility is the first result of IBM's technical collaboration with laser-Pacific Media Corporation announced earlier this year. Support for MPEG-2 compression is planned for later date.

CONTACT: IBM Corp., Yorktown Heights | Denis Arvay, 914/945-3471

[04-12-93 at 09:21 EDT, Business Wire, File: b0412092.301]

SUBJECT: LSI LOGIC LAUNCHES MPEG DECODER ICS, SIGNS DIGITAL TV WITH PHILIPS
SOURCE: IDG via First! by INDIVIDUAL, Inc.
DATE: April 9, 1993
INDEX: [1]

EINDHOVEN, the Netherlands - IDG News Service via First! : LSI Logic Corp. yesterday announced it will collaborate with Philips Consumer Electronics Co. here to develop integrated circuits for compressed digital video broadcasting techniques that are being considered for high-definition television (HDTV) in North America.

The announcement came with LSI Logic planning to introduce on Monday a family of decoder ICs supporting compression techniques backed by the Motion Pictures Expert Group (MPEG). The chips are being targeted at a range of systems, from digital TV to multimedia personal computer applications to advanced entertainment systems using laser discs.

The MPEG compression standard is now the basis of a U.S. digital HDTV proposal from the Advanced Television Research Consortium (ATRC), which includes Philips, France's Thomson Consumer Electronics, David Sarnoff Research Center, Compression Labs and the National Broadcasting Co. (NBC).

LSI Logic's agreement with Philips comes nearly three months after Texas Instruments, Inc. announced it was backing the MPEG-based HDTV format promoted by ATRC. TI is not directly involved in MPEG-related IC development with any of the ATRC members, said a company spokesman yesterday. However, TI and LSI Logic are now separately backing the same MPEG approach competing with rival U.S. proposals supported by Motorola, Inc. and AT&T.

Although the MPEG-related HDTV work is now only focused on the U.S. market, a Philips spokeswoman here said the Dutch company could consider the technology in future work on televisions for Europe. The European Community is expected to look for a new digital standard to replace its ill-fated multiplexed analog component (MAC) format.

With the launch of its new MPEG decoder family, LSI Logic taking an aggressive path to lowering the cost of digital TV. The family of audio, video and error correction decoders will become a two-chip set solution for decompression of MPEG signals in 1994, and a single-chip solution is planned by 1996, according to LSI Logic's roadmap.

On Monday LSI Logic is introducing separate decoders for MPEG- compressed audio, video and error correction. The ICs are designed to be compatible with the MPEG-2 standard, which is in being drafted and expected to be competed by the end of 1994. The MPEG-2 standard is aimed at supporting digital TV at 4 to 15 megabits per second rates.

LSI Logic claims to have the first single-chip MPEG decoders for audio, video and error correction. The L64111 audio decoder provides compact disk quality sound from MPEG-compressed signals. It is being sold for $35.95 each in 1,000-piece quantities. The L64112 video decoder has been designed specifically for digital cable-TV applications. It costs $125 each in 1,000-piece quantities. A family of devices are also being offered for Reed Solomon forward error correction of high-speed digital data streams. The error-correction decoders cost $35 each and the encoders cost $27 each in 1,000-piece lots.

Volume shipments of the audio and error-correction decoders start in the second quarter while the production shipments of the video decoder will begin in the third quarter.

J. Robert Lineback, IDG News Service, European correspondent

SUBJECT: FCC SHOULD HALT VIDEO DIAL TONE APPLICATIONS, CABLE AND CONSUMER GROUP S SAY<>
SOURCE: Warren Publishing via First! by INDIVIDUAL, Inc.
DATE: April 9, 1993
INDEX: [2]

Communications Daily via First! -- FCC SHOULD HALT VIDEO DIAL TONE APPLICATIONS, CABLE AND CONSUMER GROUP S SAY

FCC should refuse to accept any more video dial tone (VDT) applications because under current rules it can't guarantee that cross-subsidization won't occur, NCTA and Consumer Federation of America (CFA) said in joint filing Thurs. Groups asked FCC to begin rulemaking to establish cost allocation rules for VDT and to set up special board to recommend procedures to deter cross-subsidization of VDT by telephone ratepayers. "Failure to act will impose a heavy burden on consumers and undermine competition in the video marketplace," groups said.

Filing said that in VDT decision, FCC "left critical implementation issues unresolved" (CD July 17 1992 p1) and would force telephone ratepayers to "bear the costs of millions of dollars of fiber optic lines being installed for video services." To avoid that, groups said, FCC should: (1) Establish Federal-State Joint Board to recommend formula to assure that plant costs attributable to VDT aren't allocated to local telephone service because telcos have, "unsurprisingly, proposed to assign the entire cost of plant used jointly for video and telephony to basic ratepayers." (2) Adopt VDT-specific regulations to ensure costs of providing VDT services aren't paid for by telephone ratepayers. (3) Require telcos to establish separate access charge categories and price caps for VDT, because including VDT in existing categories "virtually invites cross-subsidization." (4) Adopt procedures for separating costs of providing regulated VDT platform from unregulated enhanced VDT services. (5) Create VDT-specific rules for joint marketing and customer privacy that would prevent telco representatives from marketing VDT and telephone services simultaneously as well as telco use of customers' calling patterns to competitive advantage.

SUBJECT: NTN COMMUNICATIONS INCREASES EXPOSURE OF ITS INTERACTIVE TV PROGRAMMING TO 35,000 HOMES VIA CONTINENTAL CABLEVISION ON EAST COAST
SOURCE: Business Wire via First! by INDIVIDUAL, Inc.
DATE: April 8, 1993
INDEX: [1]

CARLSBAD, Calif.--(BUSINESS WIRE) via First! -- Premier Interactive television programmer NTN Communications Inc. (ASE:NTN) has expanded the availability of is programming, including sports and trivia games and informational services, to more than 35,000 homes throughout Massachusetts on the sophisticated GTE Main Street cable service, it was announced Thursday by Pat Downs, president of NTN.

Available on Boston's Continental Cablevision, this marks the first time GTE Main Street, including NTN's programming, is being offered to a large group of customers on the East Coast. NTN's programming is also available on GTE Main Street to a potential 50,000 Daniels Cablevision customers in San Diego County, Calif. (December 1992).

NTN's interactive entertainment programming is received through a viewer's television set. The viewer uses the TV remote control device to interact with his television. The cost of the GTE Main Street service is $9.95 per month, per household. The entire service offers more than 50 individual programs to choose from.

NTN Communications, based in Carlsbad, is an international producer, programmer and broadcaster of interactive television games and shows. Established in 1983, NTN was the first company to develop an interactive television game and take it to the home video market. Today NTN owns and operates the only interactive television network in North America that broadcasts seven days a week, 24 hours a day, with subscribers all across North America.

CONTACT: Bender, Goldman & Helper | Jenny Roelle or Dean Bender, 310/473-4147

[04-08-93 at 14:26 EDT, Business Wire, File: b0408142.600]

SUBJECT: FEIGE NAMED TO MANAGE TIME WARNER FULL SERVICE NETWORK
SOURCE: Business Wire via First! by INDIVIDUAL, Inc.
DATE: April 8, 1993
INDEX: [2]

STAMFORD, Conn.--(BUSINESS WIRE) via First! -- Time Warner has tapped veteran cable operations executive Thomas C. Feige to manage the development of the company's Full Service Network slated to be built this year in the Orlando, Fla., area.

Feige, 39, will be president of the Orlando full service network and have offices at the Time Warner Cable Central Florida Division there. He also will be vice president of full service network development for Time Warner Cable Ventures.

Time Warner announced in January the initial phase of the first switched broadband multimedia "telecommunication superhighway." Scheduled to be in service early next year, it will utilize fiber optics, digital compression and digital switching to provide video-on-demand, interactive games, full-motion video shopping, distance learning and other video, voice and data services initially to approximately 4,000 customers in the Orlando area.

Feige, who had been vice president, Eastern Group, of Time Warner Cable's

Engelwood, Colorado-based National Division, joined American Television and Communications Corp. in 1978 as a salesman in Albany, N.Y. His first operations responsibility was that of general manager of the ATC system serving Torrington and Litchfield, Conn. After serving as northeast regional manager, he became a division manager before being named to his most recent position.

Feige earned his bachelor's degree from Kalamazoo (Mich.) College and a J.D. degree from Gonzaga University School of Law in Spokane, Wash.

CONTACT: Time Warner Cable, Stamford | Jim Duffy, 203/328-0620

[04-08-93 at 11:11 EDT, Business Wire, File: b0408111.401]

SUBJECT: ^TELE-COMMUNICATIONS INC. TO UNVEIL ELECTRONIC DATA HIGHWAY PLANS@
SOURCE: Reuters via First! by INDIVIDUAL, Inc.
DATE: April 6, 1993
INDEX: [2]

WASHINGTON, The Reuters Business Report (U.S.) via First! : Tele-Communications Inc., the nation's biggest cable television company, said Tuesday it will unveil its plans for an electronic information 'highway' next week.

The highway, an electronic system aiming at carrying signals for a wide range of new services, be an upgraded cable network with advanced fiber optic technology in hundreds of U.S. cities. The system is expected to be put in place over the next four years.

The network will allow subscribers to plug into a wide range of interactive television options from accessing data bases to banking at home.

TCI will announce it plans next Monday via satellite from its Denver headquarters to 11 cities.

The Clinton Administration and members of Congress have both called for a revamp of the telecommunications infrastructure and the development of such an electronic highway. Vice President Gore, when he was a senator, backed initial legislation that would have promoted such a network.

The company would not provide exact details about the cost of building the network but characterized it as a multi-billion-dollar construction project that would affect millions of consumers.

Tele-Comm President John Malone and other company officials will provide more details about their plans at the noon EST press conference Monday, the company said.

Tele-Comm's senior vice president of finance last week told security analysts in New York the cable operator would spend $750 million in 1993 on capital improvements to operating systems, up from $525 million a year before.

The company's data highway, called ''the infostructure network.'' would help to bring voice, data, video and computer service into U.S. homes through their cable systems.

Other cable companies and telephone companies have been exploring similar projects. Cablevision Systems Corp. said in February it would build a high-speed fiber optic link as a first step toward a nationwide data network.

[04-06-93 at 18:19 EDT, Copyright 1993, Reuters America Inc., File: r0406181.901]

SUBJECT: MITSUBISHI ELECTRIC TO RELEASE 36-INCH HDTV
SOURCE: Comline via First! by INDIVIDUAL, Inc.
DATE: April 5, 1993
INDEX: [1]

Comline Electronics Wire via First! -- Mitsubishi Electric Corp. <6503> plans to release a 36-inch high-definition TV by this May.

Equipped with a MUSE decoder developed through a joint project involving 10 Japanese and US firms, the HDTV features an aspect ratio of 16:9 and a built-in MUSE-NTSC converter. The price will be set at about 1.2 million yen (US$10,435). Mitsubishi will initially manufacture 1,000 units monthly.

The HDTV market, which totaled 10,000 units last year, is expected to expand to 50,000 units mainly due to the planned wedding of the Crown Price of Japan in June.

Contact: Tel: +81-3-3218-2111 Fax: +81-3-5252-7119 Des: ZAB11/ZAA70/ZDA72/ZNJ61/ZNJ66/YAA05 Ref: Japan Industrial Journal, 04/02/93, p.4

SUBJECT: JAPAN SHOULD JOIN EUROPE IN SETTING UNIFIED DIGITAL HDTV STANDARD ACCEPTABLE TO U.S., SAID MARTIN BANGEMANN<>
SOURCE: Warren Publishing via First! by INDIVIDUAL, Inc.
DATE: April 3, 1993
INDEX: [1]

Communications Daily via First! -- Japan should join Europe in setting unified digital HDTV standard acceptable to U.S., said Martin Bangemann, telecommunications commissioner for European Community. In news conference Fri., he said digital HDTV is wave of future and mandating D2-MAC or HD-MAC "would be a mistake." In separate news conference Fri., U.K. company that invented MAC, now called National Transcommunications Ltd. (NTL), declared MAC obsolete. NTL R&D Dir. Michael Windram said MAC was good design, but has been passed by digital. NTL is now pushing own digital HDTV system.

SUBJECT: GOV. CASEY CALLS FOR JOBS-RELATED CONSIDERATION IN TV DECISION
SOURCE: PR Newswire via First! by INDIVIDUAL, Inc.
DATE: March 30, 1993
INDEX: [2]

DUNMORE, Pa., March 30 /PRNewswire/ via First! -- Gov. Robert P. Casey, siding with the Clinton administration, today urged the Federal Communications Commission (FCC) to adopt a standard for high-definition television (HDTV) based in part on whether American jobs are created as a result.

The governor outlined his position after a tour of Thomson Consumer Electronics, which is part of a consortium that has an HDTV proposal before the FCC. Thomson has more than 1,200 employees at its picture tube plant here and another 250 at its design facility in Lancaster.

"The Thomson consortium is the only proposal pending before the FCC that pledges to build HDTV tubes and receivers in the United States, and more importantly, in Pennsylvania," Casey said.

"So HDTV is more than just the greatest leap in television technology in 40 years. HDTV means jobs. Good paying high-tech jobs for working men and women here in Pennsylvania and elsewhere in America; more than 10,000 American jobs altogether.

"That's why I'm throwing my support behind the Thomson consortium's proposal."

The commission is considering adoption of a national broadcast standard for HDTV, the next generation of television technology which promises dramatically improved reception and picture clarity. As part of the plant tour, the governor witnessed a demonstration of HDTV -- the first time the technology has been exhibited in Pennsylvania.

Casey sent letters today to President William Clinton, U.S. Secretary of Labor Robert B. Reich, and FCC Chairman James H. Quello in support of the Thomson coalition, formally known as the Advanced Television Research Consortium. The consortium consists of Thomson, Philips Consumer

Electronics Co., Compression Labs Inc., the David Sarnoff Research Center and the National Broadcasting Co. (NBC).

Writing on behalf of the Clinton administration, Reich last month urged the FCC to base its HDTV decision on the technologically appropriate system that offers "the greatest contribution to domestic high-wage employment."

Casey said he too is asking FCC Commissioner Quello to pick the Thomson proposal "because it would preserve and create good jobs for Americans and for Pennsylvanians.

The governor noted that Thomson provided a major economic boost to the state when it began its Pennsylvania operations in 1966.

"Today, it's still a big player in our economy," the governor said. "It's high tech. It's tomorrow's jobs here today.

"That's why my administration invested more than $3.5 million in Commonwealth funds over the past two years for equipment, training and renovations to help Thomson modernize this facility and meet the challenges of a global marketplace."

The governor said that Pennsylvania ranks second nationally in high-technology investment, and the state's high-tech firms have grown at twice the national average.

"I have a high-tech vision for Pennsylvania," Casey said. "It's a vision that incorporates the creation and retention of high quality, high-wage jobs for our working men and women. Thomson Consumer Electronics and HDTV is a big part of that vision."

/delval/

/CONTACT: Bob Fisher deputy press secretary of Commonwealth News Bureau, 717-783-1116/

[03-30-93 at 12:00 EST, PR Newswire, File: p0330122.200]

Attachment: Draft Memo on Interoperability Testing

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13 April 1993 * * * D R A F T * * *

Mark Richer
Vice President, Engineering & Computer Services, PBS
Chairman, FCC Advanced Television System Subcommittee-Working Party 2

CC: Richard Wiley, Joseph Flaherty, Bob Sanderson, Jim Gaspar, Bob Hopkins, Peter Fannon

Re: Interoperability Testing

Dear Mark,

As you know, we offered to coordinate interoperability testing once the new testing was announced. During our activities in the last six weeks, we have been able to propose an interoperability testing process. We further have been able to garner broad cross-industry support for interoperability testing by contacting a number of key companies who are willing to contribute technology, time, effort, and possibly funding for interoperability testing.

However, it appears that the current testing process and schedule, under the direction of PS-WP2, does not allow us to accommodate such interoperability testing. Due to the rapid evolution of the ATV process from analog systems to digital, and due to the relatively long development times of ATV systems, we find the ACATS test process is configured inappropriately for digital interoperability testing. (Please see the detailed appendix on interoperability

testing.)

We therefore face the challenge of how to incorporate such interoperability tests into the ultimate selection and refinement of ATV systems. Advanced Television was originally conceived as an improved entertainment medium. It is now apparent that Digital Advanced Television is much broader in scope than entertainment. Interoperability of ATV systems is essential for digital image communication over the coming National Information Infrastructure of high performance digital networks. Interoperability with computer displays also takes on special significance in light of the convergence of computers and television, and the use of multimedia computers in education, in addition the broad use of computers in production.

In light of this convergence of computers, television, and communications, it will be necessary to perform thorough interoperability tests before any ATV system architecture, including any proposed "Grand Alliance" system, can be embraced with confidence.

It is therefore necessary to consider how to best shedule and perform interoperability testing in light of the apparent inadequacy of the current testing process and schedule.

Sincerely,

Gary Demos Mike Liebhold

Appendix

Interoperability Testing Status

by: Gary Demos

13 April 1993

Testing Materials

According to Peter Fannon at the Advanced Television Testing Center (ATTC), all interoperability testing materials are needed at the ATTC by Friday of this week (17 April 1993). In order to provide such testing materials, it would be necessary to agree on resolutions for such materials, create the materials in these resolutions, gain approval of WP-6, and convert the materials from Exabyte (or other tape media) to HDD-1000. These steps cannot happen within this time being allotted.

It would also be desirable to have higher quality image materials for the progressive scan proponents. One source of higher quality image data would be to scan film at Kodak Cineon or RFX. There has not been sufficient time to select film materials or to perform such scanning.

Without new testing materials, interoperability with a variety of applications for moving images cannot be evaluated.

It would also be desirable to provide 24 frame per second as well as 60 frame per second materials. However, the existing ATV proponent hardware is constrained to use 3-2 pulldown due to the previous testing process. Neither the testing center nor the proponent systems appear to be capable of doing true 24 frame per second tests. It is hoped that 24 frame per second capabilities can be simulated through the existing facility.

It is of some concern that the test materials may not represent the state of the art in image quality in the current round of testing. There appears to be a bias toward live camera images vs film images. Computer Generated Images (CGI) may also be important as a source of future ATV pictures. Use of CGI, film, and live camera images should all be considered fully.

It is of further concern that many other interoperability test images cannot be accommodated within the current process and schedule. Many applications and industries cannot be represented with test imagery under the current testing plan.

It does appear that still images, such as a large map or schematic diagram, could be panned and moved up and down using the Pixar. It is hoped that such a test may reveal some properties of the various proponent systems.

Packetization Testing

In addition to new testing materials, it is also desirable to test packetization for each of the proposed ATV systems. Such tests could evaluate the viability of various header and descriptor mechanisms in the presence of normal errors and packet losses on various transport media. The ability to support a wide variety of data types is central to interoperability.

It would also be desirable to test interoperability of the ATV data stream with

various existing and proposed networks including ATM, FDDI, and fast Ethernet. Bellcore, IBM, Hewlett Packard, and others have offered to help with this testing.
Two of the system proponents have VCR implementations. It certainly seems worthwhile to test packetization structures for normal VCR operation (with normal tape errors) as well as for trick modes such as fast forward and fast rewind.

It was our plan to record the compressed bitstream in order to allow the packetization testing to occur subsequent to the testing at the ATTC. However, there has been insufficient time thus far to prepare the instrumentation recorder. WP-2 also has required us to define all of the testing procedures before WP-2 will approve the use of the data recorder. There is insufficient time to prepare the detailed testing plan prior to system tests. It seems to us that the data should be recorded while the systems are in the testing center, even though the subsequent testing procedures cannot yet be fully defined.

The lack of a software simulation of the decoding process for some proponents (at least AT&T/Zenith) would require that processing of the instrumentation data be followed by decoding using proponent hardware.

Thus, it does not appear that any of these packetization and header tests can be performed in the existing process and schedule.

Computer Display Interoperability

In this series of tests, the plan is to evaluate the various systems when their decoded ATV images are displayed on typical computer screens. Since computer screens uniformly have square pixels, and are not interlaced, conversions will be necessary for those ATV systems which are interlaced and non-square pixels. It may be desirable to attempt to use the motion vectors from these systems to de-interlace for such display. However, without an instrumentation recording of the motion vectors, such tests cannot be performed.

Most computer displays use refresh rates above 70 Hz to support the industry trend toward larger and brighter screens. Since the proposed ATV systems operate at 59.94 Hz, a temporal conversion will be necessary. Such a temporal conversion may also find some advantage in the use of motion vectors. However, since there has been no agreement as yet to record the compressed data, such tests may not be possible.

It was claimed by at least one proponent during the WP-4 interoperability review that simple display techniques are sufficient for displaying ATV images on computer displays. Others disputed this assertion. Since interoperability with computer displays affects production as well as a variety of industries and applications, it would seem to be important to test such interoperability.

There may be interactive uses of ATV. The latency and responsiveness characteristics of each proponent system may differ substantially for interactive uses. No procedure for testing interactive use of Advanced Television has yet been devised.

Scalability, & Resolution Conversion

It is likely that ATV receivers will present NTSC programs on the display. It would seem worthwhile to test such NTSC presented at full height (with blank side panels), full width (with discarded top and bottom), and at 1:1 size (small) in the screen center. No material has been prepared for such tests.

Similarly, MPEG-1 decoded images may become popular. The affect of each proponent's coder on decoded MPEG-1 images might be useful to test. MPEG-2 has portions of its coder algorithm in tentative acceptance. MPEG-2 decoded images may also be worth testing.

Similarly, it may be useful to use decoded ATV images as input to MPEG coders to evaluate this relationship of the coders.

In any such concatenated coding tests, it may be desirable to investigate possible coding performance improvement when motion vectors and other coding parameters can be communicated directly between the coders. An instrumentation recording of the compressed bitstream, as well as a software simulation of the proponent ATV system, may be required in order to perform any such tests.

It appears that none of these tests will be possible under the current testing plan and schedule.

The existing proposals do not exhibit much resolution scalability. However, quality can be scaled by one level in some of the systems by decoding a fixed portion of the full data rate. Apparently this reduced quality "usable" image will be evaluated as part of this new round of testing.

Also, it appears that a test of various ancillary data rates has been approved. The systems will be tested for image quality while transmitting 1,2,3, and 4 Mbits/second. The ancillary data will be dummy data, however. Sensitivity to impairments for both the image quality as well as for ancillary data integrity may be a worthwhile test.

ATTC Configuration

One significant hindrance to interoperability testing for these digital ATV systems is the configuration of equipment at the Advanced Television Testing Center. The testing center was initially designed at a time when all of the ATV proposals were still analog. As a result, there are many analog steps in the current testing process. Some of the steps and practices which appear to be questionable in light of digital interoperability testing include:

*) The format converters only accept analog RGB inputs for conversion to recording on the digital HDD 1000. They only provide analog RGB outputs during playback for use as input to the ATV system coders.

*) As a consequence, all of the ATV test systems only provide analog inputs and outputs.

*) There is no mechanism in place to allow moving sequences to be provided via industry-standard tape media (such as 8mm digital tape).

*) Under the current plans, the compressed digital bitstream is not recorded.

*) The Japanese interlaced non-square pixel 1035 line system is used as a "reference".

*) There is no provision for direct evaluation of 24 frame per second film-originated material.

*) The transmitted signal is treated as an RF signal for terrestrial broadcast simulation and for cable testing. No packetized network testing or simulation facilities are available.

Thus the existting testing center is organized in such a way that it does not easily support interoperability testing.

f: ATV

Advanced TV (same as HDTV)

Computing, Communications, and Media

Interplay and Merger of the Industries, Products, and Services

Collision and Convergence and Opportunity

15 November 1992
(27 September 1992)

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Corporate Research and Architecture

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Preface

This discussion of the merger of industries is based on presentations I've made over the past couple of years. Thus, much of the information is not really new. Indeed, it can be partially traced to ideas put forward by the MIT Media Lab as long as 7 years ago. In the past few years, the ideas have been developing in technical and business relevance to the computing industry. The last several months have seen the relevance increase dramatically.

The discussion does really aim to present a specific call to action. Instead hopefully, it offers a useful perspective on a major trend that seems on the verge of erupting. The specific actions that could be taken need to be considered in the context of the company's individual efforts, broader corporate strategy, and company, national, and world economics and markets.

Feel free to borrow and adapt the figures and ideas for your own needs for use inside the company (many already have). Of course, I welcome comments, suggestions, and questions.

Introduction

Computing, communications, and media (including consumer electronics) are adopting a common set of base digital technologies. The common technology base and the economies of scale in the marketplace are driving the industries together. The result is much more than a simple technological leverage across industries, that was called the "technology food chain" (c.1988). Instead, there is an impending interplay and merger of the industries, products, and services themselves.

This **convergence** is now broadly accepted as inevitable. One needs only to look at recent issues of the Wall Street Journal, Fortune, Business Week[1], Newsweek[2], etc. to find articles providing view on the convergence and cross-industry developments. (The convergence theme is appearing in industries' conferences[3].)

A couple of years ago, the situation was often characterized as a **collision** among the industries. It was (and to some extent still is) uncertain how businesses adapt to and succeed in the conversion. Thus, conversion was often treated with apprehension due to the change that it brings to all the industries.

Though there is indeed collision with the convergence, it translates into **opportunity** for those companies that approach convergence as a new way of looking at their future business.

The convergence will happen sooner or later. Events have shown that delaying tactics of an individual player or industry have only a temporary effect – the technological and market drivers are too compelling. Further, recent events have shown that an individual player (or segment of players) can advance the convergence, and can advantageously position themselves.

The importance of the convergence to Digital lies in our core competencies: computer system design, VLSI, networking, interactivity, distributed processing, product distribution, services, etc. By applying ourselves effectively, we can steer many of the details of the convergence in directions that better enable us to take advantageous incremental steps into the future.

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1 Cover Story; Your Digital Future: Soon, a host of gadgets will alter work and play – and reshape familiar industries; Business Week, 7 Sep 92, pp 56-77.

2 Cover Story; The Next Revolution: A marriage of computers and [consumer] electronics will spawn everything from smart TVs to portable secretaries – and change how you live and work; Newsweek, 6 Apr 92, pp 42-48.

3 The Society of Motion Picture and Television Engineers (SMPTE) Advanced Television and Electronic Imaging Conference held February 1992 was titled Collision or Convergence: Digital Video/Audio, Computers, and Telecommunications

Market Evolution

Convergence is not new. In many respects, it's been occurring quietly for many years. For example, seven years ago, the establishment of the MIT Media Lab[4] (and similar efforts) brought attention and focus to convergence. Figure 1 depicts the market evolution of convergence. The sizes and overlaps of the industry circles represent relative market size. The shadowed areas represent the pure non-overlapped computer market.

In **1970**, the three industries were relatively distinct. Exploratory work was occurring on computer networking and remote timeshare computing, but these were small markets. Throughout the 70s in the computing industry, there was a clear trend toward **decentralization** – LSI, minicomputers, departmental computing, timesharing, etc. drove computer industry growth. The customer benefited from easier more-interactive access to shared-resources computing. Also, the 70s saw the beginning of technology migrating across industry boundaries – e.g., TV display technology was used for computer graphics displays and desktop video display terminals; consumer analog cartridge tape storage was adopted for data storage; dialup telephone modems were used for remote access; computers began being used in professional media production, e.g., video editing and newspaper copy writing; and LSI enabled pocket calculators.

By **1980**, the industries began to show some interplay. The 80s major technological drivers derived from **VLSI and miniaturization** and further dedication of computing resources to the individual – personal computers and workstations. The decentralization drive continued as both wide- and local-area computer networking spread. Microprocessors gave birth to calculators and home video games. The cable TV industry with new media providers (e.g., HBO, CNN) mushroomed at the expense of major broadcast networks, and provided greater viewing choices for the individual – by stretching point a little, the loss of marketshare by the major TV networks to cable can be compared to the decentralization transition from mainframes to timesharing. Cable TV provided another wire into the home, higher bandwidth than telephone, albeit still analog and one-way. CDs brought digital sound to the consumer, and totally replaced analog vinyl records. Interestingly, record companies readily embraced CDs, recognizing that they were in the music business, not the vinyl business. The record industry was in the doldrums when CDs came along; the technology resuscitated the market. Also interesting is that during the 80s many record and film/video production companies were purchased by consumer electronics companies – a merger of content and delivery platform.

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4 Stewart Brand; The Media Lab: Inventing the Future at MIT; Viking Penguin, 1987.

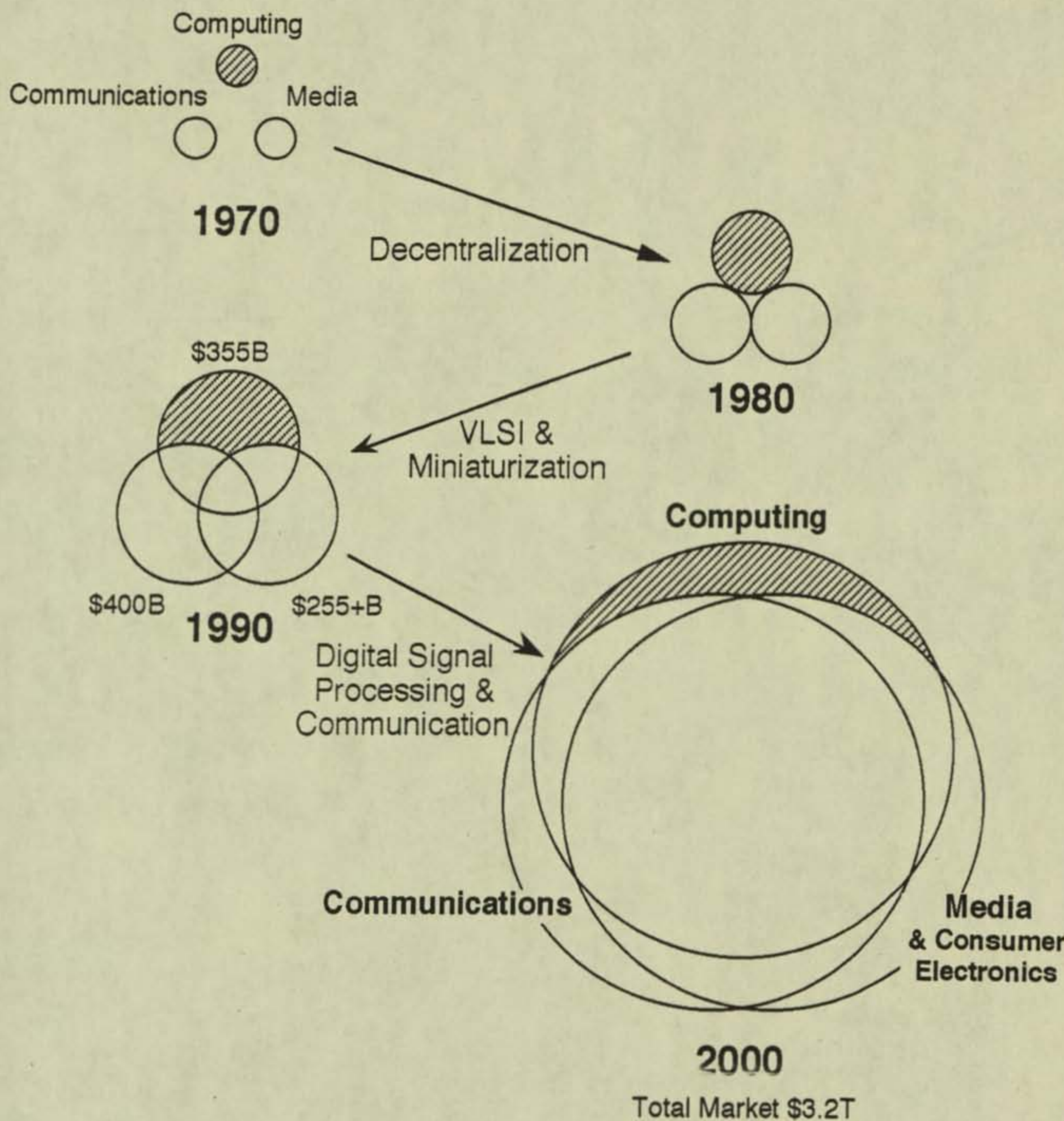

Figure 1: Market Evolution[5]

[5] Market size numbers come from analysis by Gill Press of various market studies, Aug 92.

Now in the **90s**, the convergence is more apparent, and clearly enabled by the move to **digital signal processing and communications technologies**[6]. The initial pivotal technology was/is HDTV[7]. In 1988, the news media focused attention on the potential importance of HDTV to core technologies, the technology food chain, and industrial competitiveness. By the beginning of 1990, the full implications of the converging television, communications, and computing industries were promoted, and by the beginning of 1991, all U.S. HDTV proponents were digital – Europe and the Pacific Rim are going digital as well. Digital TV (HDTV and NTSC) is assured.

In recent months, interactive TV and non-couch-potato interactive services are receiving greater recognition. Hence, the emerging pivotal driver is global, interactive, open access, interoperable communications infrastructure for voice, data, images, and video. (An upcoming book from MIT researchers coins the term OCI – Open Communications Infrastructure[8].)

At each stage of market evolution, companies that didn't (or didn't want to) recognize the occurring shifts went by the wayside or restricted themselves to ever decreasing markets (e.g., mainframe companies (Sperry, Burroughs) resisted the shift to decentralized computing). Other companies emerged (e.g., Apple, Sun) when existing computer companies were reluctant to deploy new computing styles to try to protect existing business models. A few companies were able to take advantage of a shift (albeit sometimes through circuitous routes – e.g., IBM PCs).

By **2000**, some say sooner, the combined markets will total more than $3.2 billion, the bulk of which is in the merged segment. The market available to companies that do not participate in the convergence will dwindle as they are pushed into the decreasing sliver of their un-merged industry segment.

Merged Industries Landscape (c. 1992)

Figure 2 shows the current emerging landscape of the merged industries – a fairly busy diagram that tries to show several important aspects of the merging of the industries.

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6 Robert W. Lucky (formerly Bell Labs); Silicon Dreams: Information, Man, and Machine; St. Martin's Press, New York, 1989.

7 High Definition Information Systems; Subcommittee on Technology and Competitiveness, House of Representatives Commitee Science, Space, and Technology, July 1992.

8 W. Russell Newman, Lee McKnight, and Richard J. Solomon (MIT); The Gordian Knot: Political Gridlock and the Communications Revolution; MIT Press, Cambridge, 1993.

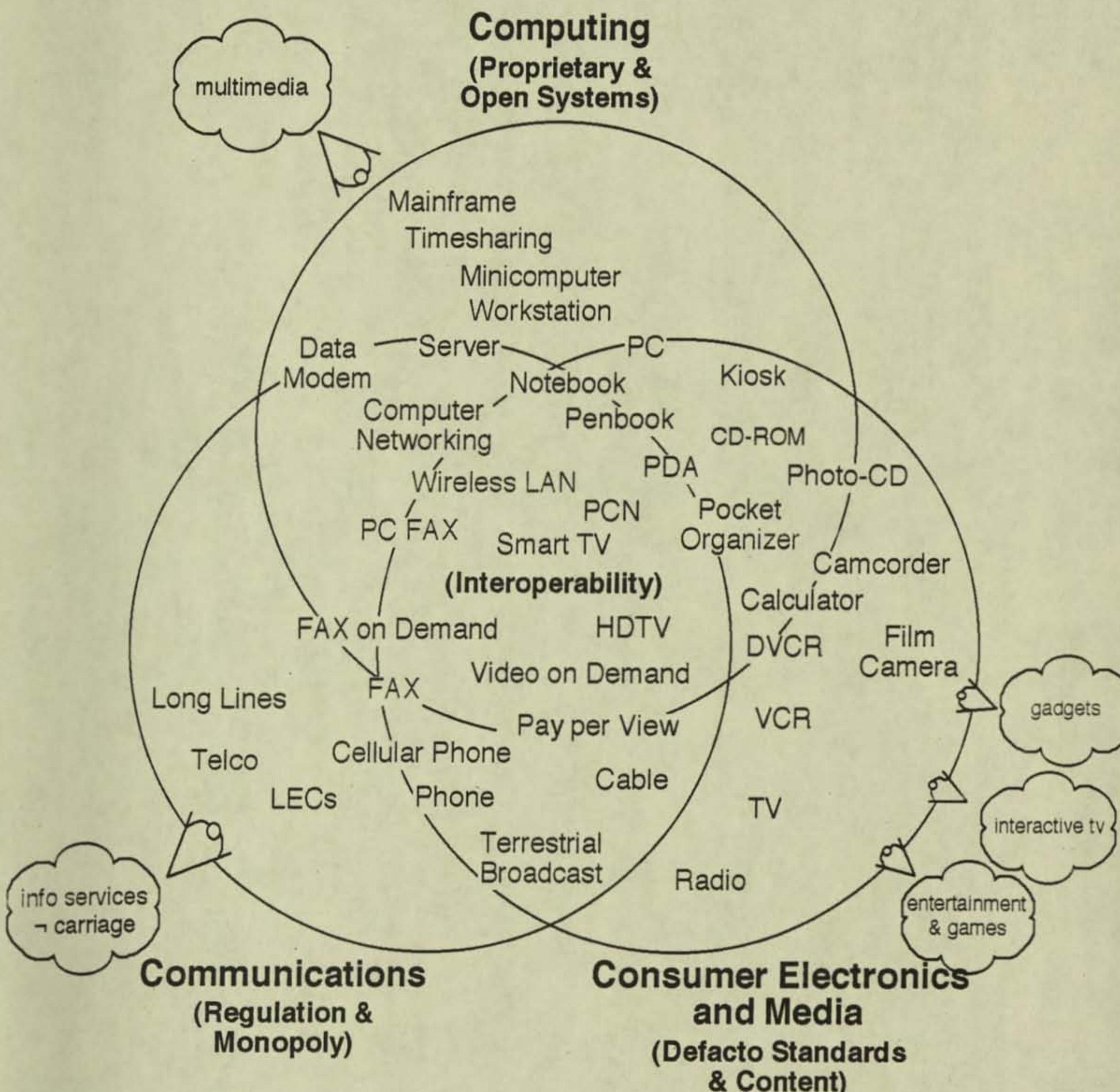

Figure 2: Merged Industries Landscape (c. 1992)

In the **computing industry**, we see the progression of computing platforms as they move closer to interconnected personal devices. The mainframe is the farthest from the consumer. Very few people could touch one; the majority computer users who did use a mainframe did so by submitting batch jobs with interactivity measured by hours. Timesharing made computing more accessible to computer users and enabled some interactive applications; however, competition for computing resources produced undependable interactivity – afternoon sluggishness. Though the cost per user of a timesharing system permitted wide use, it was still limited to organizations that could support the high aggregate cost of the central machine.

And so it progressed, with minicomputers, workstations, and PCs. Where now, the cost of personal dedicated access to computing, the range and usability of interactive applications, and the high level of interactivity has brought computing to a large segment of the population. Further, simultaneous with the growth of the user population, the interconnection into computer networks and remote access began the overlap of computing and communications.

The **communications industry** (or largely the telephone industry) does not reflect the same kind of migration as the computer industry. Universal access to telephone services has long been the mandate. However, the carriage of non-voice information (either through dedicated lines, packet switched networks, or telephone fax and data modems) on the telecommunications plant has increased – the computing and media related content represents the major potential growth factors. The other migration (somewhat hidden to the average telephone user, except for improved sound clarity) is the conversion to digital encoding of voice in all but the last mile.

The **media and consumer electronics** migration path also moves from analog to digital processing and encoding – e.g., digital signal processing to enhance analog video signals, vinyl records to CDs, impending deployment of digital NTSC and HDTV, etc. New devices and services emerge that borrow computing and communications technology – e.g., calculators and pocket organizers, pay-pre-view cable programming.

The products in the merger among two or three of the industries are the most recent, and demonstrate the multiple use technologies. CDs used for music, data, and photos, with consumer products and computer peripherals capable of reading all formats. Pocket organizers as an electronic Filofax™ that can exchange data with a PC. FAX machines and PC FAX modems bring a kind of electronic mail. FAX on demand (where you dial a phone number, step through a keypad dialog to select the information you want, which is then Faxed to you) offers a form of information access. All of these are fairly crude early examples that portend the convergence. Interestingly, computers (in limited embedded form) are behind all of these, but only the slightest portion of these examples is claimed by the computer industry.

A second aspect of Figure 2 is what motivates the individual industries.

Computing is driven by **proprietary and open systems**. Each company would like a proprietary advantage to differentiate themselves and lock in a market segment. Failing that (or as technology matures), the industry is driven to open systems.

Communications is driven by **regulation**, which arises from the allocation to individual companies of a **monopoly** for a geographical region (in the case of telephone and cable) and/or of radio frequency spectrum (in the case of television and radio broadcast and satellite and microwave transmission).

Media is driven by **defacto standards** and the availability of **content**. Individual companies attempt to establish their own products as a universal standard with cross licensing to their competitors and wide availability. The drive to have captive content emerged in the 80s when Sony lost the BetaMax/VHS battle not because of product availability, price, performance, or quality, but because there was more content (aka software) easily available on VHS.

Each industry's **business model** is motivated differently.

Computing is driven by return on investment (**ROI**): hardware and software products and services, maintaining periodic upgrade purchases as technology improves, and an attempt to lock the customer (customer loyalty) into a company's "unique" value added.

Communications is driven by return on assets (**ROA**) of the infrastructure (wire plant, cable plant, antenna tower, etc.). A company often will carry a large debt burden to establish the asset, then return on the asset services the debt. Also, monthly billing (c.f., public utility) plays a major role. (Bob Lucky has said that the majority of the cost of telephone service goes to billing operations and that plain old telephone service would (almost) be free if it weren't for billing.)

Media and consumer electronics are driven by a combination of ROI and ROA but in a different manner than the other industries – it is more like the **razor and**

blades scenario – sell the razor at a low margin and profit on the blades. Investments are made to create a product (e.g., walkman, VCR) or asset (e.g., album, movie), and an annuity of sorts derives from the play and replay of the asset – **repeatability** is important (e.g., Casablanca) to maintain the long term value of the asset. An important difference from razor and blades is that the content is not locked into a particular format. When a new delivery vehicle is created (e.g., CDs, colorization), the old content is repackaged increasing its asset value (e.g., old albums and b&w movies). There is also a strong **fashion and fad** component to competition and marketing among companies[9].

A final aspect of Figure 3 is how each industry currently **views** the impending merger. In many ways, these are parochial views still locked into the traditions of the separate industries – almost a denial of the merger at this early stage exploration, adjustment, and transition.

Computing looks at the merger as **multimedia** – the addition of voice, images, and pictures as new data types to existing computer platforms and applications (e.g., video mail).

Communication looks at the merger as **information services** – freeing themselves from their regulatory constraints as simply carriage providers by the addition of content repositories to their central offices and access to content through their existing wire plant.

Media and consumer electronics seem not to have a single view, but a variety of views – new forms of **games and entertainment**, new types of **gadgets**, limited **interactive TV** for the coach potato, etc. These remain within the traditional mold of the industry.

The merged industry must recognize and balance all the industries' traditional drivers, but will be primarily driven by a new kind of **interoperability**. We're approaching a situation where the heterogeneity of content, services, and devices will go well beyond anything that was ever considered by the computer industry under the umbrella of heterogeneous systems. It will not be sufficient to simply pursue the next breakthrough technologies within a single industry; the opportunity is in combining technologies across industries into hybrid technologies – a fusion

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9 Faith Popcorn; The Popcorn Report: on the Future of Your Company, Your World, Your Life; Doubleday, 1991.

of technologies and markets, "techno-fusion"[10]. Interoperability will be sought across all generation, transport, and delivery mechanisms, across industry operating styles, across business models, etc. Indeed, each of the industries is already making forays into adopting the drivers of the others.

Directions

Do Not Sit Back

Minicomputers subsumed mainframes. PCs and workstations subsumed minicomputers. Each transition expanded the availability, interactivity, and usefulness of computing services to the customer. There will be a next generation of delivering computing to subsume 80s style PCs and workstations. Our active participation in steering toward the next generation (invisible computing) is mandatory. (Regulatory issues are a new factor for us, and the regulatory landscape is in flux. However, we can influence that as well.)

Companies in the various industries are beginning to pick their approaches to the convergence: Kodak PhotoCD, Apple PDA/Newton, Motorola wireless data comm, Bellcore HDSL, various companies' HDTV, etc.

Play To Our Strengths

Hudson's VLSI design and fabrication skills are uniquely suited to the computationally intensive requirements of digital video and communications. Computer networking, network protocols, client-server experience, and distributed services are key technologies needed in a broader communication infrastructure. Our experience with ethernet on community cable systems is unique as well, and leverages our orientation toward peer-to-peer communication more so than alternative near-term communication styles. Our corporate influence in technology forums and consortia is significant.

Develop key enabling/leveraging products for the merged industries, e.g.:

- VLSI
  - Programmable multi-standard MC-DCT compression/decompression
  - Alpha into volume consumer products

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10 Fumio Kodama (Saitama Univ, Japan; Harvard); Technology Fusion and The New R&D; Harvard Business Review, Jul/Aug 92, pp 70-78.

- Network – establish common protocols across computer networking, telecomm, and cable environments (e.g., ATM?)
- Services – implement a value added cable network for information, education, health care, small business, work at home, mobile communications,...
- Etc.

Alliances

We do not possess (nor does any other company for that matter) all the technology or market access needed to proceed effectively. Interestingly though, through many of our key customers and relationships, we do have potential entree to a large repertoire. It will be important to establish well-considered technical and content services alliances.

Identify key players in other industries, e.g.:

- Telco (AT&T, MCI, Ameritech,...)
- Cable (TCI, Cablevision,...)
- Consumer electronics (Sony, Philips, NEC,...)
- Content providers (Turner, Viacom, NBC,...)
- Production houses (Paramount, Columbia/Sony,...)
- Libraries, archives, museums,...

Establish critical alliances with key players that:

- Complement our core competencies
- Compensate for our weaknesses
- Are mutually beneficial to all parties
- Are truly collaborative

Recognize (and adapt to) the way the other industries operate. Make appropriate adjustments to how we do business. We are facing new markets that require different approaches to marketing, sales channels, and the way we develop products. (Alliances are one way to learn this.)

Pay As You Go

To date, many of our investments have been exploratory, and have returned valuable exposure to the technical issues. As we move forward, it is necessary that our steps be incremental, and exhibit an incremental return on investment – technical and market experience and revenue. We should not fall prey to mortgaging against elusive future profits. Nor, should we avoid making investments due to short-sighted concerns.

Choose Wisely

The landscape is in flux. Though there is general agreement as to the ultimate long-term objectives and outcomes, an optimal path is not apparent. Some companies invested and committed heavily in particular directions, only to be blindsided with emerging technology. To the extent possible and practical, we should not prematurely preclude alternative paths.

Capitalize on our name digital

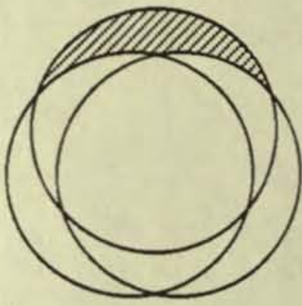
The move to digital coding, storage, and transmission is the underpinning technological driver of the convergence of industries. It is already becoming synonymous with goodness – it is the fashion. Consider the what would happen if we licensed our logo to business partners. digital could appear on everything from supercomputers to personal organizers to TVs – "digital Inside", "digital Ready". What would our competition think about us cornering the "digital" label? Perhaps, failing to establish our mark might negate much of its value (c.f., kleenex, jello).

Choices

It is not news that we are at a critical stage in the corporation, nor are we unique in the computer industry or other industries worldwide[11]. The merger of industries also is at a critical stage. We are making needed decisions that will determine what kind of company we will become. Some of the decisions are necessarily short term oriented. As we make decisions that position us for the future, a critical consideration is how we see ourselves participating in the merged industry marketplace and how much of the marketplace is available to us. There are three

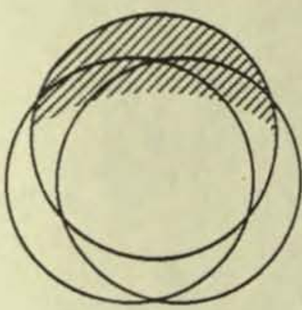
11 Rosabeth Moss Kanter, Barry A. Stein, and Todd D. Jick (Harvard); The Challenge of Organizational Change: How Companies Experience It and Leaders Guide It; The Free Press (Macmillan), 1992.

broad scenarios from which to choose. Neither is correct nor incorrect. But, each implies a different set of corporate directions and investments.



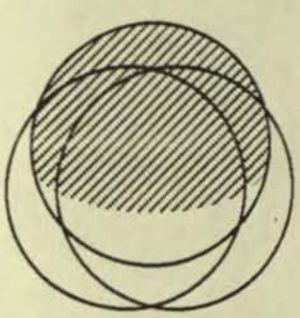
Pure Computer Industry

Concentrate on traditional computer platforms (hardware and system software, severs and desktop). There could be minor investments toward making the platforms media ready, but largely, media technology and applications are deferred to third party developers. Unless a critical alliance (e.g., Microsoft Windows/NT) establishes the draw for third parties, it seems unlikely that there will be many applications or significant market potential. Even if the partner does pursue the merged industries, our platforms may be appropriate only for a small market segment.



Foray into Merged Industry

Establish a few key communications and media alliances that are mutually beneficial and bring us into the merged market. Concentrate on pay-as-you-go investments. Influence the convergence by participating in a few key merged-industry technologies, business practices, and market efforts. Pursue a few customer driven markets – e.g., education, healthcare, retail, government.



Become a Major Player

Pursue a major thrust in cross-industry alliances (consider content alliances as well) along the lines being pursued by Apple, IBM, Sony, etc. Establish public mindshare, e.g., make digital synonymous with "digital". Gradually develop new core competencies and business practices that will be important in the merged industry marketplace.

Of course, the three scenarios are not fully mutually exclusive. It may be possible to defer some decisions, but not too long, months rather than years. And, there is value to incremental decisions. However, the longer we wait, the more costly will be the move into the merged marketplace and the fewer and less effective will be the opportunities to establish alliances, products, services, and public mindshare.

DRAFT
v0.0

Position/Briefing Paper on Digital's Role in ATV/HDTV
11/19/92
Ed McGrath

What follows covers many of the issues and questions that may come up in discussions, interviews, etc. and offers suggestions for responses. It also offers samples which may be used for quotes or in the body of press releases.

The "digitalization" of television is very exciting to Digital Equipment Corporation as a company. If properly defined, this new technology offers the opportunity for many new entertainment features and services, but perhaps even more importantly, it offers the opportunity to bring television out of the realm of a purely entertainment medium and to use it to offer educational services, human services, health care services. Digital has seen this opportunity and is working actively to help accomplish this goal. This is not an entirely altruistic quest. With the merger of the computer, communications, and media industries, driven by digitalization and the capabilities of VLSI, we see that many of the future opportunities for Digital Equipment lie in this overlap region. Digital's future growth relies on this technology and our relationships with companies in these industries. You may note that several months ago we established a Business Unit to focus on opportunities in the Cable Television Industry. More recently, we established a new Business Unit in Entertainment as well. We can see the potential that these developments in ATV/HDTV can do a lot to help revitalize both the computer industries and the consumer electronics industry in the U.S. A bigger, better television alone won't do that. It's the new applications of television that can. The issues addressed by this committee are key to making this happen.

What does Digital have to add to this ATV discussion?:

The movement to a digital standard was a critical turning point. This brings the television industry out of the realm of analog circuitry where technology change happens relatively slowly and standards last easily for several decades, into the dynamic new world of digital VLSI. The predictable, inexorable advances in this technology mean that it is essential that this standard be flexible and extensible enough to work not only with today's technology but the technology 10 and 20 years from now. Digital has a lot of experience designing architectures to be both flexible and extensible. Our VAX line of computers was designed to last through many generations of chip technology. The new Alpha line demonstrates Digital's leadership semiconductor technology. Finally, Digital is a leader in open standards, especially in this area. We sit on the ISO (International Standards Organization) committees on JPEG (Joint Picture Experts Group), and MPEG (Moving Picture Experts Group) and more recently, Branko Gerovac sits on the FCC ACATS and WP4 committees on ATV.

Tell me more about this merger of industries:

include words and perhaps pictures from presentation

Tell me more about these potential applications for ATV:

Digital has been a leader in developing and demonstrated some of these new applications. Several weeks ago in southwest we demonstrated ....

then the remote health care and education applications we demonstrated in atlanta,

then the applications we will be demonstrating at the western cable show the first week in December.

Is Digital going to be building TV's?:

It's very difficult to make money in the consumer electronics business today. I don't see Digital building commodity televisions as purely entertainment devices, but the technologies are merging. We already use much of this same technology in our Workstation products today. With the digitalization of television, televisions are going to take on some of the aspects that people commonly attribute to computers and vice versa. Some of the visionaries at Digital and in the industry tell me that it may be hard to tell them apart 10 years from now. In the short term, what we will be doing is exploiting the technology that comes out of this in our products, finding areas in the industry where Digital's strengths add value (Computing, Silicon, Networking, Systems Integration) and align with companies in this industry to deliver products here. Our Cable Television and Entertainment Businesses are already well down the road in accomplishing this.

In our Cable Television business, some of the products we offer are:
-Data communications over the existing cable infrastructure extending our leadership Ethernet Local Area Networking to Metropolitan Areas.
- Under development we have a Digital Advertising Insertion system for cable operators which uses this same digital video compression /decompression technology to use PC's and Computer Storage to replace banks of tape players and operators.
-We have seen a lot of interest in extending this concept to providing Video on Demand services as well.

Explain some of the terms and issues in your letter to the FCC:

-put these issues in near layman's terms.

Is Digital's role unique as a computer vendor in this discussion?:

No.but...

Draft

To: Al Sikes
Richard Wiley

Cc: Robert Sanderson
Ed Horowitz
Robert Hopkins

From: <<we need to determine who signs this letter, Marty?>>

Subject: Digital Equipment Corporation endorses the
FCC ACATS PS/WP4 Interoperability Review Findings

Digital Equipment Corp. would like to commend the FCC and ACATS for your foresight in establishing the work of the PS/WP4 committee. We endorse the findings of the committee's recent Interoperability Review, and encourage the ATV selection process to apply maximum weight to the criteria of "Interoperability, Extensibility, and Scope of Features and Services" in deciding the direction for advanced television.

The ATV outcome has crucial implications to future technology innovation and commercial success across all industries and applications. Further, a true interoperable and extensible ATV system presents substantive economic and qualitative advantages in areas that are of critical importance to the future of the United States: education, health care and human services, commercial enterprise, and competitiveness -- the list continues.

Interoperability and extensibility are the keys that unlock information and interactive communications and services in all forms, easily conveyed, viewed, and manipulated across the variety of consumer and professional settings and applications. The vision is so compelling that it will produce a revolution in personal growth and quality of life, large and small business productivity and competitiveness, and government effectiveness. All of this is achieved while simultaneously reducing or eliminating the high cost of use that would otherwise be caused by the need to convert signals across environments. In turn, this enables advanced services, which are now available to a fortunate few, to be universally accessible to the larger public.

It is widely recognized that ATV must be deployed expeditiously. A non-interoperable ATV system, though somewhat easier to define initially, will actually take longer to deploy in the long run (and will delay reallocation of NTSC spectrum to emerging uses). A non-interoperable ATV system would not provide the full benefit and potential of ATV, and would be in jeopardy of being supplanted by an interoperable system that will necessarily emerge, probably outside the ATV arena. An interoperable and extensible ATV system will have more avenues for early application across industries that will more rapidly grow the demand and deployment.

While the Interoperability Review findings do not suggest a clearly dominant system among the current proposals, the findings do point out the critical factors and features that are necessary to achieve the full benefits of ATV. We endorse the Conclusions and Recommendations from the Interoperability Review, and reinforce the recommendations:

Digital Implementation -- While digital format is absolutely necessary, simply being digital without providing the other factors is insufficient.

Universal Header/Descriptor (Ref. SMPTE standards effort) -- Given the variety of uses and content and given the rapid development of technology, a universally self-identifying data stream is mandatory to achieve extensibility and longevity of the standard.

Progressive Scan Transmission Format -- The traditional television industry represents the only significant use of interlace scan -- for historic technical reasons. An interoperable long-lived standard at a minimum requires the transmission signal to be progressive scan -- regardless of whether in the short term the two extreme ends of the delivery chain (cameras and displays) remain interlace with de-interlacing occurring in or near the camera before transmission and with scan reduction occurring at the display.

Packetized Data Structure -- Digital communications long ago recognized the benefits of packetized data structures and layered communications protocols for managing the complexity of communications. Digital television will be transported through and among a variety of media -- terrestrial broadcast, cable, satellite, telecommunication networks, computer networks, and packaged media. To expedite development efforts, to reduce product costs, and to extend features, packetization has proven successful.

Square Sampling Grid (Square Pixels) -- The television industry represents the only significant use of non-square pixels. (The first CRT displays used in the computer industry often used non-square pixels and interlace scan. It was quickly realized that this was not acceptable for ergonomic, picture quality, and computational needs across the variety of uses of picture material.) Square pixels are critical to sharing picture information across industries and uses.

Dynamic Reallocation of the Digital Data Stream -- The full power and potential of a digital data stream comes from the realization that "bits are bits" and that digital data can represent any desired information -- whether moving or still pictures, sound, text, subscriber addresses, ordering and billing, control signals, and so forth without end. Being able to reallocate the data stream to different uses opens up a wide variety of applications, including within terrestrial broadcast. (The additional Interoperability Review requirement of "still picture mode and motion picture window within still mode" is just one of many examples.)

Recognition of International Standards -- All industries are moving toward open systems as defined by formal standards. Regardless of whether the origins of a standard are de facto, developed in committee, or mandated, the primary requirement is to avoid establishing arbitrarily non-compliant system features when an existing or emerging standard is available or can be influenced that largely addresses the needs. (For example, ISO is nearing closure on MPEG2, which is largely similar to the ATV proponents' compression/decompression techniques. An international standard would obstruct anti-competitive efforts to partition world ATV markets.)

Modular Architecture and Cost Effective Range of Implementation -- There will be a wide range of devices from very low cost to highly advanced. They will vary across many features -- e.g., black & white or color, small to large display, pocket sized to wall mounted, intelligent and interactive. The inexorable advances of VLSI technology, digital signal processing and communication, display technology, etc. will rapidly bring new features and capabilities. The ATV decision needs to endure for several decades in this context of inevitable and continual advances.

Thank you for the opportunity to comment on this critical phase of the ATV process. We look forward to achieving an interoperable and extensible ATV standard.

| d | i | g | i | t | a | l | TM

NAME:	Bill Styslinger
MS/LOC:	MRO1-3/C9
DTN:	297-9380
E-MAIL:	@CORE
DATE:	17 June 92

SUBJECT: GENERAL INSTRUMENT/DIGITAL EQUIPMENT COMPOSITE ANALYSIS OF OUTCOMES

TO:	Charlie Christ	223-2361
	Dick Fishburn	223-3965
	Russ Gullotti	276-0297
	Win Hindle	223-0200
	Marty Hoffmann	223-0200
	Bill Johnson	223-6094
	Bob Palmer	223-2299
	Dick Poulsen	244-6111
	Charlie Mapps	223-8780
CC:	Bob Good	297-1407
	Jim Cudmore	223-3965
	Peter Fontaine	223-5431
	Sam Fuller	223-3965
	Branko Gerovac	617/489-5917
	Karen Kupferberg	
	Ed McGrath	225-4681
	Lucia Quinn	223-1994
	John Sims	223-0200
	Jack Smith	223-0200
	Bill Steul	
	Don Zereski	297-1407

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NAME: Bill Styslinger and Dick Clinton
MS/LOC: MRO1-3/C9
DTN: 297-9380
E-MAIL: @CORE
DATE: 17 June 1992

TO: INVESTMENT COMMITTEE

SUBJECT: GENERAL INSTRUMENT/DIGITAL JOINT VENTURE
COMPOSITE ANALYSIS OF OUTCOMES

In order to help your decision on the proposal by the Cable IBU to enter into a joint venture with General Instrument, Dick Fishburn asked for a composite analysis of the return to Digital of five possible outcomes.

Branko Gerovac, advisor to the FCC, has estimated G.I.'s current chances of being selected at 45%. We assigned the following probabilities of the GI/MIT proposal being selected by the FCC as the HDTV standard:

	PROBABILITY
GI loses, terminate the J.V. January 1993	20%
GI loses, terminate J.V. July 1993	35%
GI wins, conservative case	10%
GI wins, expected case	30%
GI wins, agressive case	5%
	100%

It is likely that Digital's participation in the J.V. will enhance GI/MIT's likelihood of selection. This improvement has not been included above.

HDTV royalty payments to Digital recovering our upfront investments have, conservatively, been omitted for this analysis. These payments effectively eliminate Digital's downside financial exposure.

THE COMPOSITE ANALYSIS, ATTACHED, INDICATES IT IS DESIRABLE TO PROCEED WITH THE J.V. THE COMPOSITE CASH FLOW SHOWS AN IRR OF 46%, WITH A NPV OF $3.6M (AT 10% COST OF CAPITAL) IN THE COMPOSITE OF THE FIVE CASES.

D. Clinton 6/17/92

agrcomp.xls

DIGITAL'S CASH FLOW - JOINT VENTURE WITH G.I.
PROBABILITY ANALYSIS
COMPOSITE OF 5 CASES

Note: Should Digital agree to form the J.V., GI's probability of success with the FCC would be increased (above the aggregate 45% shown below).

		<—invest—> 1992	1993	<—dividends—> 1994	1995	1996	1997	total (non-disc) cash flow	IRR	NPV at 10% cost of capital NPV@10%	COMMENTS
Case 1) GI loses, fold	j.v profit		none	none	none	none	none				HDTV royalties from GI
J.V. in 6 months	cash flow ($k)	-750						-750	#NUM!	-682	covering our investment
20% PROBABILITY		-150	0	0	0	0	0				are excluded.
Case 2) G.I loses, fold	j.v profit		none	none	none	none	none				HDTV royalties from GI
J.V. in 1 year	cash flow ($k)	-750	-2,000					-2,750	#NUM!	-2,335	covering our investment
35% PROBABILITY		-263	-700	0	0	0	0				are excluded.
Case 3) GI wins,	j.v profit(k)			none	10,000	5,400	none				HDTV royalties from GI
Conservative case	cash flow ($k)	-750	-4,500	-1,200	2,800	1,512		-2,138	-16%	-2,451	covering our investment
10% PROBABILITY		-75	-450	-120	280	151	0				are excluded.
Case 4) GI wins,	j.v profit(k)			11,400	23,500	34,400	11,000				shows attractive return
Expected case	cash flow ($k)	-750	-4,500	3,192	6,580	9,632	3,080	17,234	79%	10,211	on investment, with
30% PROBABILITY		-225	-1,350	958	1,974	2,890	924				positive NPV
Case 5) GI wins,	j.v profit(k)			11,900	41,000	90,400	77,400				shows very substantial
Aggressive case	cash flow ($k)	-750	-4,500	3,332	11,480	25,312	21,672	56,546	133%	33,894	ROI, very positive
5% PROBABILITY		-38	-225	167	574	1,266	1,084				NPV
COMPOSITE PROBABLE CASH FLOW		-750	-2,725	1,004	2,828	4,306	2,008	6,671	46%	3,559	Composite case shows attractive ROI, with positive NPV.

Assumptions CASH FROM DIGITAL: For simplicity, cash flows above are consolidated as if occuring on July 1
Actual cash in to the j.v. by Digital would occur in smaller and more frequent intervals,
based on specific milestones. Timing of outflow (maximum):

Jul-92	Oct-92	Jan-93	Apr-93	Jul-93	Oct-93	Jan-94
$750	$0	$900	$1,100	$1,250	$1,250	$1,200

Case 1 >——————>
Case 2 >——————————————>
Case 3 >——————————————————————————>
Case 4 >——————————————————>
Case 5 >——————————————————>

DIVIDEND PAYMENTS FROM J.V. TO DIGITAL:
J.V tax rate assumed 30%, 80% dividend payout, 1/2 to Digital (i.e. 0.28 of pretax profit)

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NAME: Bill Styslinger
MS/LOC: MRO1-3/C9
DTN: 297-9380
E-MAIL: @CORE
DATE: 15 June 92

SUBJECT: GENERAL INSTRUMENT CORPORATION

TO:

Charlie Christ	223-2361
Dick Fishburn	223-3965
Russ Gullotti	276-0297
Win Hindle	223-0200
Marty Hoffmann	223-0200
Bill Johnson	223-6094
Bob Palmer	223-2299
Dick Poulsen	244-6111
Charlie Mapps	223-8780
Bill Steul	297-1333
Sam Fuller	223-3965
Jack Smith	223-0200
John Sims	223-0200

Number of pages to follow: 19

FROM: Bill Styslinger

TO: Investment Committee

SUBJECT: Proposal to form a joint venture with General Instrument Corp. for the purpose of designing video chips which implement the anticipated FCC HDTV standard.

DATE: 15 June 1992

This proposal is being faxed to members of the Investment Committee. Upon your approval (to be obtained by telephone on Wednesday, June 17), we will proceed with the negotiations with G.I. this week.

Attached is an investment proposal for $5.25M to enter into a joint venture with General Instrument Corp. G.I. is a sponsor, with MIT, of two of four digital proposals for the U.S. HDTV (high-definition television) standard. Testing of competing proposals is underway, with final selection expected in one year (June 1993). In January 1993 the FCC will decide to proceed to field test with one (possibly two) of the proposals. At that point, it should be clear whether the G.I. proposal is likely to prevail. As G. I. has flawlessly completed the first round of testing, we believe that G.I. currently has the highest probability of selection.

We expect the financial return to Digital over 5 years to be approximately 50% of the pre-tax profit of about $64M.

In order for Digital to capitalize on the convergence of digital video communications, and computing, we propose that Digital enter into a joint venture with G.I.. The purpose is to design the VLSI (video chips) necessary to implement the HDTV standard. This standard will greatly influence all video compression standards. Early time-to-market is absolutely necessary to fully exploit the built-in advantage of G.I.'s selection. The joint venture will market and sell chips. Digital will decide where the chips are manufactured.

The benefits to Digital are outlined in the attached proposal. Perhaps the most significant benefit is for Digital to be perceived as a technology leader in the emerging market for digital video communication, storage and manipulation.

The downside risk is limited. Should it appear likely in January 1993 that the GI/MIT proposal will not be selected by the FCC, the joint venture could be terminated. Digital's investment to that point should not exceed $750K. If, as is anticipated, the GI/MIT proposal is selected, an additional $4.5M will be invested in the joint venture. The level of our participation is to be negotiated.

I strongly urge your approval for the up-front investment (initially $750K, then $4.5M through December of 1993) and to proceed with negotiations with G.I.

PROPOSAL

PROPOSAL TO THE INVESTMENT REVIEW COMMITTEE

TO

FORM A JOINT VENTURE
(A SEPARATE COMPANY, JOINTLY OWNED)

BY
DIGITAL EQUIPMENT CORPORATION

AND

GENERAL INSTRUMENT CORPORATION

THIS IS A KEY OPPORTUNITY FOR DIGITAL TO PARTICIPATE MORE DIRECTLY IN THE CONVERGENCE OF COMPUTING AND COMMUNICATIONS, TECHNOLOGIES AND MARKETS.

TABLE OF CONTENTS

PAGE #

PURPOSE

The purpose of the joint venture company is to:

DESIGN a digital video chip set to the ATVA* definition (and follow-on chip sets)

MARKET AND SELL the chips to TV manufacturers.

POSITION the joint venture owners (Digital and G.I.) as leaders in digital video communications, networking and computing.

MAKE PROFIT for the joint venture owners (Digital and G.I.)

*ATVA (American Television Alliance) - G.I./MIT proposed HDTV standard. MIT, as a junior partner, will fund research through a royalty sharing agreement with G.I. In addition, MIT seeks to influence the HDTV standard to be compatible with computing.

OBJECTIVES/BENEFITS

OBJECTIVES/BENEFITS TO DIGITAL

PROFITABLE RETURN on investment

POSITION DIGITAL as leader in the storage, manipulation, transmission of digital video

DEVELOP COMPETENCY in the technologies of digital video communications, storage and manipulation

. access G.I.'s RF technology for digital channel encoding
. early experience with HDTV chip design
. transfer of video technology into computer chips (Hudson's goal for the J.V.)

POSITIONS DIGITAL as key technical supplier to the cable industry

LEVERAGES our influence to have the HDTV standard as computer -like as possible

HELPS THE SUCCESS of Digital's investment in many areas (multimedia, storage, networks, VLSI, video, services)

OBJECTIVES/BENEFITS TO GENERAL INSTRUMENT

. Gets access to worldclass VLSI design capabilities

. Increases the probability that G.I. will win the HDTV standard

. Capitalizes on G.I.'s time-to-market advantage with HDTV standard (quick ramp up of new chips)

. Gains major computer company support for HDTV standard

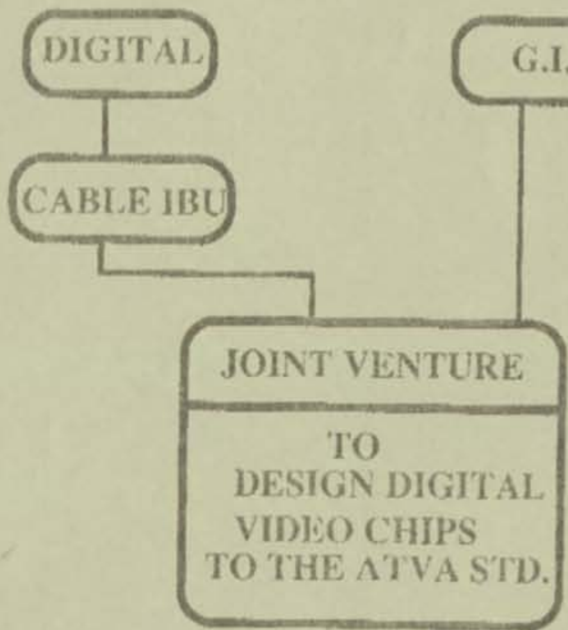
. Access to a computer company's system/network architecture and design skills

WIN/WIN

DIGITAL EQUIPMENT CORPORATION	GENERAL INSTRUMENT
• Corporate impact: — critical time for positive publicity — builds image of successful pursuit of emerging technologies/markets — increased attractiveness to other potential partners • Faster implementation of, and access to HDTV technologies • Learning: compression/decompression and transmission technologies cable industry business and channels consumer electronics business and channels • Relationship with major cable hardware supplier for future product/service definition	• Computer company participation in HDTV proposal to FCC; improved chances of • World class VLSI design/ manufacturing/procurement • Computer system architecture/design skills • Faster implementation of HDTV technologies; de facto standard • Major company national influence • Global company presence and customer base

STRUCTURE

PRELIMINARY STRUCTURE OF THE J.V. COMPANY



CEO: Digital to select

ENG. MGR.: TBD

SALES/MKTG: TBD

Location: TBD (Hudson)

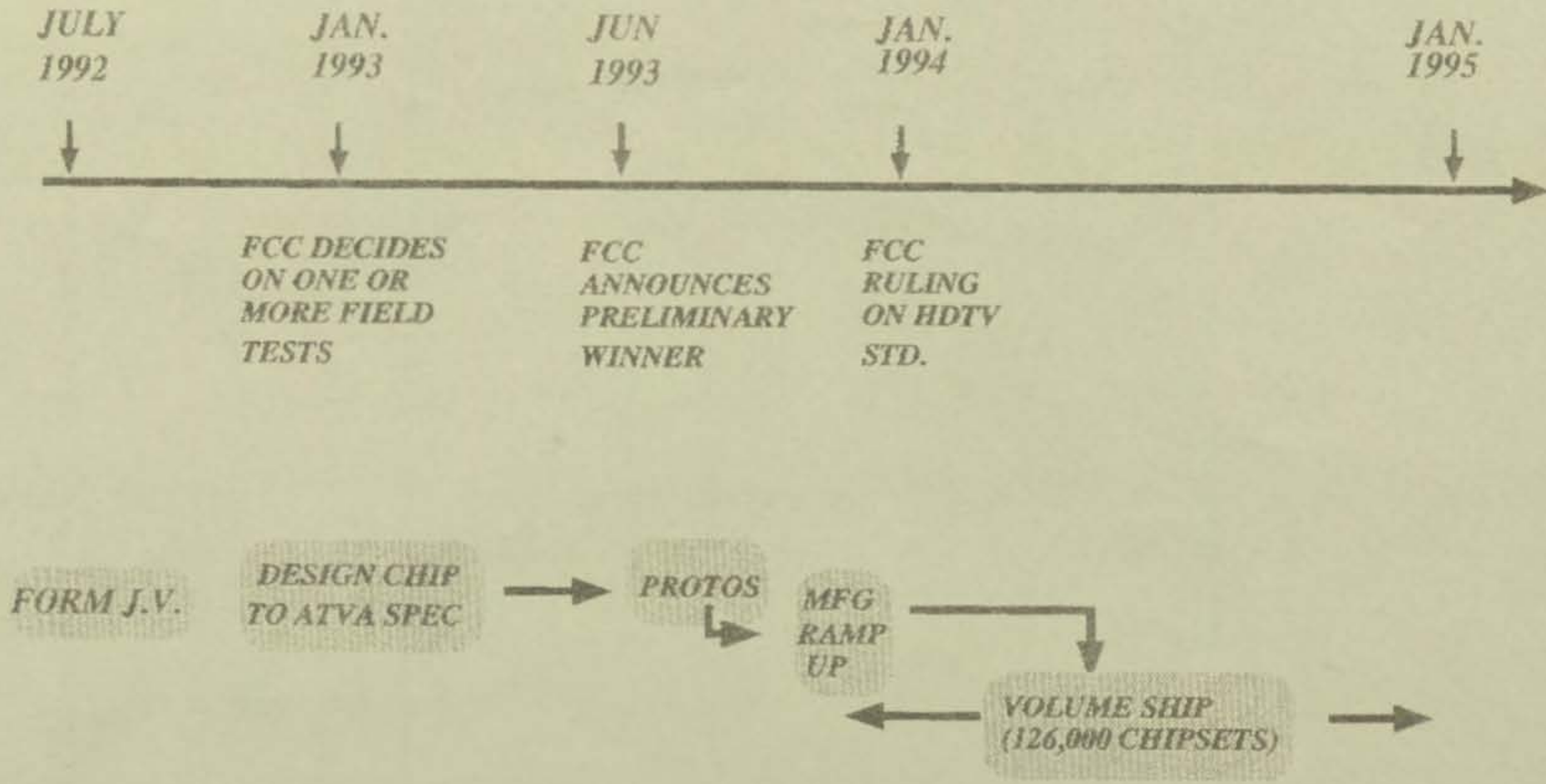
Responsibility within Digital:

Digital partner: the Cable IBU

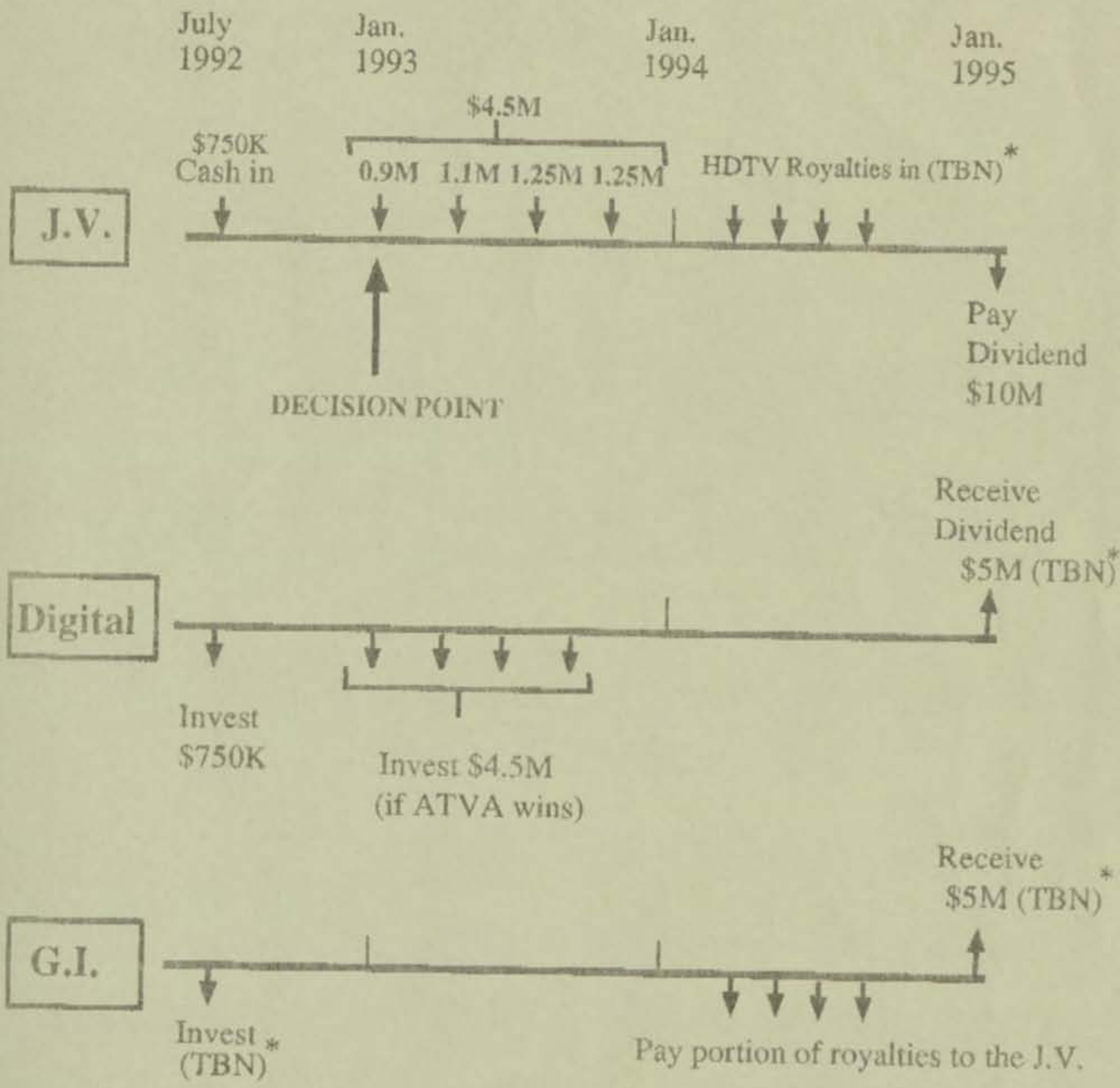
Competition: AT&T's Microelectronics division is competing for the HDTV standard. Based on G.I. and AT&T's royalty sharing agreement, AT&T will obtain a high level system design from which AT&T will design and manufacture chips. G.I./MIT will provide the system implementation and design consulting to the J.V. giving the J.V. a six month lead time over AT&T.

Many others (Motorola, several Japanese vendors) will also compete, although with some lag.

FCC Decision Timeline



CASH FLOW



DECISION POINT: Terminate the J.V. if ATVA loses. Royalties to continue to Digital until the initial investment is recovered

(TBN)* =To Be Negotiated

FINANCIALS

The following financial projections for the joint venture are based on current assumptions by the FCC for HDTV sales.

Three cases are examined:

EXPECTED enables the joint venture to recover initial investment by the end of 1994, and generate profits thereafter.

AGGRESSIVE shows the joint venture with rapid recovery of initial investment, and substantial future profit.

CONSERVATIVE shows the joint venture recovering initial investment by 1995, with low profits (turning to losses).

THE FINANCIAL MODELS SHOW THAT THE JOINT VENTURE IS A DESIRABLE INVESTMENT. THE MODELS ARE, HOWEVER, HIGHLY SENSITIVE TO THE RATE OF PENETRATION OF HDTV AND , OF COURSE, TO THE MARKET SHARE, SPEED OF COMPETITIVE ENTRY, AND PRICE/COST ASSUMPTIONS.

THE JOINT VENTURE START UP PROJECTION BY QUARTER SHOWS BREAKEVEN IN Q2, FY94 AND RECOVERS TOTAL COST IN Q4, FY94. THIS IS BASED ON THE *EXPECTED* CASE.

a:GIONE.xls

EXPECTED CASE

6/15/92 18:10

HDTV ANNUAL UNIT SALES ESTIMATES

	year -1 1992	year 0 1993	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
TV households - TVHH (000)	93,000	93,500	94,000	94,470	94,942	95,417	95,894	96,374	96,855
HDTV price (retail)			$4,000	$4,000	$3,800	$3,000	$2,500	$2,000	$1,800
TVs purchased (000) (20% of TVHH)	18,600	18,700	18,800	18,894	18,988	19,083	19,179	19,275	19,371

FCC and G.I.'s BASE CASE - One Million annual HDTV's by 1996; 12.7% penetration by 2000; 75% by 2010

	1994	1995	1996	1997	1998	1999	2000
Percentage (HDTV/all TVs)	1%	3%	6%	9%	12%	15%	18%
Annual HDTV units (000)	188	567	1,139	1,718	2,301	2,891	3,487
Cum HDTV units	188	755	1,894	3,612	5,913	8,804	12,291
Penetration (HDTV/TVHH)	0.2%	0.8%	2.0%	3.8%	6.2%	9.1%	12.7%

G.I. / DIGITAL JOINT VENTURE FINANCIAL PROJECTIONS

EXPECTED CASE

PENETRATION: 0.2% in 1994; One Million annual HDTV's by 1997; 10% penetration by 2000; 60% by 2010
MARKET SHARE: 2/3 share, dropping to 30% share by 2000
PRICE: 5% of retail, dropping to 2.5% of retail in 2000
COST: $70, dropping 15% per year

	year -1 1992	year 0 1993	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
Percentage (HDTV/all TVs)			1%	3%	5%	7%	10%	13%	13%
Annual HDTV units (000)			188	473	953	1,248	1,932	2,433	2,458
Cum HDTV units			188	661	1,614	2,863	4,795	7,228	9,686
Penetration (HDTV/TVHH)			0.2%	0.7%	1.7%	3.0%	5.0%	7.5%	10.0%
penetration increase				0.5%	1.0%	1.3%	2.0%	2.5%	2.5%
J.V. FINANCIALS									
J.V. market share			67%	50%	45%	40%	30%	30%	30%
volume of chip sets			125,960	236,645	428,728	499,397	579,859	729,994	737,258
Chip set PRICE as % HDTV retail			5.0%	4.5%	3.8%	2.5%	2.5%	2.5%	2.5%
Price of chip set			$200	$180	$143	$75	$63	$50	$45
VLSI cost (reducing 15% per year)			$70	$59.50	$50.58	$42.99	$36.54	$31.06	$26.40
Gross margin per unit			$130.00	$120.50	$91.93	$32.01	$25.96	$18.94	$18.60
GROSS MARGIN (million)			$16.4	$28.5	$39.4	$16.0	$15.0	$13.8	$13.7
ENG (5 eng in 92+Mgmt; 20 in 93)	0.75	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
SALES/MKTG		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
profit	-0.8	-5.0	11.4	23.5	34.4	11.0	10.0	8.8	8.7
			<--- Venture recovers investment in 1994 at				82,692 chip sets		
annual breakeven volume			38,462	41,494	54,392	156,195	192,507	263,983	268,824

Initial investment is recovered by end of 1994, with some profit.

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AGGRESSIVE CASE

HDTV ANNUAL UNIT SALES ESTIMATES

6/15/92 19:11

	year -1 1992	year 0 1993	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
TV households - TVHH (000)	93,000	93,500	94,000	94,470	94,942	95,417	95,894	96,374	96,855
HDTV price (retail)			$4,000	$4,000	$3,800	$3,000	$2,500	$2,000	$1,800
TVs purchased (000) (20% of TVHH)	18,600	18,700	18,800	18,894	18,988	19,083	19,179	19,275	19,371
FCC and G.I.'s BASE CASE - One Million annual HDTV's by 1996; 12.7% penetration by 2000; 75% by 2010									
Percentage (HDTV/all TVs)			1%	3%	6%	9%	12%	15%	18%
Annual HDTV units (000)			188	567	1,139	1,718	2,301	2,891	3,487
Cum HDTV units			188	755	1,894	3,612	5,913	8,804	12,291
Penetration (HDTV/TVHH)			0.2%	0.8%	2.0%	3.8%	6.2%	9.1%	12.7%

G.I. / DIGITAL JOINT VENTURE FINANCIAL PROJECTIONS

AGGRESSIVE CASE

PENETRATION: 0.2% in 1994; One Million annual HDTV's by 1996; 10% penetration by 1998; 75% by 2010
MARKET SHARE: 2/3 share, dropping to 35% share by 2000
PRICE: 5% of retail, dropping to 3.0% of retail in 2000
COST: $66, dropping 20% per year

	year -1 1992	year 0 1993	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
Percentage (HDTV/all TVs)			1%	3%	10%	17%	19%	18%	18%
Annual HDTV units (000)			186	568	1,903	3,257	3,674	3,421	3,455
Cum HDTV units			188	756	2,658	5,916	9,589	13,010	16,465
Penetration (HDTV/TVHH)			0.2%	0.6%	2.8%	6.2%	10.0%	13.5%	17.0%
penetration increase				0.6%	2.0%	3.4%	3.8%	3.5%	3.5%
J.V. FINANCIALS									
J.V. market share			67%	55%	50%	45%	40%	35%	35%
volume of chip sets			125,960	312,268	951,313	1,465,862	1,469,423	1,197,358	1,209,249
Chip set PRICE as % HDTV retail			5.0%	5.0%	3.8%	3.0%	3.0%	3.0%	3.0%
Price of chip set			$200	$200	$143	$90	$75	$60	$54
VLSI cost (reducing 20% per year)			$66	$52.80	$42.24	$33.79	$27.03	$21.63	$17.30
Gross margin per unit			$134.00	$147.20	$100.26	$56.21	$47.97	$38.37	$36.70
GROSS MARGIN (million)			$16.9	$46.0	$95.4	$82.4	$70.5	$45.9	$44.4
ENG (5 eng in 92+Mgmt; 20 in 93)	0.75	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
SALES/MKTG		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
profit	-0.8	-5.0	11.9	41.0	90.4	77.4	65.5	40.9	39.4
			<——— Venture recovers investment in 1994 at				80,224	chip sets	
annual breakeven volume			37,913	33,967	49,870	88,958	104,240	130,300	156,245

Best case shows rapid
recovery of initial investment,
with substantial future profits

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CONSERVATIVE CASE

HDTV ANNUAL UNIT SALES ESTIMATES

6/15/92 21:56

	year -1 1992	year 0 1993	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
TV households - TVHH (000)	93,000	93,500	94,000	94,470	94,942	95,417	95,894	96,374	96,855
HDTV price (retail)			$4,000	$4,000	$3,800	$3,000	$2,500	$2,000	$1,800
TVs purchased (000) (20% of TVHH)	18,600	18,700	18,800	18,894	18,988	19,083	19,179	19,275	19,371

FCC and G.I.'s BASE CASE - One Million annual HDTV's by 1996; 12.7% penetration by 2000; 75% by 2010

	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
Percentage (HDTV/all TVs)	1%	3%	6%	9%	12%	15%	18%
Annual HDTV units (000)	188	567	1,139	1,718	2,301	2,891	3,487
Cum HDTV units	188	755	1,894	3,612	5,913	8,804	12,291
Penetration (HDTV/TVHH)	0.2%	0.8%	2.0%	3.8%	6.2%	9.1%	12.7%

G.I. / DIGITAL JOINT VENTURE FINANCIAL PROJECTIONS

CONSERVATIVE CASE

PENETRATION: 0.1% in 1994; One Million annual HDTV's by 1999; 10% penetration by 2002; 50% by 2010

MARKET SHARE: 50% share, dropping to 10% share by 2000

PRICE:4% of retail, dropping to 2.0% of retail in 2000

COST: $80, dropping 10% per year

	year -1 1992	year 0 1993	year 1 1994	2 1995	3 1996	4 1997	5 1998	6 1999	7 2000
Percentage (HDTV/all TVs)			1%	3%	4%	5%	5%	7%	7%
Annual HDTV units (000)			94	567	763	961	971	1,270	1,379
Cum HDTV units			94	661	1,424	2,385	3,356	4,626	6,005
Penetration (HDTV/TVHH)			0.1%	0.7%	1.5%	2.5%	3.5%	4.8%	6.2%
penetration increase				0.6%	0.8%	1.0%	1.0%	1.3%	1.4%
J.V.FINANCIALS									
J.V. market share			50%	30%	20%	15%	15%	10%	10%
volume of chip sets			47,000	170,187	152,569	144,194	145,630	126,964	137,911
Chip set PRICE as % HDTV retail			4.0%	4.0%	3.5%	3.0%	3.0%	2.5%	2.5%
Price of chip set			$160	$160	$133	$90	$75	$50	$45
VLSI cost (reducing 10% per year)			$80	$72.00	$64.80	$58.32	$52.49	$47.24	$42.52
Gross margin per unit			$80.00	$88.00	$68.20	$31.68	$22.51	$2.76	$2.48
GROSS MARGIN (million)			$3.8	$15.0	$10.4	$4.6	$3.3	$0.4	$0.3
ENG (5 eng in 92+Mgmt; 20 in 93)	0.75	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.5
SALES/MKTG		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
profit	-0.8	-5.0	-1.2	10.0	5.4	-0.4	-1.7	-4.6	-4.7
				<-------- Venture recovers investment in 1995 at				134,063	chip sets
annual breakeven volume			62,500	58,818	73,314	157,828	222,104	1,811,069	2,012,290

Conservative case achieves investment recovery in 1995, with low profits (turning to losses.) Worth pursuing through 1996, then the venture must find new markets, or withdraw.

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J.V. STARTUP PROJECTION
BY QUARTER
BASED ON THE EXPECTED CASE

	<----FY93			---->	<---- FY 94			---->	<---FY 95	--->
	1	2	3	4	1	2	3	4	1	2
	Birth		FCC selects proposals for Field Test (Jan)	FCC announce prelim winner (June)	FCC ruling on STD (Sept?)		First HDTV ships			
# people -Mgr (@$200)	1	1	1	1	1	1	1	1	1	1
Eng (@ $125)	5	8	20	20	20	20	20	20	20	20
Mktg/Sales (@$125)	1	2	4	10	15	15	15	15	15	15
Admin (@ $75)	1	2	3	3	3	3	3	3	3	3
EXPENSE - people	$256	$400	$856	$1,044	$1,200	$1,200	$1,200	$1,200	$1,200	$1,200
- other	$44	$50	$56	$56	$50	$50	$50	$50	$50	$50
total	$300	$450	$912	$1,100	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250
1st year ramp (125,960)						10%	20%	30%	40%	
Chip sets sold to TV MFR's						12,596	25,192	37,788	50,384	59,161
Gross Margin ($130 per chip set)						$1,637	$3,275	$4,912	$6,550	$7,129
Fixed Expense (above)	$300	$450	$912	$1,100	$1,250	$1,250	$1,250	$1,250	$1,250	$1,250
OPERATING PROFIT	($300)	($450)	($912)	($1,100)	($1,250)	$387	$2,025	$3,662	$5,300	$5,879
cumulative profit	($300)	($750)	($1,663)	($2,762)	($4,012)	($3,625)	($1,600)	$2,063	$7,363	$13,241

J.V. BREAKS EVEN IN Q2 FY94

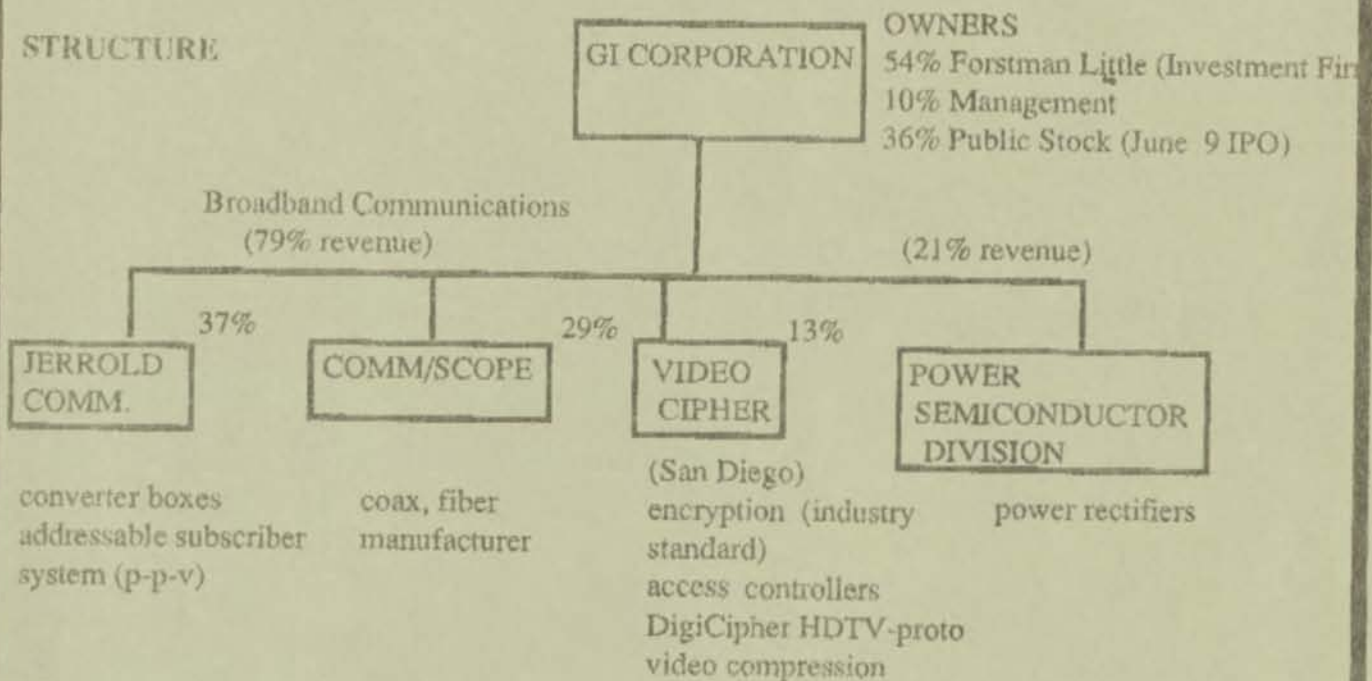
J.V. RECOVERS TOTAL COST IN Q4 FY94

APPENDIX
GENERAL INSTRUMENT CORPORATION

BUSINESS: The leading supplier of systems and equipment to the Cable TV Industry

Sales: $1B
Location: Chicago (HQ)
Employees: 8,600 (2,600 in US, 4000 Taiwan manufacturing)

STRUCTURE



G.I. STRENGTHS

1. proposer, with MIT, of Digital HDTV std.
2. Technologies:
   digital video compression
   Video on demand (p-p-v)
   PCN (Telephony over cable)
   HDTV
3. Dominant supplier to US and International Cable Cos.
4. Reputation for quality and research

G.I.WEAKNESSES

1. Highly leveraged even after IPO (LBO in August 1990, IPO in June 1992)
2. Dependent on capital spending patterns of cable TV industry:
   . long term very positive
      . upgrade CATV plant (more channels, pay-per-view)
      . Telephony
      . PCN
      . digital communications
   . reduced capital spending (1990-92)
      . New tech (fiber, digital compression)
      . Rate regulation threat (now reduced)
      . access to capital (HLT rules) ends June
3. Showing an operating profit, but a net loss due to interest expense.

APPENDIX

GENERAL INSTRUMENT CORPORATION

FINANCIALS

(10 Months Ending December 1991)

Statement of Operations

Revenue		$785M	
Mfg.	$566		(72%)
Selling	103		(13%)
R&D	46		(6%)
Other	22		(3%)
Total		$737	(94%)
Op. Profit		+ 48	(6%)
Interest Expense		-103	
Divestures, tax, etc.		- 39	

Net Loss		<$94M>	

Balance Sheet (Adjusted for the IPO)

	Assets		*Liabilities*
Current (cash, A/R, etc.)	$ .3B	Current (payables current LTD)	$ .4B
PP&E	.3	LTD	1.0
Excess of cost of acquisitions over value	1.2	Equity	.4
	------		------
Total	$1.8B	Total	$1.8B

Note: G.I. shows an operating profit, but net loss after interest on $1.33b of debt (now reduced $330M by the June 9 IPO) .he company continues to be highly leveraged in the debt/equity ratio about 2.5X

APPENDIX

HDTV COMPETITION STATUS

There are four digital proposals and one analog proposal before the FCC's Advisory Committee on Advanced Television Service (ACATS) - The FCC will select the preliminary winner in June of 1993

ESTIMATED PROBABILITY OF WIN (June 1993)

45%	. GI/MIT (ATVA) - test of the first of two proposals has been successful
20%	. SARNOFF/PHILIPS/THOMSON/NBC have admitted they will begin testing 2 weeks late due to unfinished engineering
30%	. AT&T/ZENITH - 2nd test delayed, now successful
0%	. [NHK (Japan) - analog solution]
100%	

Estimates of success provided by Branko Gerovac.

APPENDIX

HDTV ROYALTY SHARING POSSIBILITIES

(ROYALTIES ON EACH HDTV)

IF G.I./MIT WIN

G.I. $5 -----> proposal:flow $1 into joint venture
MIT <2
AT&T (1/3) 3 <----- per sharing agreement if G.I. win

$10 royalty per HDTV

Our negotiating posture with G.I. will be to flow $1 royalty to Digital for each HDTV sale to cover our initial investment.

IMPACT ON THE CABLE IBU

If we create the joint venture:

. We continue our positive momentum evident in the cable industry press (Multichannel News) and in our discussions with TCI, Time Warner, Cable Labs, Cablevision, Teleport, G.I., Colonial, Continental, etc. for data communication services, video storage systems and billing systems.

. The proceeds of the joint venture become additive to the Cable IBU plan.

NOTE: Joining with G.I. will cost us our appearance of neutrality and our position on the FCC's advisory panel for HDTV. (Branko Gerovac holds this position).

If we do not create the joint venture:

. We expect another computer compny will partner with G.I. to ally themselves with the dominant cable equipment supplier, thereby gaining access to technology and distribution.

. We would not expect to achieve our planned dominant market share of 40%. A 5% drop in market share would result in 12.5% fall in anticipated revenues in FY94 and beyond.

THERE IS NO OPPORTUNITY TO BE A FOLLOWER HERE.

SUMMARY.XLS

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Cable IBU - Financials TOTAL IBU

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These financials are specific for costs identified and needed by the IBU.

	<-EST-->	<---------PLANS		---------->	<----GOALS	---->
	FY92	FY93	FY94	FY95	FY96	FY97
Product NOR	5.0	14.6	65	252	500	810
Service NOR	2.0	4.9	20	48	100	190
pilots/programs		0.5				
Total NOR	7.0	20.0	85	300	600	1000
Transfer Cost		6.1	29	114	223	363
Service COD		2.5	10	24	50	95
IBU Marketing		5.0	8	15	25	40
ENG: Camel's Nose, followons		2.0	5	10	15	20
ENG: video chip (GI joint vent.)		2.5	2.5			
Total IBU direct		9.5	15.5	25	40	60
Total Selling		2.2	6	14	27	42
Engineering Expense		1.5	5	17	35	68
All other company charges		0.7	12	77	156	258
OPERATING PROFIT Total ($)		-2.4	8	30	69	124
Total (%NOR)		-12%	9%	10%	12%	12%

incl video compression chip

19

S. Fuller

f: HDTV

| d | i | g | i | t | a | l |

Interoffice Memo

TO: Digital TV Subcommittee

DATE: 3 February 1992
FROM: Dick Fishburn
DEPT: Investments and Business Development
EXT: 223-4225
LOC/MAIL STOP: MLO12-2/T81

SUBJECT: Minutes of 22 January Meeting

Attendees: Marty Hoffmann, Win Hindle, Bill Johnson, Bill Steul, Sam Fuller, Dick Fishburn. Absent: Bill Strecker, John Sims. Also Attending: Bill Styslinger

The agenda for the meeting is included as Attachment I. Dick Fishburn indicated that the White Paper was scheduled to be completed the week of 27 January (a draft was given to Dick on 31 January). The purpose of the White Paper was to have a core document that could be circulated to a wide audience on a need-to-know basis. The objective of the Paper is to create a common base of knowledge throughout the Corporation on the opportunities, providing the framework for ongoing strategy, organization, and executive discussions.

A brief status of Opportunity Programs was provided. With regard to Imaginet, concern was raised that a specific proposal and associated funding had not come forward. Subsequent to the meeting, a pilot and associated funding of $250,000 was approved (Mike Thurk handling). For General Instrument, Marty mentioned that Donald Rumsfield would be visiting Digital in early February; we should have a clear position on the FCC licensing process. It was noted that the RBOC Multimedia Network opportunity should recognize initiatives with Ameritech, Nynex, US West and Bell Atlantic. The Committee also asked that Philips be added as an Opportunity Program.

The Committee then discussed organization structure (Pages 2-4 of agenda attachment). The decision to establish a Cable Industry IBU and a Metropolitan Area Network PCU (Engineering group?) was confirmed; Bill Steul and Mike Thurk will handle respectively. The Committee also agreed to form a small Program Office for the broadly-defined opportunity, reporting jointly to the Cable Industry IBU and MAN PCU.

Dick Fishburn recommended that at this point, Digital strategy vis-a-vis data sources, information providers, and users in multiple locales should be Communication Provider neutral. Marty suggested that we should presumptively assume this until someone proposes otherwise; this was agreed.

The Committee agreed that Digital strategy regarding the Information Provider segment of the opportunity was either unclear or non-existent. Work to propose a strategy would be done internally; BJ was to identify a person.

No discussion occurred regarding the recommendation for the next Communication Business Council to develop a common message on the Digital strategy toward the Communication Providers.

The Committee suggested at least one more meeting be held, to be scheduled in late February/early March. Everyone reiterated that they continue to dislike the Subcommittee name (Digital TV Subcommittee); we also failed to pick a new one.

RJF:fc
Attachment

DIGITAL TV SUBCOMMITTEE

PROPOSED AGENDA

0830	Review of Agenda	All
0835	Status of White Paper	Dick Fishburn
0840	Status of Opportunity Programs (Program "Manager") - Imaginet (Terry Wright) - Singapore (Eric Lawrence) - Alpha Chips (Ed Caldwell) - General Instrument (Marty Hoffmann) - Cable Market Initiative (TBD; Bill Steul) - Broadband ISDN Products (Mike Thurk) - Transport Proposal - Router/Switch - RBOC Multimedia Network (David Nunnerley)	
0900	Organization Structure for the DEC Opportunity	Issues Paper To Be Handed Out
1000	End of Meeting	

DIGITAL TV

ORGANIZATION STRUCTURE - ASSUMPTIONS

- There is a significant stand-alone opportunity for High Definition TV, particularly in those markets that are likely to have a digital standard in the early 1990's.

- The organizational structure should be wholistic, i.e. address all affected interfaces for the opportunities.

- The opportunity need not be managed from a single organizational structure, but the interdependencies and the process to create a single strategy should be clear.

- The interfaces include:

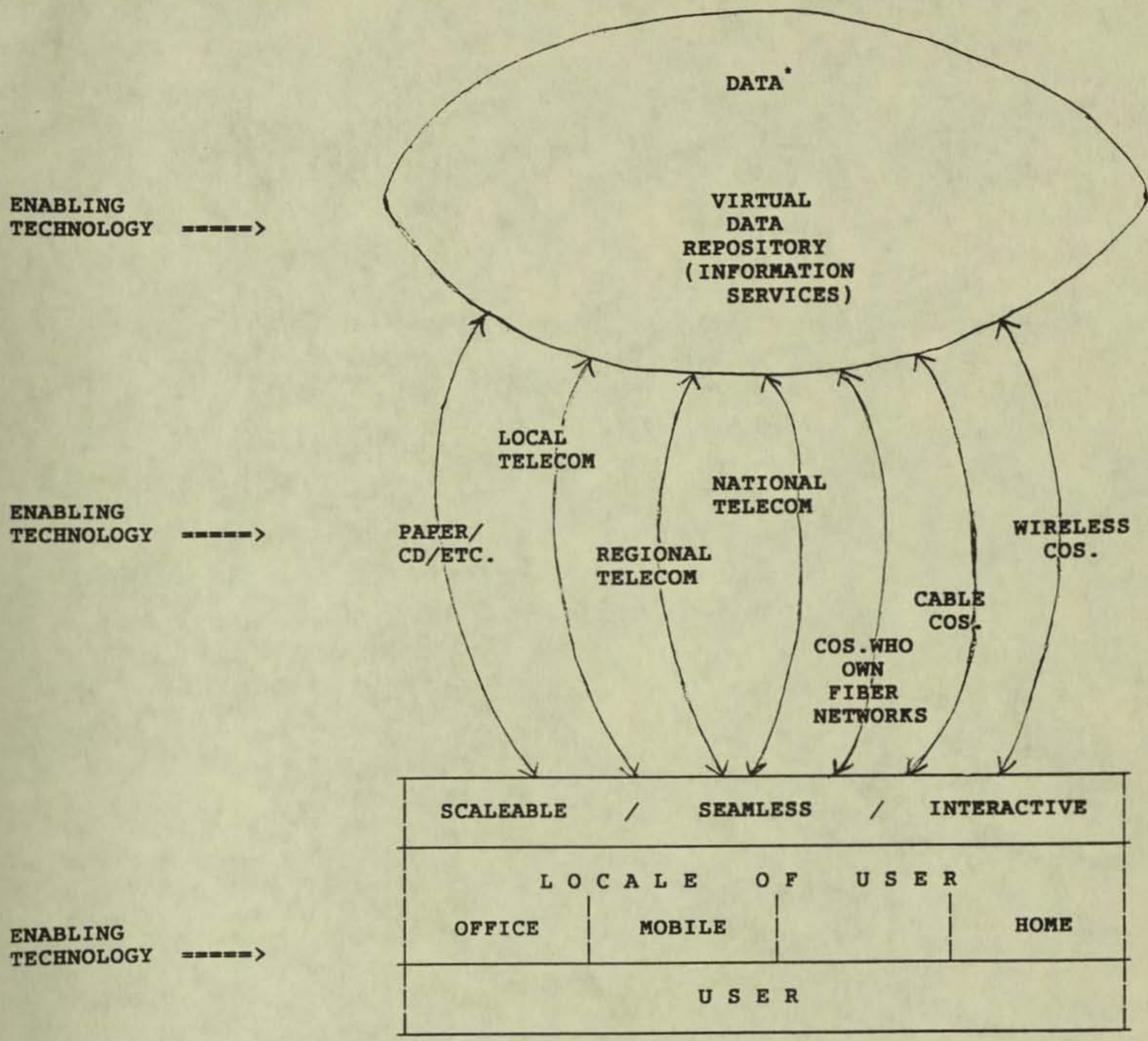
  - Data sources

  - Information providers

  - Users in multiple locales

  - Communication among providers and users

- For discussion: Digital's interface strategy toward data sources, information providers, and users should be communication provider neutral.



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* e.g., MOVIE, FINANCIAL DATA, ELECTRONIC MAP

DIGITAL TV

ORGANIZATION STRUCTURE - RECOMMENDATIONS

Apparent Agreement

1. A Cable Industry IBU should be created ASAP and its business plan developed. This IBU should be domiciled in the US.

2. A Metropolitan Area Network PCU should be created, reporting to Mike Thurk.

3. The above business units should be the primary units to justify product and cable industry sales resource investments for the communication providers.

For Discussion

1. There is no strategy as to how Digital should take advantage of the Information Provider segment of the opportunity. This work should be commissioned internally or an outside consultant engaged. Based on the outcome of the study, an organizational recommendation can be made.

2. The above should also clarify Digital's strategy toward data sources (e.g., Blockbuster and movies)

3. There should be a common message to customers on Digital strategy toward the Communication Providers. This should be addressed at the next Communication Business Council meeting (early February).

4. There should be a focal point for 1, 2, and 3. I'd suggest a small program office reporting jointly to the Cable Industry IBU and MAN PCU.

5. A set of products at the user level to take advantage of these trends also appears appropriate. This is part of a broader Lifestyle Human Interface Strategy that needs to be developed by the PCU's.

f: [illegible] H.D.T.V.

Communications, Television, Computing: Collision and Convergence and Opportunity

—

HDTV: "Not Just About Television" *

for CRA Staff

5 February 1992

Branko J. Gerovac

Digital Equipment Corporation
Corporate Research and Architecture

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phone: 617-253-0669
fax: 617-489-5917

HDTV is Not Just About Television *

- HDTV (High Definition Television) studies began ~1968 as just television with enhanced picture and sound

  POTv – (Enhanced) Plain Old Television

- In the meantime, there was rapid development of digital signal processing, digital signal transmission, high performance computing, and computer networks

- Converging to a common set of underlying digital technologies for imaging, television, video, communication, and computer industries

- Since 1988, derivative technologies (e.g., displays, VLSI) were considered useful across industries – "technology food chain"

- Quickly, an impending interplay and merger of the industries, products, and services themselves was recognized

- In the past year, the situation has changed dramatically:
  - the move from analog to digital signal basis
  - digital processing and communication are widely accepted
  - the 4 leading proponents to the FCC HDTV trials are digital

- HDTV currently is pivotal

- Communications will be the next pivotal technology

Interoperable Communications Infrastructure

- Emerging vision – a global, interactive, open access, interoperable communications infrastructure
  - carries voice, video, images, data, etc.
  - video everywhere – variety of application requirements
  - transparently across and among fiber optic, coax, wire, cellular radio, satellite,... media
- Will not happen all at once
  - no single predefined path to get from the partitioned variety of communications now to a interoperable infrastructure

HDTV as Pivotal

- Digital HDTV is *currently* the pivotal driving technology
  - though the FCC decision has yet to be made, it is virtually assured that the outcome will be digital compression and digital transmission
- Already, this seemingly simple outcome has enabled cable television and terrestrial broadcast to propose expanding the number of NTSC television channels by a factor of 4 to 5 as a coexisting alternative to single channel HDTV
- Information services have exposed the need to consider flexible, interactive communications protocols and network services

Communications as Pivotal

- The *next* pivotal technology will be communications
  - three broad styles of communication are vying as the next driver: telephone, cable television, and computer networks
- Each communications style has its technical advantages; as the vision emerges, a combination of the best of each style occurs
  - telephone is **universal**, but at low bandwidth
  - CATV (with satellite) provides **high bandwidth** over a broad area, but without interactivity
  - computer networks are **interactive**, and offer a **variety of services**, but are not realtime and not universally available

Digital's Contributions

- Exploratory technical contributions, including:
  - setting the agenda for digital television
  - introducing computer networking concepts into video and television transmission
  - working with the cable operators to provide community cable computer networking
  - incorporating media technologies to expand computer services
  - etc.
- Directions
  - well positioned to apply our core technical competencies in computational circuitry design, VLSI, networking, interactive processing, distributed processing,...
  - influence industry, standards, consortia,...

Outline

Abbreviated History

FCC HDTV Proponents/Proposals

COHRS Agenda

Communications Issues

An Abbreviated History

The idea of an enhanced television with improved picture and sound began 25 years ago. The simple intent was to provide 35mm film quality pictures and high fidelity stereo sound. (Film and audio have improved since then. What we have now in HDTV is the quality of 25 year old film.) The expectation was that this new television would be in the same mold as existing color television (NTSC), i.e., analog.

1968 NHK (Japanese Broadcasting Co.) began research program

1972 NHK defined the basic parameters of their HDTV proposal (5:3 aspect ratio, 1125 lines, 60 Hz interlaced)

1981 NHK with Sony demonstrated prototypes for cameras, video tape recorders, satellite transmission, and displays

1982 FCC forms Advanced Television Advisory Committee (ATSC); their underlying agenda is to standardize on the NHK system, now called MUSE (MUltiple Sub-nyquist Encoding)

Though all along, some research occurred in the U.S. and Europe, Japan's growing strength in consumer electronics motivated them to greater levels of investment. It appeared that MUSE would be adopted as a worldwide HDTV standard.

However:

1986 European consumer electronics companies blocked adoption (for economic reasons) of the MUSE system parameters at the plenary meeting in Dubrovnik of the CCIR (~Consultive Committee for International Radio)

In the meantime, there was rapid development of digital signal processing, digital signal transmission, high performance computing, and computer networks. This led a few people (mostly researchers at the Massachusetts Institute of Technology (MIT)) to realize the feasibility, advantages, and implications of digital rather than analog HDTV.

1988 FCC creates Advisory Committee on Advanced Television Service (ACATS) to guide a competitive trial of HDTV proposals

1988 FCC mandates that HDTV fit within the same 6MHz spectrum allocations as existing television – a constraint that favored digital compression techniques

1988 DARPA recognizes national interests in display technology and derivative video and signal processor technologies

Realization grew of the broader industrial derivatives of HDTV. News media coverage and American Electronics Association (AEA) called for addressing the “technology food chain”.

Then, the full implications of merged computing, communications, and television technology was raised:

1990 (January) Committee on Open High Resolution Systems (COHRS) was initiated through MIT as an ad hoc multi-industry committee (including computer interests, e.g., Digital Equipment Corp.); COHRS promotes "architectural goodness" criteria of open systems, extensibility, scalability, interoperability, etc.

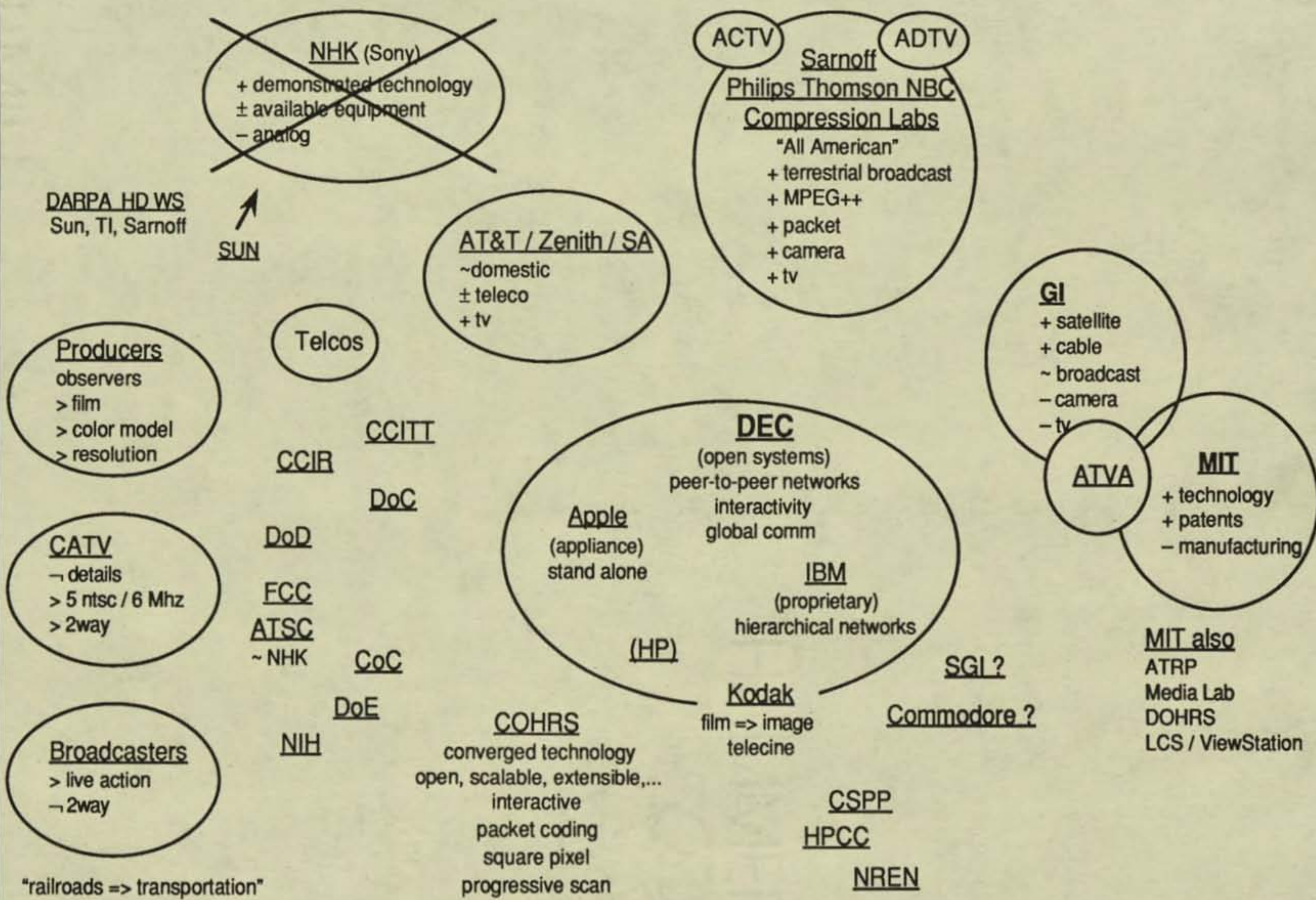
1990 (June) General Instruments proposes the first "all digital" HDTV system; MIT's system long was an analog/digital hybrid

1991 (January) Four of six HDTV proposals to the FCC adopt all digital systems

1991 (summer) COHRS "architectural goodness" criteria adopted as part of the FCC HDTV testing process

1991 (August) CableLabs issues RFP for digital compression methods and equipment for cable TV systems

The FCC testing process is now beginning. Initial testing results will be reported in June 1992. Additional terrestrial broadcast and cable testing will occur in late 1992. Final reports will appear in early 1993. And, the final FCC ruling on a U.S. HDTV system will appear in mid 1993. Deployment is expected to begin in 1994.



HDTV Landscape

FCC HDTV Proponents/Proposals

- Two of them don't count because they are analog. Everyone now agrees that the result will be digital
  - NHK/Sony Muse – significant past investment and early product development
  - Sarnoff ACTV – hopes to make ACTV a compatible extension to current television transmissions (NTSC), regardless of the HDTV trials outcome
- Four are all digital
  - AT&T / Zenith / Scientific Atlanta
  - Sarnoff / Philips / Thomson / NBC / Compression Labs
  - General Instruments (GI) ATVA-I
  - MIT (w/GI) ATVA-P

FCC HDTV Proponents, cont.

- AT&T / Zenith / Scientific Atlanta
  - Zenith is the only U.S.-owned consumer electronics manufacture of television sets – though, much of their manufacturing occurs in Mexico, none in U.S.
  - AT&T brings big company backing, infrastructure and manufacturing, digital communications and VLSI experience. AT&T gains a foothold in content delivery
  - Scientific Atlanta is a major supplier of CATV equipment; joined in December
  - Original proposal was derived from early MIT work, many of the parameters are the same
  - AT&T is capitalizing on their strong Washington DC lobbying skills to bring the AT&T/Zenith proposal to a perceived leading position

FCC HDTV Proponents, cont.

- Sarnoff / Philips / Thomson / NBC / Compression Labs
  - Sarnoff Labs (nee RCA) was the source (in the 50s) of the NTSC color television system we now use
  - Philips and Thomson bring consumer electronics experience with televisions, cameras, VCRs, etc. – it is their U.S. subsidiaries that are involved
  - They call themselves "all American", though some point out their European connection
  - They adaptively offer 4 picture formats rectangular/square pixels, interlace/progressive scan
    - 1440 x 960 2:1 60Hz or 1:1 30Hz, ~CCIR 601
    - 1440 x 810 2:1 60Hz or 1:1 30Hz, square pixels
  - Sarnoff derives their compression scheme from MPEG (the ISO standards activity for compression of motion pictures), giving them some support from the MPEG community
  - Sarnoff is the only proponent that has a packetization and protocol layering scheme that is somewhat recognizable as a computer network protocol – it could be better, but is far beyond what the other proponents (currently) attempt
  - Sarnoff promotes the COHRS criteria

FCC HDTV Proponents, cont.

- General Instruments (ATVA-Interlace)
  - GI is a dominant supplier for satellite and cable transmission systems and cable converter boxes.
    They use digital encrypted video satellite transmission.
    They use DEC computers to control their satellite uplink/downlink equipment
  - GI was the first proponent to offer an all-digital HDTV system. (MIT's system was a hybrid digital/analog for a long time.) In many respects, GI broke the ice by going digital that led the other proponents reevaluate their analog approaches and go all digital as well
  - GI is planning to use their digital compression scheme to place 4-5 NTSC program channels in a single 6 MHz cable channel, thereby increasing the number of cable channels from ~60 to ~300. The cable TV industry is very interested in this, as evidenced by a recent RFP. Others are beginning to look at this approach as well

FCC HDTV Proponents, cont.

- Massachusetts Institute of Technology (ATVA-Progressive)
  - Last spring MIT joined with GI to form the American Television Alliance (ATVA). MIT continues to develop their own system distinct from GI's. Of course, they are sharing a lot of technology. MIT essentially has adopted GI's digital RF modulation scheme
  - MIT is the source of much of the digital video technology that appears in the other proponents' systems. Many of the principal developers at the other proponents were educated at MIT. MIT likely will receive some royalty payments regardless of the outcome of the FCC trials
  - MIT has the last FCC testing slot (Spring 1992); thus, they have a longer time to develop the equipment for the test, and can benefit from seeing the other proponents' systems. GI will build the equipment for the test
  - In many respects, MIT's system is technically superior to the others

Preliminary Table of Attributes, Characteristics, and Processes of the Digital HDTV Terrestrial Broadcasting Systems

	GI ATVA-I	AT&T Zenith	Sarnoff ADTV	MIT ATVA-P	
Picture:					
Lines/Frame	1050	787/788	1050	787/788	
* Frames/Sec	29.97	59.94	29.97	59.94	Hz
* Interlace	2:1	1:1	2:1 1:1	1:1	
Horiz Deflection	31.469	47.203	31.469	47.203	KHz
Aspect Ratio	16:9	16:9	16:9	16:9	
* Active Pixels lumi	1408:960	1280:720	1440:960/810	1280:720	h:v
chroma	480:352	640:360	720:480	640:360	h:v
* Pixel Aspect	33:40	1:1	27:32	1:1	v:h
Bandwidth lumi	21.5	34.	24.5	34.	MHz
chroma	5.4	17.	12.25	17.	MHz
Colorimetry	240M	240M	240M	240M	SMPTE
* Video Compression	mc-DCT	mc-DCT/VQ	MPEG++	mc-subband	
Block Size	8:8	8:8	8:8	8:8	pixels
Sample Frequency	53.65	75.3	54.	75.3	MHz
Audio:					
Bandwidth	20.	20.	23.	20.	KHz
Sample Freq	47.2	47.203	48.	48.	KHz
Dynamic Range	90.	96.	96.		db
Channels	4.	4.	4.	4.	
Date Rate:					
Video	17.47	17.2	17.73	17.	Mb/s
Audio	503.	500.	512.	500.	Kb/s
Control Data	126.	40.	40.	126.	Kb/s
Auxiliary	126.	600.	256.	126.	Kb/s
Sync	n/a	580.	n/a	n/a	Kb/s
* Total Data	18.22	21.52	24.00	19.	Mb/s
Error Correction	6.17	2.5	4.96	3.	Mb/s
Terrestrial:					
* RF Modulation	16/32 QAM	4 VSB	SS-QAM	16/32 QAM	
3 db Bandwidth	4.88	5.38	5.2	4.88	MHz
C/N Threshold	19.	18.	16.1	19.	db
Channel Equalization	-2-24	-2-20		-2-24	μs
Satellite:					
RF Modulation	QPSK	MSK	QPSK		
3 db Bandwidth	24 /2	20 /1	36 /3		MHz
C/N Threshold	8.	8.	8.		db

COHRS Agenda

The loosely organized ad hoc Committee on High Resolution Systems (COHRS) has been extremely successful in establishing the new agenda for HDTV.

- **merger of television, communications, and computing**

  In other words, interactive information services. None of the proponents bring this to the full extent. Though, all are positioning themselves as compliant to some extent

- **all digital systems** – now, a done deal – not sufficient

- **architectural goodness** criteria (etc.):

  - **interoperability** – the optimal sharing of data streams across generation, carrier, and equipment technologies, and services and applications

  - **extensibility** – the ability to incorporate future technological advances in encoding and services without obsoleting then existing components and infrastructure

  - **scalability** – permit encodings whereby uniform generation, transmission, and display characteristics can support a range of product quality and cost

- **interactivity** – realtime broadband communications

- **open access, interoperable communications infrastructure**

COHRS Agenda, cont.

- **header / descriptor** (c.f., SMPTE)

  Proper attention to a self identifying data stream protocol is critical to provide interoperability, extensibility, etc. Key here is accommodating a variety of data stream encodings to permit adjusting signal characteristics to meet application needs (i.e., a computer network presentation level protocol)

- **cross application system parameters**

  - **square pixels** (as opposed to rectangular pixels)

    Best for computer generated images. AT&T/Zenith and MIT have square pixels. Sarnoff has both rectangular and square pixel formats. GI has rectangular pixels. It is generally agreed to go with square pixels

  - **progressive scan** (as opposed to interlace scan)

    Ten/fifteen years ago, computer displays started out with interlace scan, but quickly found it to be inadequate. Now all computer displays are progressive scan. AT&T/Zenith and MIT are progressive. Sarnoff has both interlace and progressive formats. GI is interlace. This is still a debate

  - **source flexibility**, compliance with film, >60 Hz refresh

Communications Issues

- Relationship of HRS/HDTV to network protocols
  - layered protocols
  - separation of content (video, audio, text, etc.) and transport method (RF, cable, fiber, etc.)
  - interoperability among communication media
  - interoperability among applications

- Synchronous and asynchronous higher level protocols
  - **minimum services guarantees**, managing and negotiating transport characteristics
    - packet size
    - effective bandwidth (allocation method)
    - completion rendezvous
    - error protection robustness
    - explicit sequencing and timing; etc.
  - **negotiated graceful degradation**
    - image quality
    - image resolution
    - image size
    - update rate
    - service cost; etc.

- Connectionless and connection oriented protocol implications
  - broadcast
  - "one-way interactive", e.g., pay-per-view
  - interactive

Communications Issues, cont.

- Packet content elements and alternative organizations

- Inter-packet synchronization – a logically single transmission can consist of multiple related data streams – various applications will require alternative packet organizations

  - some with continuous realtime content (e.g., multiple video and audio data streams, closed captioning, timecode)
  - some with data attribute content (e.g., resolution, frame rate, colorimetry, compression parameters and algorithms)
  - some with periodic content (e.g., program notes, cataloging information, copyright information)
  - as well as some with connection management information.

- Multiplexing audio and video data streams important to enhance editability

  - interleaving the audio/video streams that allows fast access to different parts of a video or audio sequence
  - audio mixing and video compositing

- Implications of a peer-to-peer client/server architecture (as opposed to master/slave)

  - service benefits (e.g., applicability, cost efficiency, performance efficiency, etc.)
  - stateless or state oriented attributes and parameters of the data stream(s)

Discussion Topics

- Digital CATV as an interim step to fiber to the curb and fiber to the home and as a municipal LAN (~MAN)
- Sonet / ATM as a universal network access protocol
- Other communications methods, e.g., orthogonal frequency division multiplexing, spread spectrum, mini-cellular radio,...
- etc.

From: • DECPRL::DECPRL::BAUDELAIRE "Patrick Baudelaire" 17-JAN-1992 08:41:37.46
To: europe::horner, rdvax::fuller
CC: rdvax::deluca, decsrc::taylor, crl::victor, decwrl::swan, rdvax::gannon, rdvax::bonney, rdvax::person, rdvax::berard, decprl::baudelaire
Subj: European research investment options: ORL vs. ECRC

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DIGITAL CONFIDENTIAL
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Date: January 17, 1992
From: Patrick Baudelaire
To: Mike Horner, Sam Fuller, CRA staff
Subject: European research investment options: ORL vs. ECRC

These are my conclusions regarding the invitation extended to Digital to join the European Computer-Industry Research Center (ECRC) consortium, following CRA staff discussions and a visit to Munich by Mike Horner and I on November 5, 1991.

This is, embarrassingly, a rather late response. On the other hand, since this is the start of FY93 budget planning, it allows me to fold into my analysis some considerations on CRA's funding constraints. In particular, it seems clear that any new outside research investment by Digital in Europe would have to be weighted against the option of increasing its funding share in the Olivetti laboratory (ORL) in Cambridge, England.

The visit to ERCR was certainly useful and instructive to me. Our host were friendly and open. I was pleased to meet Gerard Comyn (Managing Director) and the senior ECRC researchers, and get acquainted with the place. I believe I got a good sense of the style of the lab and its research agenda. The afternoon demos were instructive. By and large, my impressions confirmed opinions expressed by CRA researchers Luca Cardelli (SRC) and Hassan Ait-Kaci (PRL) -- see the excerpt from a 1989 trip report by Hassan in the Appendix.

From CRA's perspective, ECRC's past emphasis on knowledge-based and symbolic processing research (see Appendix) was not very attractive. Following the departure in 1990 of Herve Gallaire (ECRC Managing Director since its foundation in 1984) and some of the key staff in logic programming, and perhaps under other influences as well, the lab has shifted its direction to include graphics, interactive computing, parallel and distributed systems. This is fine, but ECRC has no momentum yet in those areas: the project leaders are newcomers; they sounded like reasonable people but they don't have exceptional track records. In fact, one project in this area, which is carrying over from the previous period, the TUBE user interface toolbox, is plain obsolete--and they didn't seem to be aware of it!

I think ERCR's main claim for recognition is the CHIP Constraint Logic Programming system. I believe it is acknowledged as a major contribution in the domain, its uniqueness being its special techniques for controlling search in the solution space. I saw an application demo of the system (with a graphical interface) which I found quite impressive. However, most of the talent behind the CHIP system has left ECRC to form the COSYTEC start-up. (It turns out that PRL is discussing with a key implementor of the CHIP compiler for a research position with the Paradise project. This is in fact the most effective way for Digital to benefit from the CHIP technology...)

I will not dwell on the remaining projects, past or current, such as the KCM Prolog machine, the EKS deductive data base system, and the ElipSys parallel logic programming system. I don't think that they stand out as exceptional, and, again, their knowledge-based emphasis is not of prime interest to Digital.

I will add one comment on the operating style of ECRC which I see as a negative point. It is organized in a management hierarchy with an organizational partitioning of project areas reflected even in the facilities layout. You can see the results, for instance, in how many (too many) different Prolog-style languages have been developed in the various groups. This is quite in contrast to the operating principles of CRA research labs which are basically flat organizations: project boundaries don't become explicit structural walls that hinder the sharing of results and the osmosis of ideas.

In summary, making an overall judgment on ECRC based on its track record, its research staff reputation, its research agenda, and its operating style, and adding to that the intrinsic complexity of a multivendor consortium, the ECRC invitation is not a very interesting research investment for CRA.

By contrast ORL is a much better research opportunity which I will just summarize in a few points:

- Track record of Andy Hopper and ORL staff in computer and communication systems engineering.
- Close links with an academic center of excellence, the Cambridge University Computer Lab (Pr Roger Needham).
- Good match with Digital's technical priorities in systems and application areas.
- Good on-going connections with CRA and WorkSystems Engineering.

It is clear that ECRC has a very strong involvement with the EEC. More than 20% of its funding in 1990 and 1991 has come from ESPRIT. Participation to ECRC would certainly have good geo-political value for Digital in Europe. But more collaboration with Olivetti around ORL might also have equivalent value from Brussels' viewpoint.

So my recommendations are as follows:

- The best investment opportunity in collaborative research in Europe today is ORL rather than ECRC.

- The current funding split (20% paid by Digital) leaves ORL in a precarious position given Olivetti's unclear research policy. Sustaining ORL may require an increase of Digital's contribution.

- Under the foreseen engineering and research budget constraints of coming years, CRA will be hard-pressed to grow its ORL funding share.

- If Digital Europe wishes to strengthen its European "citizenship" by a collaborative European investment in research, ORL is, on technical grounds, a better choice than ECRC. Perhaps an equally good one on political grounds.

PB--17/1/92

APPENDIX: Excerpt form ECRC trip report, Hassan Ait-Kaci, July 1989.

ECRC is pushing four lines of research: (1) logic programming technology and extensions, (2) knowledge bases and expert systems, (3) sequential and parallel hardware for logic programming, and (4) human interface and graphics tools. Their most interesting achievements have been (a) the realization and construction of the fastest prolog machine (KCM) yet built [4 megalips] and the design and software emulation (on a parallel machine) of a hardware prototype of an or-parallel prolog machine, and (b) the design and implementation of a constraint logic programming language (CHIP = Constraint Handling In Prolog). I spent time with the latter group headed by Mehmet Dincbas(*). I knew of their system, of course, but was nonetheless impressed by the demos which are extremely polished and varied as they attacked, and elegantly and efficiently solved difficult (NP-hard or -complete) real-life problems (warehouse location, job scheduling, VLSI hardware verification, large assignment problems, etc...). Essentially, they have specialized prolog to deal with three classes of constraints: (1) rational linear equations, disequations, and inequations; (2) finite domains; and (3) boolean constraints. They also have devised appropriate general strategies for dealing with the classes of problems that are subject to these types of constraints.

(*) M. Dincbas is now with COSYTEC.

% ====== Internet headers and postmarks (see DECWRL::GATEWAY.DOC) ======
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% Message-Id: <9201171328.AA13537@perle.prl.dec.com>
% From: Patrick Baudelaire <decprl::baudelaire>
% Date: Fri, 17 Jan 92 14:28:22 +0100
% To: europe::horner, rdvax::fuller
% Cc: rdvax::deluca, decsrc::taylor, crl::victor, decwrl::swan, rdvax::gannon, rdvax::bonney, rdvax::person, rdvax::berard, decprl::baudelair
% Subject: European research investment options: ORL vs. ECRC