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Experts Group for ATM Video Coding

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COSMIC

ALGORITHM PROPOSAL

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COSMIC

CONTENTS

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1. Introduction

A Compatible Scheme for Moving Image Coding (COSMIC) is a layered coding scheme used to achieve compatibility between MPEG-1/H.261 and MPEG-2/H.26x. The major emphasis of this proposal is to demonstrate that compatibility can be achieved using a layered technique. It may be that the coding in the second layer described here is not the most effiicient. However it would not be difficult to substitute a more efficient DCT based coding scheme into the second layer.

Significant amounts of the coding in the second layer are identical to that of MPEG-1 and/or H.261 this is denoted throughout the algorithm description as follows:

* same as MPEG-1
** same as H.261.

This allows the use of common hardware for such parts.

The remainder of this section describes the concept of layered coding, an encoder/decoder description and the benefits that the coding offers .

1.1. Compatability

It is desirable that MPEG-2 /H.26x should be fully compatible with MPEG-1 /H.261. Full compatiblity will allow service providers and manufacturers an easier entry into the market reaching a larger number of consumers more rapidly. It also has the benefit to consumers and manufacturers that their investment in decoding equipment and software is protected, and allows manufacturers to develop a range of different products with different performances that will all work with the same coding material.

There are different degrees of compatibility. These are forward, backward, upward and downward compatibility. A fully compatible sytem will fulfil all four types of compatibility completely. Forward and backward compatibility refer to the bitstream. Upward and downward compatibility refer to the picture formats.

To ensure full compatibility the MPEG-2/H.26x bitstream needs to include a MPEG-1/H.261 bitstream. This can be done by including a MPEG-1/H.261 encoder in the MPEG-2/H.26x scheme. This is outlined in the following section.

1.2. Overview

The approach adopted is a layered coding scheme, that is, the resulting bitstream contains an embedded MPEG-1/H.261 bitstream. The outline block diagram of figure 1 shows the encoder and decoder. The compatibility is achieved by incorporating the MPEG-1/H.261 pictures as one of the prediction modes.

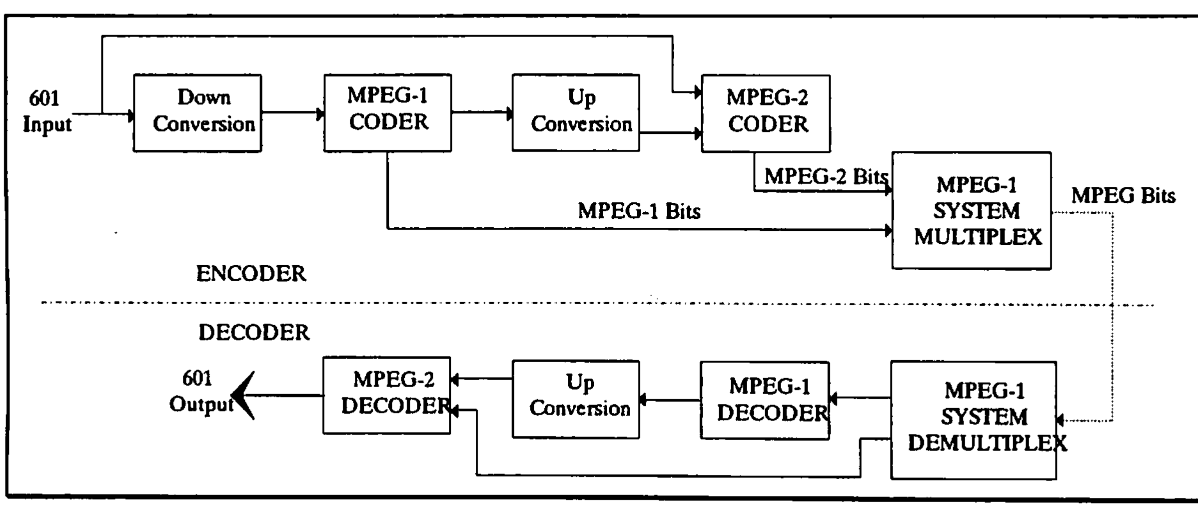


Figure 1. Block diagram of encoder and decoder.

The MPEG-1/H.261 bitstream is derived in the normal way by down-sampling the CCIR601 resolution input pictures to SIF/CIF resolution pictures. This is termed a "pel split". These are coded using the MPEG-1/H.261 algorithm and a bitstream is generated.

The coded SIF/CIF pictures from the MPEG-1/H.261 layer are up-sampled to CCIR601 resolution. These pictures form one of the prediction modes for coding the input pictures. These pictures are coded and the resulting bitstream is multiplexed with the MPEG-1/H.261 bitstream using the MPEG System multiplex to form the complete bitstream.

1.3. Benefits

The scheme offers the following benefits:

1.3.1. Forward compatibility

The MPEG-2 /H.26x)decoder can decode pictures from MPEG-1 /H.261)encoded bitstreams.

1.3.2. Backward compatibility

The MPEG-1 /H.261 decoder can decode pictures from part of the bitstream of a MPEG-2 /H.26x)encoder.

1.3.3. Scalability in resolution
A low and high resolution picture is available at the decoder.

1.3.4. Differing aspect ratios
The input picture could be of 16 by 9 aspect ratio. The SIF/CIF windows this to 4 by 3 and down converts it. The upconverted prediction picture is only 4 by 3. The side windows are set to mid-grey.
The second layer would then code the full 16 by 9 aspect ratio.

1.3.5. Cell loss resilience
Two-layer coding for ATM networks is known to provide high cell loss resilience. The base layer is transmitted using high priority cells. The second layer is transmitted using low priority cells. For those cells in the second layer that do not reach the decoder the base picture is used to conceal the corrupted parts of the picture.

1.3.6. Flexibility in products
Manufacturers can provide a range of products from low cost to high cost. A layered coding technique provides the most viable solution for those equipment manufacturers wishing to provide decoders capable of decoding both MPEG-1/MPEG-2 or H.261/H.26x bitstreams (simulcasting requires separate decoders probably unable to share common features).

1.3.7. VLSI chip sets
One VLSI chip set has the capability of covering both MPEG-1 and MPEG-2 applications. This provides VLSI manufacturers with potentially larger volumes of sales and hence cheaper chip sets. Equipment manufacturers are able to develop a range of products from the same chip set. It is also easier and cheaper to get circuitry for both MPEG-1/H.261 and MPEG-2/H.26x on to one board eg. in PCs.

1.3.8. Non-compatible coding
It is possible for the algorithm to work in a non-compatible mode. To achieve this the MPEG-1 prediction mode in the enhancement layer can be switched off at the encoder.

2. Algorithm description

The encoding/decoding algorithm will now be described.

2.1. Symbols and abbreviations

The mathematical operators used to describe this algorithm are defined in this section.

=	Assignment operator.
+	Addition.
-	Subtraction.
*	Multiplication.
/	Integer division with truncation of the result toward zero. For example, 7/4 and -7/-4 are equal to 1 and -7/4 and 7/-4 are equal to -1.
//	Integer division with rounding to the nearest integer. Half integer values are rounded away from zero unless otherwise specified. For example, 3//2 is 2, and -3//2 is -2.
>	Greater than.
> =	Greater than or equal to.
<	Less than.
< =	Less than or equal to.
=	Equal.
> >	Shift right with sign extension.
< <	Shift left with zero fill.

2.2. MPEG-1

2.2.1. Down-sampling

The CCIR601 interlaced pictures are down-sampled to 25Hz SIF progressive pictures. This procedure is not defined. The procedure used for coding sequences for the November MPEG tests is described in section 2.1.1.

2.2.2. MPEG-1 Coding

The 25Hz SIF progressive pictures are coded according to the MPEG-1 algorithm. The procedure is not defined here. The procedure used for coding sequences for the November MPEG tests is described in section 2.1.2.

2.2.3. Up-sampling

The SIF progressive pictures are up-sampled to 50Hz CCIR601 interlaced frames by the procedure described below. Note. It is only necessary to follow this procedure to form the prediction for enhancement coding and decoding; it is not necessary to follow this procedure to display MPEG-1 pictures.

a) Pictures are repeated to obtain 50Hz pictures.

b) The interlace is re-introduced by vertically shifting luminance lines +/- 1/4 line and chrominance lines +/- 1/8 and +/- 3/8 line. A five tap interpolator is used. Each tap is represented by an eight bit signed integer. Full precision is retained throughout the calculation. The luminance taps are as follows:

9	-28	231	59	-15	//256

The chrominance +/- 1/8 taps are as follows:

-7	25	249	-17	6	//256

The chrominance +/- 3/8 taps are as follows:

11	-33	198	104	-24	//256

In all cases the order of taps is reversed in order to shift in the opposite direction.

c) Horizontal pels are interpolated to increase the number of pels from 352 to 704. A eight tap interpolator is used. Each tap is represented by an eight bit signed integer. Full precision is retained throughout the calculation. The taps to interpolate luminance pels in the 1/4, 3/4 positions are as follows:

-9	20	-43	233	76	-28	14	-6	//256

The taps to interpolate chrominance pels in the 3/8, 5/8 positions are as follows:

-8	19	-41	120	205	-51	23	-11	//256

The taps to interpolate chrominance pels in the 1/8, 7/8 positions are as follows:

2	-5	11	-26	248	34	-14	6	//256

In all cases the order of the taps is reversed to interpolate the other pel.

d) The interlaced fields are split into blocks of 8 pels and 4 lines. The mean and variance of the pels in each block are evaluated. The variance of each block is compared with a threshold, and if less than the threshold, all pels are set to the mean value, otherwise are left unchanged. For luminance blocks the threshold is 120; for chrominance blocks it is 30.

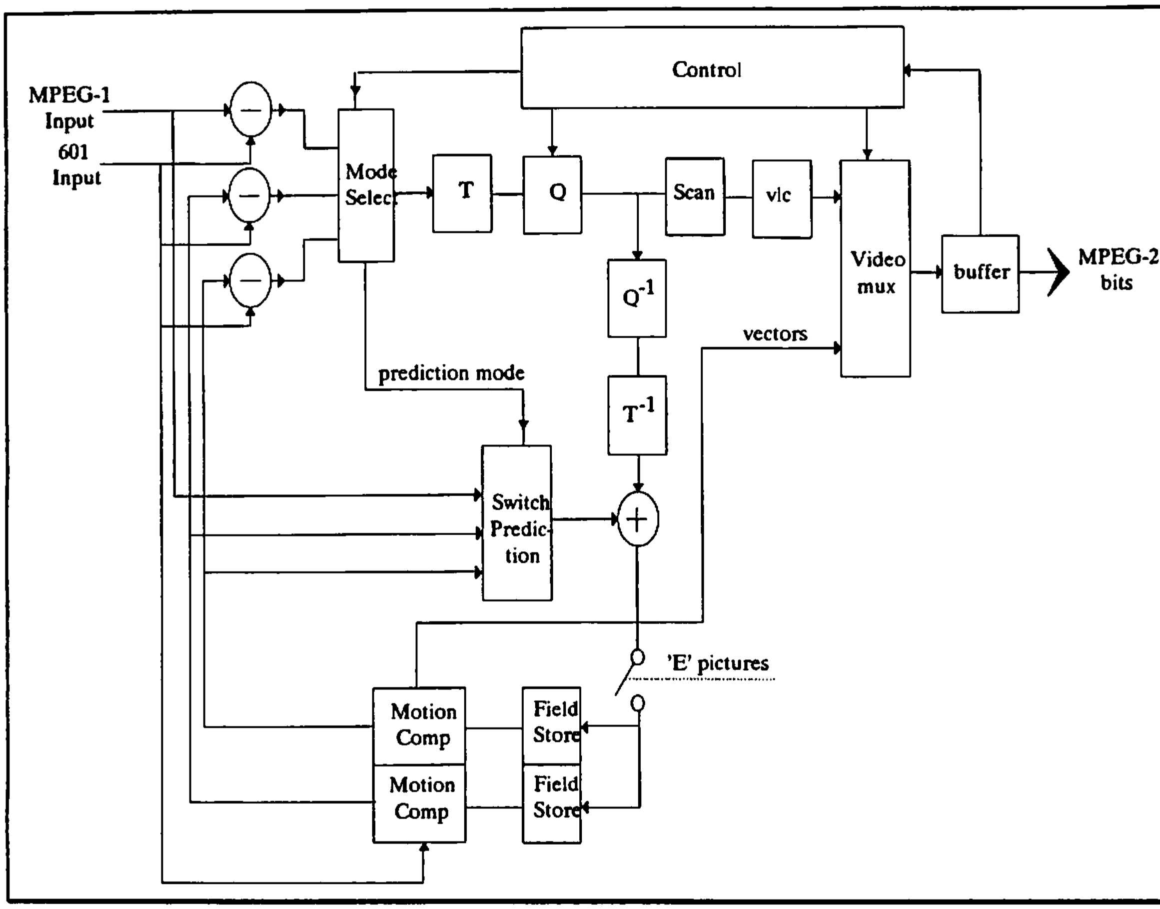


Figure 2. Enhancement encoder

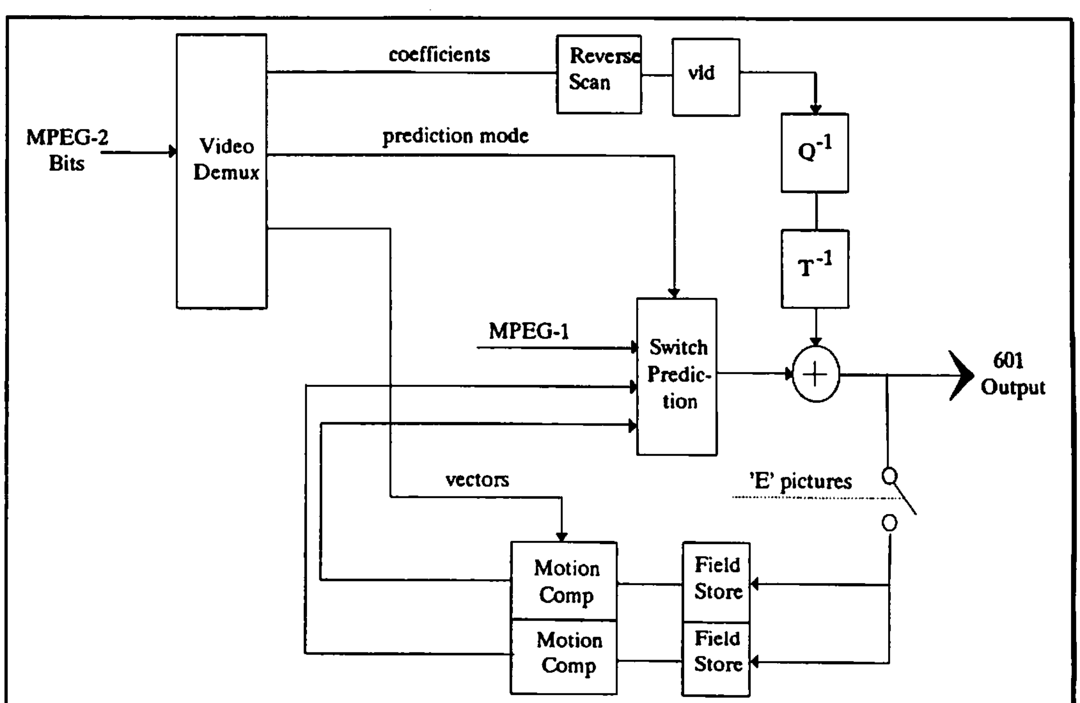


Figure 3. Enhancement decoder

2.3. Enhancement

Block diagrams of the enhancement encoder and decoder outlining the essential features are shown in figures 2 and 3.

2.3.1. Source format

The source coder operates on interlaced fields occurring at 50Hz. The fields are coded as luminance and two colour difference components (Y, Cb and Cr). These components and the codes representing their sampled values are as defined in CCIR Recommendation 601.

Black = 16
White = 235
Zero colour difference = 128
Peak colour difference = 16 and 240

These values are nominal and the coding algorithm functions with input values of 0 to 255** *.

The luminance sampling structure is 288 lines per field (576 lines per frame), 720 pels per line in an orthogonal arrangement. Sampling of each of the two colour difference components is at 144 lines per field, 360 pels per line, orthogonal; that is, 4:2:0, the chrominance is sub-sampled vertically from 4:2:2.

The source input frame is windowed to give 704 luminance pels per line and 352 colour difference pels per line. This is done by ignoring the first and last 8 luminance pels and the first and last 4 colour difference pels.

2.3.2. Source coding algorithm

The main elements of the video coding algorithm are prediction, block transformation and quantization.

The prediction mode is chosen and the prediction error is sub-divided into 8 pel by 8 line blocks which are segmented as coded or non-coded. The criteria for choice of mode and encoding a block are not defined and may be varied dynamically as part of the data rate control strategy. Encoded blocks are transformed and resulting coefficients are quantized and variable length coded.

2.3.2.1. Field coding type

Fields can be coded as intra, predicted or extrapolated fields. This coding algorithm places no restriction on the choice of field coding type for any given field. However, for coding sequences for the November MPEG tests, a repeating pattern of field types was chosen. This is described in section 2.2.1.

2.3.2.2. Prediction

The possible prediction modes for a field depend on the field coding type and the field coding type of the previously coded field. They are as follows:

Intra fields
- from the up-sampled MPEG-1 coded field

Predicted and extrapolated fields
- from the up-sampled MPEG-1 coded field
- from the previously coded intra or predicted field
- from the previously coded intra or predicted field of the same parity, provided that the previously coded field was not intra coded.

Note. Extrapolated fields are never used for prediction.

2.3.2.3. Motion Compensation*

The decoder will accept one vector per macroblock. When a non-zero macroblock motion vector is present, it specifies, as an offset, the area of the prediction field to be used for prediction.

Luminance integer pel motion vector components, int_right and int_down, and half pel offsets, half_right and half_down are given in terms of the decoded vector components , vec_right and vec_down, by:

```
int_right = vec_right >> 1          half_right = vec_right - 2*int_right
int_down = vec_down >> 1            half_down = vec_down - 2*int_down
```

Chrominance integer pel motion vector components, int_right and int_down, and half pel offsets, half_right and half_down, are given in terms of the decoded vector components, vec_right and vec_down, by:

```
int_right = (vec_right / 2) >> 1    half_right = (vec_right / 2) - 2*int_right
int_down = (vec_down / 2) >> 1      half_down = (vec_down / 2) - 2*int_down
```

Defining pel_pred[][] as pels of the prediction field and pel[][] as the pels of the picture being decoded, the prediction for pel[i][j] is:

```
( pel_pred[i+int_down][j+int_right] + pel_pred[i+int_down+half_down][j+int_right] +
  pel_pred[i+int_down][j+int_right+half_right] + pel_pred[i+int_down+half_down][j+int_right+half_right] ) // 4
```

Note. A positive value of horizontal and vertical component of the motion vector signifies that the prediction is formed from pels in the prediction field which are spatially to the right of or below the pels being predicted.

Motion vectors are restricted such that all pels referenced by them are within the coded picture area.

2.3.2.4. Transform** *

Blocks are coded with a separable 2-dimensional Discrete Cosine Transform (DCT) of size 8 by 8. The input to the forward transform and output from the inverse transform have 9 bits. The transfer function of the inverse transform is given by:

$$f_{(x,y)} = \frac{1}{4} \sum_{u=0}^{7} \sum_{v=0}^{7} C_{(u)} \cdot C_{(v)} \cdot F_{(u,v)} \cdot \cos \frac{pi(2x+1)u}{16} \cdot \cos \frac{pi(2y+1)v}{16}$$

with u, v, x, y = 0, 1, 2 7

where x, y = spatial coordinates in the pixel domain;
u, v = coordinates in the transform domain;

$C_{(u)} = \frac{1}{\sqrt{2}}$ for u = 0; $C_{(u)}$ = 1 otherwise;

$C_{(v)} = \frac{1}{\sqrt{2}}$ for v = 0; $C_{(v)}$ = 1 otherwise.

Note: within the block being transformed, x=0 and y=0 refer to the pel nearest the left and top edges of the field respectively.

The arithmetic procedures for computing the transforms are not defined, but the inverse one should meet the error tolerance specified in CCITT Recommendation H.261, Annex 1, 'Inverse Transform Accuracy Specification'.

2.3.2.5. Quantization ** *

The number of quantizers is 31. Their characteristics are not defined. The procedure used for coding sequences for the November MPEG tests is described in section 2.2.4. The decoder reconstruction process is defined below.

$$RX_{(i,j)} = (2 * QX_{(i,j)} * W_{(i,j)} * QI) / 16$$

```
IF (RX even)
{
 IF (RX > 0)  RX = RX - 1
 IF (RX < 0)  RX = RX + 1
}
```

where $QX_{(i,j)}$ is the encoded level;
$W_{(i,j)}$ is the entry in the weighting matrix;
$RX_{(i,j)}$ is the reconstructed level;
QI is the encoded quantizer index.

The reconstruction levels are clipped to within the range -2048 to +2047.

The weighting matrix, W[][] is given in figure 4.

increasing cycles per picture width ——>

16	16	18	20	23	23	24	27
16	16	20	21	23	24	27	29
18	20	21	23	24	27	27	29
20	20	23	23	24	27	29	30
20	23	23	24	26	28	30	34
23	23	24	26	28	30	34	39
23	23	24	27	29	33	38	45
23	24	28	29	33	38	45	51

Figure 4. Quantization weighting matrix.

2.3.2.6. Clipping of reconstructed picture** *

To prevent quantization distortion of transform coefficient amplitudes causing arithmetic overflow in the encoder and decoder loops, clipping functions are inserted. The clipping function is applied to the reconstructed picture which is formed by summing the prediction and the prediction error as modified by the coding process. This clipper operates on the resulting pel values less than 0 or greater than 255, changing them to 0 and 255 respectively.

2.3.3. Video multiplex coder

The function of the video multiplex is to assemble the various data produced by the source coder into one serial stream and in such a manner that a decoder is able to separate these data for the reconstruction of images.

2.3.3.1. Data structure

Unless specified otherwise, the most significant bit is encoded first. This is bit 1 and is the leftmost bit in the code tables given in this document.

2.3.3.2. Video multiplex arrangement

The video multiplex is arranged in a hierarchical structure with four layers. From top to bottom the layers are:

Field
Slice
Macroblock
Block

2.3.3.3. Field layer

Data for each field consists of a field header followed by data for one or more slices. The field header is shown below.

<FSC ><TREF ><FIELD>< FTYPE ><VBV DELAY><HALF PEL><VECTOR TABLE><EFB><FSPARE>

2.3.3.3.1. Field start code (FSC 32 bits)*

The field start code is the bit string '0000 0000 0000 0000 0000 0001 0000 0000'.

2.3.3.3.2. Temporal reference (TREF 10 bits)*

The temporal reference is a number associated with each input frame. It is incremented by one for each input frame.

2.3.3.3.3. Field parity (FIELD 1 bit)

This indicates the field parity. Zero indicates an odd field, one indicates an even field.

2.3.3.3.4. Field type (FTYPE 3 bits)

The field type indicates whether a field is intra-coded (I), predictive coded (P) or extrapolated (E) according to the following table.

FTYPE	Coding Method
000	Reserved
001	intra coded (I)
010	predictive coded (P)
011	extrapolated (E)
100	Reserved
101	Reserved
110	Reserved
111	Reserved

2.3.3.3.5. VBV delay (VBV DELAY 16 bits)*

The VBV delay indicates the time for which the VBV buffer should be filled from an empty state, at the video bit rate, to the correct level immediately before the current field is removed from the buffer. VBV delay is coded as a 16 bit unsigned integer measuring this delay in periods of a 90KHz clock.

2.3.3.3.6. Half pel (HP 1 bit)*

If set to '1', then the motion vector values decoded from the tables 5, 6 and 7 are multiplied by 2 before they are used . It is used to indicate the resolution of motion vectors, 1 = integer pel vectors, 0 = half pel vectors.

2.3.3.3.7. Vector table (VECTOR TABLE 3 bits)*

An unsigned integer indicating which of the tables 5, 6 and 7 should be used for decoding the motion vectors in the frame according to the following table.

VECTOR TABLE	Motion Vector Table
000	Reserved
001	Table 5
010	Table 6
011	Reserved
100	Table 7
101	Reserved
110	Reserved
111	Reserved

2.3.3.3.8. Extra field bit (EFB1 bit)*

EFB is a bit which when set to 1 signals the presence of the following optional data field.

2.3.3.3.9. Spare information (FSPARE1 bit)*

If EFB is set to 1, then 9 bits follow consisting of 8 bits of data (FSPARE) and another EFB bit to indicate if a further 9 bits follow and so on. FSPARE is reserved for future use and so should not be inserted by encoders.

2.3.3.4. Slice layer
Data for a slice consists of a slice header followed by data for one or more macroblocks from the same field. The slice header is shown below.

< SSC > < SVP > < SQUANT > <ESB> <SSPARE>

2.3.3.4.1. Slice start code (SSC 24 bits)*
The slice start code is the bit string '0000 0000 0000 0000 0000 0001'.

2.3.3.4.2. Slice vertical position (SVP 8 bits)*
This is an unsigned integer giving the vertical position in macroblock units of the first macroblock in the slice. The slice vertical position of the first row of macroblocks is one. The maximum value of slice vertical position is 175.

2.3.3.4.3. Slice quantizer (SQUANT 5 bits)** *
This is an unsigned integer in the range 1 to 31 which indicates the quantizer to be used in the slice until overridden by any subsequent MQUANT.

2.3.3.4.4. Extra slice bit (ESB1 bit)
ESB is a bit which when set to 1 signals the presence of the following optional data field.

2.3.3.4.5. Spare information (SSPARE 1 bit)
If ESB is set to 1, then 9 bits follow consisting of 8 bits of data (SSPARE) and another ESB bit to indicate if a further 9 bits follow and so on. SSPARE is reserved for future use and so should not be inserted by encoders.

2.3.3.5. Macroblock layer** *
A macroblock relates to 16 pels by 16 lines of Y and the spatially corresponding 8 pels by 8 lines of each of Cr and Cb. Data for a macroblock consists of a macroblock header followed by data for blocks. The macroblock header is shown below.

<MBA> <MTYPE> <MQUANT> <MVD> <CBP>

2.3.3.5.1. Macroblock address (MBA)** *
This is a variable length codeword indicating the position of a macroblock within a frame. It is coded as in table 1. The maximum value of MBA for which there is a codeword is 33. Values greater than 33 are encoded using the macroblock escape codeword. The MBA is preceded by zero or more escape codewords. The MBA is given by the encoded value plus 33 for each occurrence of the escape codeword. An example is given below.

MBA 41 is coded as <ESC> <8> (33 + 8).

Macroblocks are numbered in raster scan order. The macroblock in the top left corner of the is numbered zero. The macroblock position is given as the sum of the previous macroblock position and the MBA.

At the start of a slice the previous macroblock position is set to (SVP-1)*width - 1, where SVP is the slice vertical position in the slice header and width is the number of macroblocks across the field.

2.3.3.5.2. Macroblock type (MTYPE)
This gives information about the macroblock and which data elements are present. Macroblock type codes and included elements are listed in tables 2, 3 and 4.

2.3.3.5.3. Macroblock quantizer (MQUANT 5bits)** *
MQUANT is present only if so indicated by MTYPE.

It is a codeword of 5 bits signifying the quantizer to be used for this and any following macroblocks in the slice until overridden by any subsequent MQUANT.

Codewords for MQUANT are the same as those for SQUANT.

2.3.3.5.4. Motion vector data (MVD)** *
Motion vector data is included only if so indicated by MTYPE.

The macroblock motion vector is obtained by adding the MVD to the motion vector of the preceding macroblock. For this calculation, the vector of the preceding macroblock is regarded as zero in the following three situations.

a) Evaluating for the first macroblock in the slice.
b) Evaluating for macroblocks in which MBA does not represent a difference of 1.
c) If MTYPE of the previous macroblock did not indicate the presence of MVD.

MVD consists of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component. Variable length codes are given in tables 5, 6 and 7; the table to use is indicated by VECTOR TABLE in the field header.

Advantage is taken of the fact that the range of motion vector values is constrained. Each VLC word represents a pair of difference values. Only one of the pair will yield a macroblock vector falling within the permitted range. The permitted range depends on the table used; it is listed in tables 5, 6 and 7.

2.3.3.5.5. Coded block pattern (CPB)** *

CBP is present only if so indicated by MTYPE. The codeword gives a pattern number signifying those blocks in the macroblock for which at least one transform coefficient is present. The pattern number is given by:

$$32{*}P_1 + 16{*}P_2 + 8{*}P_3 + 4{*}P_4 + 2{*}P_5 + 1{*}P_6$$

where P_n is 1 if any coefficient is present for block n, else 0. Block numbering is shown in figure 5. Variable length codes are given in table 8. Note, it is possible to indicate values of CBP equal to 0 and 63 by use of MTYPE only, as shown in tables 2, 3 and 4.

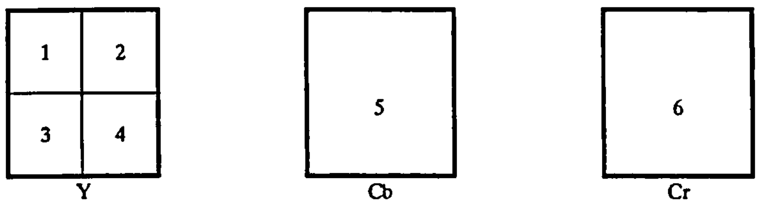


Figure 5. Arrangement of blocks in a macroblock.

2.3.3.6. Block Layer (** * VLC tables are the same)

A macroblock comprises four luminance blocks and one of each of the two colour difference blocks as shown in figure 5.

The order of blocks is as in figure 8. Data for a block consists of codewords for transform coefficients followed by an end of block marker.

Transform coefficient data is present when so indicated by MTYPE or CBP. The quantized transform coefficients are sequentially encoded according to the sequence given in figure 6.

The most commonly occurring combinations of successive zeros (RUN) and the following value (LEVEL) are encoded with variable length codes. Other combinations of (RUN,LEVEL) are encoded with an escape code followed by codes for RUN and LEVEL. For the variable length encoding there are two code tables, one being used for the first encoded LEVEL, the second being used for all others. The codes are given in table 9.

0	8	16	24	32	40	48	56
1	9	17	25	33	41	49	57
2	10	18	26	34	42	50	58
3	11	19	27	35	43	51	59
4	12	20	28	36	44	52	60
5	13	21	29	37	45	53	61
6	14	22	30	38	46	54	62
7	15	23	31	39	47	55	63

Figure 6. Scanning order for coefficients in a block.

2.3.4. Data rate control and buffering

The coding kernel inherently produces coded data at a non-constant rate which depends on the pictures to be coded. The long term average rate is controlled by alteration of coding parameters. Buffering is adopted to smooth the remaining short term variations to give a constant rate output.

Sections where parameters which may be varied to control the rate of generation of coded video data include processing prior to the source coder, the quantizer, block significance criterion and temporal sub-sampling. The proportions of such measures in the overall control strategy are not defined. However, the control strategy for coding sequences for the November MPEG tests is described in section 2.2.5.

The encoder must control its output bitstream to comply with the requirements of the Video Buffering Verifier.

The Video Buffering Verifier (VBV) is defined as follows:

1. The VBV and the video encoder have the same clock frequency as well as the same picture rate, and are operated synchronously.
2. The VBV has a receiving buffer size B, given by B = R/10, where R is the bit rate allocated to the MPEG-2 video bitstream.
3. The VBV is initially empty. It is filled from the bitstream for the time specified by the vbv_delay field in the video bitstream.
4. All of the data for the field which has been in the buffer longest is instantaneously removed. Then after each subsequent field interval all of the data for the field which (at that time) has been in the buffer longest is instantaneously removed. The VBV is examined immediately before and immediately after each field is removed. Each time the VBV is examined its occupancy shall lie between zero bits and B bits.

This is a requirement on the video bitstream.

2.4. System Multiplex

The complete bitstream is created by multiplexing the MPEG-1 video bitstream with the enhancement video bitstream using the MPEG-1 System multiplex. The procedure is not defined. The procedure used for coding sequences for the November MPEG tests is described in section 2.3.

Start codes in the range 1110 0000 to 1110 1111 are allocated to video bitstreams. Codes 1110 0xxx are allocated to MPEG-1 video bitstreams and codes 1110 1xxx to enhancement video streams. The MPEG-1 video bitstream to be used when decoding a enhancement video bitstream has the same value of xxx as that stream.

2.5. Variable length code tables

MBA	CODE	MBA	CODE
1	1	19	0000 0101 00
2	011	20	0000 0100 11
3	010	21	0000 0100 10
4	0011	22	0000 0100 011
5	0010	23	0000 0100 010
6	0001 1	24	0000 0100 001
7	0001 0	25	0000 0100 000
8	0000 111	26	0000 0011 111
9	0000 110	27	0000 0011 110
10	0000 1011	28	0000 0011 101
11	0000 1010	29	0000 0011 100
12	0000 1001	30	0000 0011 011
13	0000 1000	31	0000 0011 010
14	0000 0111	32	0000 0011 001
15	0000 0110	33	0000 0011 000
16	0000 0101 11		
17	0000 0101 10	ESCAPE	0000 0001 000
18	0000 0101 01	STUFFING	0000 0001 111

Table 1. VLC table for macro block differential addresses.

CBP	MQUANT	CODE
CBP = 63		1
x		01
CBP = 63	x	001
x	x	0001
CBP = 0		00001

Table 2. VLC table for macro block type in odd fields of intra pictures.

MPEG-1	FIELD	VECTORS	CBP	MQUANT	CODE
x			CBP = 63		01
x			x		10
x			CBP = 63	x	0000001
x			x	x	0000010
x			CBP = 0		0000011
	x	x	x		11
	x	x			001
	x		x		0001
	x		CBP = 0		0000101
	x	x	x	x	0000110
	x		x	x	0000111

Table 3. VLC table for macro block type in even fields of intra pictures.

MPEG-1	FIELD	FRAME	VECTORS	CBP	MQUANT	CODE
x				CBP = 63		001
x				x		110
x				CBP = 63	x	000001
x				x	x	000110
x				CBP = 0		0000001
	x		x	x		010
	x		x			100
	x			x		1110
	x			CBP = 0		000111
	x		x	x	x	000010
	x			x	x	000100
		x	x	x		011
		x	x			101
		x		x		1111
		x		CBP = 0		00000001
		x	x	x	x	000011
		x		x	x	000101

Table 4. VLC table for macro block type in predicted and extrapolated pictures.

Vector	CODE
-16 & 16	0000 0011 001
-15 & 17	0000 0011 011
-14 & 18	0000 0011 101
-13 & 19	0000 0011 111
-12 & 20	0000 0100 001
-11 & 21	0000 0100 011
-10 & 22	0000 0100 11
-9 & 23	0000 0101 01
-8 & 24	0000 0101 11
-7 & 25	0000 0111
-6 & 26	0000 1001
-5 & 27	0000 1011
-4 & 28	0000 111
-3 & 29	0001 1
-2 & 30	0011
-1 & 31	011
0	1
1 & -31	010
2 & -30	0010
3 & -29	0001 0
4 & -28	0000 110
5 & -27	0000 1010
6 & -26	0000 1000
7 & -25	0000 0110
8 & -24	0000 0101 10
9 & -23	0000 0101 00
10 & -22	0000 0100 10
11 & -21	0000 0100 010
12 & -20	0000 0100 000
13 & -19	0000 0011 110
14 & -18	0000 0011 100
15 & -17	0000 0011 010
N/A	0000 0011 000

Table 5. VLC table for motion vectors.
Motion vectors restricted to +/- 15.

Vector, b = 0	Vector, b = 1	CODE
-31 & 33	-32 & 32	0000 0011 001 b
-29 & 35	-30 & 34	0000 0011 011 b
-27 & 37	-28 & 36	0000 0011 101 b
-25 & 39	-26 & 38	0000 0011 111 b
-23 & 41	-24 & 40	0000 0100 001 b
-21 & 43	-22 & 42	0000 0100 011 b
-19 & 45	-20 & 44	0000 0100 11 b
-17 & 47	-18 & 46	0000 0101 01 b
-15 & 49	-16 & 48	0000 0101 11 b
-13 & 51	-14 & 50	0000 0111 b
-11 & 53	-12 & 52	0000 1001 b
-9 & 55	-10 & 54	0000 1011 b
-7 & 57	-8 & 56	0000 111 b
-5 & 59	-6 & 58	0001 1 b
-3 & 61	-4 & 60	0011 b
-1 & 63	-2 & 62	011 b
0		1
1 & -63	2 & -62	010 b
3 & -61	4 & -60	0010 b
5 & -59	6 & -58	0001 0 b
7 & -57	8 & -56	0000 110 b
9 & -55	10 & -54	0000 1010 b
11 & -53	12 & -52	0000 1000 b
13 & -51	14 & -50	0000 0110 b
15 & -49	16 & -48	0000 0101 10 b
17 & -47	18 & -46	0000 0101 00 b
19 & -45	20 & -44	0000 0100 10 b
21 & -43	22 & -42	0000 0100 010 b
23 & -41	24 & -40	0000 0100 000 b
25 & -39	26 & -38	0000 0011 110 b
27 & -37	28 & -36	0000 0011 100 b
29 & -35	30 & -34	0000 0011 010 b
31 & -33	N/A	0000 0011 000 b

Table 6. VLC table for motion vectors.
Motion vectors restricted to +/- 31.

Vector, b = 00	Vector, b = 01	Vector, b = 10	Vector, b = 11	CODE
-61 & 67	-62 & 66	-63 & 65	-64 & 64	0000 0011 001 bb
-57 & 71	-58 & 70	-59 & 69	-60 & 68	0000 0011 011 bb
-53 & 75	-54 & 74	-55 & 73	-56 & 72	0000 0011 101 bb
-49 & 79	-50 & 78	-51 & 77	-52 & 76	0000 0011 111 bb
-45 & 83	-46 & 82	-47 & 81	-48 & 80	0000 0100 001 bb
-41 & 87	-42 & 86	-43 & 85	-44 & 84	0000 0100 011 bb
-37 & 91	-38 & 90	-39 & 89	-40 & 88	0000 0100 11 bb
-33 & 95	-34 & 94	-35 & 93	-36 & 92	0000 0101 01 bb
-29 & 99	-30 & 98	-31 & 97	-32 & 96	0000 0101 11 bb
-25 & 103	-26 & 102	-27 & 101	-28 & 100	0000 0111 bb
-21 & 107	-22 & 106	-23 & 105	-24 & 104	0000 1001 bb
-17 & 111	-18 & 110	-19 & 109	-20 & 108	0000 1011 bb
-13 & 115	-14 & 114	-15 & 113	-16 & 112	0000 111 bb
-9 & 119	-10 & 118	-11 & 117	-12 & 116	0001 1 bb
-5 & 123	-6 & 122	-7 & 121	-8 & 120	0011 bb
-1 & 127	-2 & 126	-3 & 125	-4 & 124	011 bb
0				1
1 & -127	2 & -126	3 & -125	4 & -124	010 bb
5 & -123	6 & -122	7 & -121	8 & -120	0010 bb
9 & -119	10 & -118	11 & -117	12 & -116	0001 0 bb
13 & -115	14 & -114	15 & -113	16 & -112	0000 110 bb
17 & -111	18 & -110	19 & -109	20 & -108	0000 1010 bb
21 & -107	22 & -106	23 & -105	24 & -104	0000 1000 bb
25 & -103	26 & -102	27 & -101	28 & -100	0000 0110 bb
29 & -99	30 & -98	31 & -97	32 & -96	0000 0101 10 bb
33 & -95	34 & -94	35 & -93	36 & -92	0000 0101 00 bb
37 & -91	38 & -90	39 & -89	40 & -88	0000 0100 10 bb
41 & -87	42 & -86	43 & -85	44 & -84	0000 0100 010 bb
45 & -83	46 & -82	47 & -81	48 & -80	0000 0100 000 bb
49 & -79	50 & -78	51 & -77	52 & -76	0000 0011 110 bb
53 & -75	54 & -74	55 & -73	56 & -72	0000 0011 100 bb
57 & -71	58 & -70	59 & -69	60 & -76	0000 0011 010 bb
61 & -67	62 & -66	63 & -65	N/A	0000 0011 000 bb

Table 7. VLC table for motion vectors. Motion vectors restricted to +/- 63.

CBP	CODE	CBP	CODE	CBP	CODE
1	101110100	22	11111011	43	11110101
2	110010110	23	11001111	44	1100
3	11011101110	24	1011111	45	11001110
4	1011	25	111101110	46	111100
5	1011101101	26	1101110101	47	1101100
6	1100101110	27	11001011110	48	11000
7	11111111110	28	1101	49	101110101
8	11110	29	11011011	50	11011010
9	1101110100	30	111110	51	11111010
10	1011101110	31	1100100	52	1000
11	111111111110	32	11101	53	11001010
12	11100	33	1011101111	54	1111100
13	1111110	34	1011101100	55	1011100
14	11111110	35	11001011111	56	1001
15	11011111	36	1011110	57	11011100
16	11010	37	111101111	58	1111110
17	11110110	38	1101110110	59	1100110
18	11110100	39	11011101111	60	100
19	1111111110	40	1110	61	10110
20	1010	41	111111110	62	1010
21	11011110	42	1111111	63	0

Table 8. VLC table for coded block pattern.

RUN	LEVEL	CODE
EOB		10
0	1	1s FIRST LEVEL
0	1	11s OTHERWISE
0	2	0100 s
0	3	0010 1s
0	4	0000 110s
0	5	0010 0110 s
0	6	0010 0001 s
0	7	0000 0010 10s
0	8	0000 0001 1101 s
0	9	0000 0001 1000 s
0	10	0000 0001 0011 s
0	11	0000 0001 0000 s
0	12	0000 0000 1101 0s
0	13	0000 0000 1100 1s
0	14	0000 0000 1100 0s
0	15	0000 0000 1011 1s
1	1	011s
1	2	0001 10s
1	3	0010 0101 s
1	4	0000 0011 00s
1	5	0000 0001 1011 s
1	6	0000 0000 1011 0s
1	7	0000 0000 1010 1s
2	1	0101 s
2	2	0000 100s
2	3	0000 0010 11s
2	4	0000 0001 0100 s
2	5	0000 0000 1010 0s
3	1	0011 1s
3	2	0010 0100 s
3	3	0000 0001 1100 s
3	4	0000 0000 1001 1s
4	1	0011 0s
4	2	0000 0011 11s
4	3	0000 0001 0010 s

RUN	LEVEL	CODE
5	1	0001 11s
5	2	0000 0010 01s
5	3	0000 0000 1001 0s
6	1	0001 01s
6	2	0000 0001 1110 s
7	1	0001 00s
7	2	0000 0001 0101 s
8	1	0000 111s
8	2	0000 0001 0001 s
9	1	0000 101s
9	2	0000 0000 1000 1s
10	1	0010 0111 s
10	2	0000 0000 1000 0s
11	1	0010 0011 s
12	1	0010 0010 s
13	1	0010 0000 s
14	1	0000 0011 10s
15	1	0000 0011 01s
16	1	0000 0010 00s
17	1	0000 0001 1111 s
18	1	0000 0001 1010 s
19	1	0000 0001 1001 s
20	1	0000 0001 0111 s
21	1	0000 0001 0110 s
22	1	0000 0000 1111 1s
23	1	0000 0000 1111 0s
24	1	0000 0000 1110 1s
25	1	0000 0000 1110 0s
26	1	0000 0000 1101 1s
ESCAPE		0000 01

The remaining combinations of (RUN,LEVEL) are encoded with a codeword consisting of 6 bits ESCAPE, 6 bits RUN and up to 16 bits LEVEL.

RUN	CODE
0	0000 00
1	0000 01
2	0000 10
:	:
:	:
63	1111 11

LEVEL	CODE
-256	FORBIDDEN
-255	1000 0000 0000 0001
-254	1000 0000 0000 0010
:	:
-129	1000 0000 0111 1111
-128	1000 0000 1000 0000
-127	1000 0001
:	:
-2	1111 1110
-1	1111 1111
0	FORBIDDEN
1	0000 0001
2	0000 0010
:	:
127	0111 1111
128	0000 0000 1000 0000
129	0000 0000 1000 0001
:	:
254	0000 0000 1111 1110
255	0000 0000 1111 1111

Table 9. VLC table for coefficients.
The last bit 's' denotes the sign of the level, '0' for positive, '1' for negative.

3. Encoder SOFTWARE implementation

This section describes the algorithm options chosen for the coding sequences for the November MPEG tests.

3.1. MPEG-1

3.1.1. Down-sampling

The CCIR601 interlaced pictures are down-sampled to 25Hz SIF progressive pictures using the following procedure:

a) Horizontal pels are filtered to reduce the number of pels from 704 to 352. An eight tap interpolator is used. Each tap is represented by an eight bit signed integer. Full precision is retained throughout the calculation; the output is represented by an eight bit unsigned integer.
b) The interlace is removed by vertically shifting lines +/- 1/4 line. A five tap interpolator is used. Each tap is represented by an eight bit signed integer. Full precision is retained throughout the calculation; the output is represented by an eight bit unsigned integer.
c) The odd and even fields are averaged to reduce the picture rate to 25Hz. The output is represented by an eight bit unsigned integer.

3.1.2. MPEG-1 coding

The 25Hz SIF progressive pictures are coded according to the MPEG-1 algorithm by the procedure defined in Simulation Model 3, except that the value of M was set to 2, that is, there is one interpolated picture between each intra or predicted picture.

3.2. Enhancement

3.2.1. Field coding type

Fields can be coded as intra, predicted or extrapolated fields. A repeating pattern, shown below, of one intra (I), ten extrapolated (E) and nine predicted (P) fields was used.

...I P E E P P E E P P E E P P E E P P E E I P...

3.2.2. Motion estimation

Horizontal components of motion vectors were in the range +/- 15 for coding extrapolated fields and predicted fields immediately after intra fields and in the range +/- 31 for coding all other predicted fields. Vertical components of motion vectors were in the range +/- 7 for coding extrapolated fields and predicted fields immediately after intra fields and in the range +/- 15 for coding all other predicted fields. Half pel accuracy was used.

Motion vectors were chosen on a macroblock basis using the following procedure. A full search of integer displacements was performed on the source fields. A search of the eight half pel displacements around the integer displacements was performed on prediction fields. In all cases the minimum sum of absolute differences was used to select the vector.

3.2.3. Prediction modes

Up to three prediction modes are possible for any macroblock. These are MPEG-1 prediction, prediction from the previously coded field and prediction from the previously coded field of the same parity. A choice was made between all possible prediction modes using the minimum prediction error power.

3.2.4. Quantization

Quantization decision levels were chosen to be halfway between reconstruction levels.

3.2.5. Data rate control and buffering

The VBV delay field in the bitstream was not evaluated. It was set to the bit string '0000 0000 0000 0000'.

The encoder buffer size was chosen to be the video bit rate multiplied by 0.1 seconds. It was initialised to 20% fullness at the start of each sequence. A linear relationship between buffer fullness and quantizer index such that when the total bit rate was 4Mbit/s the first quantizer index chosen was 10 and when the total bit rate was 9Mbit/s the first quantizer index chosen was 5. For each change of buffer fullness of 1/32 of the buffer size, the quantizer index was changed by one step. To avoid underflow and overflow the relationship was changed when the buffer fullness was more than 90% or less than 10% of the buffer size.

A constant quantizer index was used throughout intra fields except when extrapolation of the buffer fullness trajectory predicted overflow before the end of the field. A virtual buffer, similar to that defined in Simulation model 3, was used to chose the quantizer index for all fields until the start of the next intra field. It was not adaptive: the proportion of bits allocated to predicted and extrapolated fields was constant throughout all sequences at all bit rates. Calculation of the quantization index was done every four macroblocks.

3.3. System multiplex

Only one system packet header is included in the bitstream. It includes no std_buffer_size_bound.

The multiplex contains packets from the MPEG-1 video bitstream and from the enhancement video bitstream. The packet start code 1110 0000 is allocated to the MPEG-1 video bitstream. The packet start code 1110 1000 is allocated to the enhancement video bitstream.

Each MPEG-1 packet includes the data for exactly one slice together with any preceding sequence, group or picture headers. Each enhancement packet includes the data for exactly one slice together with any preceding picture header. The complete bitstream contained a repeating pattern of one MPEG-1 packet followed by two enhancement packets. Note. This splits the 2 picture period MPEG-1 reorder delay equally between encoder and decoder.

Packet headers contain no stuffing.

STD_buffer_size is only encoded in the first packet of each stream, This field was not evaluated: it was set to the bit string '0 0000 0000 0000'.

Presentation time stamps are only encoded for MPEG-1 intra pictures and enhancement intra fields. Consequently, decoding time stamps only occur in MPEG-1 packet headers and are always 2 picture periods earlier than the presentation time stamp, that is, 7200 units less.

3.4. Trick modes

The coding algorithm has the flexibility to perform shuttle modes in both forward and reverse directions. These are achieved with the MPEG-1 pictures (if enhancement data is not decoded it is possible to decode six MPEG-1 pictures in one MPEG-1 picture period). At the point when the shuttling stops the display can revert to full resolution.

The following trick modes can be achieved with no additional hardware.

3.4.1. Fast forward

MPEG-1 pictures are decoded faster than normal speed. Displaying all MPEG-1 pictures, which occur at 25Hz, on a standard 50Hz display results in a speed up factor of two. Choosing to display only two out of every three results in a speed up factor of three. Choosing to display two out of four gives a speed up of four etc. This can be done for any speed up factor up to six. The MPEG-1 decoder needs to run at the speed up factor times its normal speed. To speed up more than this, the interpolated pictures must be ignored. This allows a speed up factor up to twelve. In this case the MPEG-1 decoder needs to run at half the speed up factor times its normal speed.

3.4.2. Normal reverse

The intra and four predicted pictures within a group of pictures are decoded at normal speed. The last is displayed immediately, the other four are stored and subsequently displayed in reverse order. Each picture is repeated once.

3.4.3. Fast reverse

Pictures are decoded and stored as for normal reverse. If pictures are not repeated, a speed up of two is achieved. To achieve faster speeds than this, pictures must be decoded at faster rates than normal, as for the case of fast forward.

3.5. Cell Loss Resilience

The B-ISDN has been developed on asynchronous transfer mode (ATM) principles. Data is transported over the network in packets called cells. Under certain circumstances it is possible for cells to be lost. This means that 384 bits of data can be lost at a time.

Cells can be transported as low and high priority. High priority cells are virtually guaranteed to arrive at their destination. Work has been done previously to show that layered coding has high cell loss resilience.

In this coding algorithm the MPEG-1 bitstream would be transported using high priority cells. The enhancement bitstream would be transported using both high and low priority cells. The intra frame would be high priority, the remaining extrapolated and predicted pictures would be low priority.

If the decoder detects cell loss in the enhancement layer, the display picture reverts momentarily to the MPEG-1 picture for the portion of picture affected.

4. RESULTS

The sequences were coded at total bit rates of 4 and 9Mbits/s. The total bit rate was divided between the MPEG-1 coding and the enhancement coding as in table 10.

MPEG-1 ENHANCEMENT	1.15Mbits/s 2.85Mbits/s	1.15Mbits/s 7.85Mbits/s
TOTAL	4Mbits/s	9Mbits/s

Table 10 : Bit rate Allocation

The results are documented in two forms. The first table gives the average values for SNR, macroblock types etc. over the complete sequence of 125 pictures. The second table lists the SNR and bits on a picture by picture basis. Also the total bits per GOP are recorded.

Notes:

- The SNR values documented in this section are for the MPEG-2 display pictures only. All other results such as macroblock types etc. are for the enhancement layer coding.
- The algorithm codes on a field by field basis, however the statistics documented here are on a picture by picture basis. This implies that for intra pictures there are predicted fields associated with them, hence the motion vectors in the summary tables under the columns intra.

4.1. Flower Garden at 4Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	28.62	29.19	30.07	27.33
	U	31.28	31.17	31.77	30.91
	V	32.51	32.34	32.74	32.36
Average QI		16.32	10.86	9.69	22.82
MBTYPE for MPEG-1 prediction	nCBP	3.73%	14.67%	5.35%	0.14%
	CBP	8.44%	47.83%	3.42%	4.23%
	nCBP+Q	0.02%	0.03%	0.04%	0.00%
	CBP+Q	0.03%	0.09%	0.02%	0.01%
	Fixed Tx	0.30%	0.20%	0.06%	0.51%
	Fixed nTx	0.27%	1.96%	0.01%	0.12%
MBTYPE for Frame prediction	MC,CBP	24.85%	0.00%	29.86%	26.02%
	MC	26.42%	0.00%	6.76%	47.81%
	noMC,CBP	0.05%	0.00%	0.05%	0.06%
	MC,CBP+Q	0.17%	0.00%	0.27%	0.12%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.14%	0.00%	0.13%	0.19%
	Fixed nTx	0.15%	0.00%	0.06%	0.25%
MBTYPE for Field prediction	MC,CBP	20.80%	26.05%	39.66%	4.48%
	MC	14.28%	8.67%	13.75%	15.89%
	noMC,CBP	0.03%	0.10%	0.05%	0.01%
	MC,CBP+Q	0.16%	0.20%	0.32%	0.01%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.07%	0.05%	0.08%	0.07%
	Fixed nTx	0.10%	0.15%	0.11%	0.08%
Number of Macroblock header bits	MB address	1588	1597	1586	1588
	MB Type	4617	3118	4794	4789
	MB Quant	29	25	52	12
	Motion Vectors	8980	3536	10641	8782
	CBP	3799	5001	4776	2759
Number of Coefficient bits	Y	84940	175275	147142	15835
	U	6286	11566	12381	264
	V	3100	5382	6287	50
	Total	94325	192223	165810	16150
Number of coefficients transmitted	Non-Zeros	15835	32468	28206	2370
	Zeros	46050	86378	80858	9523
Total bits per picture		114809	206969	189129	35550

Table 11 : Summary of the enhancement coder for 125 pictures of Flower Garden at 4 Mbits/s.

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	30.22	32.10	32.97	203569	
2	27.56	31.44	32.67	38734	
3	30.37	32.00	32.89	189230	
4	26.54	30.36	32.19	50140	
5	30.34	31.94	32.76	178405	
6	27.00	30.98	32.26	41392	
7	30.07	31.84	32.63	188864	
8	26.45	30.27	32.05	48232	
9	30.03	31.75	32.61	179385	
10	26.70	30.74	32.14	40754	1158705
11	28.95	31.18	32.21	174814	
12	26.67	30.65	32.07	36310	
13	29.90	31.81	32.61	186134	
14	28.37	31.31	32.44	31784	
15	30.77	32.50	33.10	189434	
16	28.54	31.78	32.81	35146	
17	30.84	32.55	33.18	197365	
18	28.66	31.80	32.89	33190	
19	30.89	32.60	33.27	201705	
20	27.85	31.58	32.72	40529	1126411
21	29.83	31.68	32.68	217949	
22	28.01	31.21	32.50	29838	
23	30.29	32.11	32.93	183912	
24	27.89	31.48	32.78	41098	
25	30.42	32.03	32.97	190359	
26	28.21	31.29	32.63	32359	
27	30.45	32.25	33.10	183944	
28	26.99	30.95	32.54	48735	
29	30.09	31.80	32.83	186284	
30	28.22	31.15	32.54	30060	1144538
31	29.07	31.22	32.36	204414	
32	26.65	30.67	32.16	33625	
33	29.71	31.62	32.70	189337	
34	27.34	31.05	32.52	32070	
35	30.08	31.91	32.95	185737	
36	28.17	31.30	32.73	33403	
37	30.88	32.40	33.38	188903	
38	28.53	31.63	33.09	33628	
39	30.61	32.26	33.33	198423	
40	28.72	31.56	33.04	30740	1130280
41	29.70	31.57	32.73	229786	
42	27.55	31.20	32.53	34532	
43	30.29	31.97	32.95	183649	
44	27.04	30.88	32.57	39373	
45	30.37	31.99	33.07	183822	
46	26.65	30.57	32.37	42323	
47	29.77	31.65	32.70	180426	
48	25.99	29.86	31.89	48212	
49	29.59	31.17	32.36	183389	
50	28.09	30.80	32.19	23559	1149071
51	29.06	30.82	32.14	214091	
52	27.71	30.55	32.05	26829	
53	29.70	31.34	32.52	192832	
54	26.66	30.57	32.20	37107	
55	29.56	31.23	32.40	191781	
56	27.06	30.72	32.22	33550	
57	29.67	31.36	32.47	191094	
58	27.08	30.81	32.21	30814	
59	29.56	31.15	32.33	196771	
60	27.29	30.75	32.24	29436	1144305
61	28.92	30.73	32.10	207399	
62	27.74	30.68	32.10	24005	
63	30.14	31.69	32.70	179507	

No.	snr U	snr U	snr V	Bits/pic	Bits/GOP
64	28.79	31.40	32.59	25963	
65	30.78	32.12	33.03	203294	
66	28.94	31.69	32.81	26458	
67	31.05	32.42	33.29	201253	
68	29.19	31.75	33.01	24987	
69	31.19	32.49	33.38	193643	
70	29.30	31.79	33.02	26125	1112634
71	30.27	31.72	32.76	260188	
72	27.75	31.49	32.69	28147	
73	30.36	32.03	32.97	178757	
74	28.80	31.48	32.72	27271	
75	30.77	32.31	33.17	189354	
76	28.29	31.64	32.87	31333	
77	29.90	31.58	32.68	202824	
78	26.94	30.85	32.33	32173	
79	29.45	31.26	32.42	190273	
80	26.52	30.54	32.12	36969	1177289
81	28.59	30.72	32.09	186647	
82	27.19	30.53	32.01	23339	
83	29.46	31.34	32.40	194251	
84	26.25	30.30	32.03	46297	
85	30.06	31.65	32.59	183949	
86	26.31	30.71	32.16	41480	
87	29.59	31.34	32.45	190217	
88	27.57	30.96	32.32	29287	
89	29.70	31.40	32.45	202367	
90	26.03	29.97	31.79	45604	1143438
91	28.14	30.44	31.84	171218	
92	25.53	29.81	31.64	39682	
93	29.33	31.20	32.28	181252	
94	26.00	30.23	31.93	46719	
95	29.83	31.52	32.49	182477	
96	26.12	30.34	31.99	44854	
97	29.64	31.37	32.43	191666	
98	27.43	30.95	32.22	30719	
99	29.77	31.44	32.44	203116	
100	26.29	30.42	32.04	40377	1132080
101	28.56	30.69	32.05	192934	
102	26.56	30.48	31.96	29651	
103	29.29	31.21	32.30	193707	
104	26.25	30.70	32.10	41506	
105	29.72	31.54	32.52	185073	
106	25.85	30.36	32.02	46199	
107	29.71	31.46	32.40	181749	
108	26.10	30.01	31.87	44132	
109	30.04	31.73	32.62	169045	
110	26.35	30.38	32.07	55600	1139596
111	28.57	30.86	32.08	189744	
112	25.66	30.12	31.83	41787	
113	29.43	31.32	32.41	178582	
114	27.26	31.06	32.37	31250	
115	29.72	31.57	32.58	195849	
116	28.29	31.18	32.45	26736	
117	30.50	32.16	32.93	190575	
118	27.70	31.44	32.63	40074	
119	30.05	31.76	32.73	202993	
120	28.30	31.27	32.54	25512	1123102
121	29.58	31.44	32.44	237845	
122	26.44	30.98	32.27	39954	
123	29.72	31.48	32.55	178545	
124	28.37	31.18	32.37	22394	
125	30.21	31.92	32.80	190928	

Table 12: Enhancement coder statistics picture by picture for Flower Garden at 4 Mbits/s

4.2. Flower Garden at 9 Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	33.40	34.20	35.94	31.18
	U	34.91	34.85	36.19	33.89
	V	35.41	34.96	36.33	34.77
Average QI		7.25	5.10	3.98	10.34
MBTYPE for MPEG-1 prediction	nCBP	8.06%	42.41%	6.51%	2.10%
	CBP	2.95%	18.60%	0.32%	1.78%
	nCBP+Q	0.03%	0.06%	0.05%	0.00%
	CBP+Q	0.01%	0.00%	0.00%	0.01%
	Fixed Tx	0.00%	0.00%	0.00%	0.01%
	Fixed nTx	0.00%	0.00%	0.00%	0.00%
MBTYPE for Frame prediction	MC,CBP	39.68%	0.00%	34.53%	52.15%
	MC	13.73%	0.00%	5.26%	23.44%
	noMC,CBP	0.10%	0.00%	0.12%	0.10%
	MC,CBP+Q	0.28%	0.00%	0.42%	0.23%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.22%	0.00%	0.20%	0.29%
	Fixed nTx	0.28%	0.00%	0.16%	0.44%
MBTYPE for Field prediction	MC,CBP	25.32%	32.23%	44.65%	8.28%
	MC	8.76%	5.78%	6.96%	10.83%
	noMC,CBP	0.08%	0.27%	0.11%	0.01%
	MC,CBP+Q	0.22%	0.24%	0.44%	0.03%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.12%	0.01%	0.11%	0.15%
	Fixed nTx	0.17%	0.38%	0.16%	0.13%
Number of Macroblock header bits	MB address	1590	1589	1588	1591
	MB Type	4577	2774	4805	4770
	MB Quant	42	25	73	22
	Motion Vectors	8646	3666	10221	8421
	CBP	4108	2931	4149	4322
Number of Coefficient bits	Y	250586	435123	407131	85648
	U	25220	46007	47367	3001
	V	19358	33876	38277	1058
	Total	295164	515006	492774	89706
Number of coefficients transmitted	Non-Zeros	51099	88822	85862	15155
	Zeros	91497	132500	143040	41332
Total bits per picture		315598	527459	515080	110302

Table 13 : Summary of the enhancement coder for 125 pictures of Flower Garden at 9 Mbits/s

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	34.96	35.66	35.69	494080	
2	31.28	34.13	34.80	115336	
3	36.06	36.39	36.41	512832	
4	30.36	32.79	33.94	143438	
5	36.23	36.63	36.53	494768	
6	30.99	34.09	34.86	127538	
7	35.98	36.40	36.33	512143	
8	30.30	32.71	33.92	141899	
9	35.98	36.50	36.40	497265	
10	30.48	33.41	34.41	129292	3168591
11	33.59	34.58	34.58	447810	
12	30.19	33.19	33.90	110051	
13	35.53	35.91	35.96	496443	
14	32.57	34.69	35.18	97578	
15	37.04	37.15	37.22	530230	
16	32.74	35.21	35.84	108786	
17	37.01	37.15	37.27	538543	
18	33.09	35.38	35.96	109136	
19	36.95	37.08	37.23	541305	
20	31.72	34.55	35.32	116949	3096831
21	34.82	35.48	35.43	539872	
22	31.59	34.21	34.72	85668	
23	36.21	36.57	36.59	514429	
24	31.91	34.61	35.52	115917	
25	36.34	36.56	36.59	531860	
26	32.11	34.74	35.41	87150	
27	36.64	36.84	37.01	521243	
28	31.09	33.76	34.87	150620	
29	35.96	36.35	36.44	510903	
30	32.01	34.57	35.23	80547	3138209
31	34.46	35.13	35.17	555858	
32	30.39	33.57	34.38	108108	
33	35.44	35.80	35.96	509348	
34	31.18	34.01	34.79	104980	
35	35.86	36.24	36.46	494680	
36	32.15	34.61	35.39	104709	
37	37.00	37.05	37.30	521870	
38	32.73	35.13	36.09	107926	
39	36.50	36.71	36.93	535139	
40	32.76	35.13	35.96	91369	3133987
41	34.71	35.26	35.37	562400	
42	31.40	34.00	34.72	102785	
43	36.22	36.55	36.63	510015	
44	30.91	33.57	34.74	123984	
45	36.20	36.47	36.68	500676	
46	30.65	33.39	34.67	134138	
47	35.61	35.99	36.23	492422	
48	29.82	32.25	33.73	154225	
49	35.38	35.72	35.86	495286	
50	31.91	34.50	35.14	67791	3143722
51	34.53	34.94	35.10	575812	
52	31.73	33.97	34.69	77049	
53	35.63	35.77	36.01	532355	
54	30.52	33.32	34.48	120425	
55	35.32	35.45	35.74	508380	
56	31.06	33.85	34.88	112826	
57	35.45	35.60	35.85	514264	
58	30.97	33.92	34.85	109871	
59	35.19	35.34	35.58	518820	
60	30.93	33.85	34.75	98891	3168693
61	34.16	34.74	34.87	545904	
62	31.48	34.04	34.52	72396	
63	36.20	36.24	36.47	500386	

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
64	33.19	35.04	35.79	84689	
65	36.99	36.80	37.06	551890	
66	33.15	35.32	35.96	90005	
67	36.94	36.87	37.19	544190	
68	33.16	35.31	36.12	72158	
69	37.33	37.22	37.46	536123	
70	33.41	35.48	36.10	84253	3081994
71	35.83	35.98	36.00	664169	
72	31.40	34.64	35.28	92066	
73	36.05	36.28	36.49	478950	
74	32.92	34.90	35.55	92449	
75	36.79	36.79	37.05	517797	
76	32.15	34.91	35.82	104723	
77	35.56	35.77	36.03	539858	
78	30.60	33.76	34.75	106556	
79	35.09	35.34	35.63	501776	
80	30.43	33.36	34.44	120677	3219021
81	33.36	34.13	34.34	474399	
82	30.74	33.46	34.01	67998	
83	35.41	35.60	35.80	538702	
84	30.19	32.69	33.98	146235	
85	35.96	36.18	36.26	502729	
86	30.13	33.46	34.63	129800	
87	35.32	35.57	35.73	506865	
88	31.34	34.27	35.03	90144	
89	35.62	35.76	35.95	554230	
90	29.74	32.17	33.55	140845	3151947
91	33.05	33.87	34.15	466387	
92	28.91	32.02	33.19	120044	
93	35.07	35.57	35.63	494380	
94	29.62	32.66	33.90	136205	
95	35.61	36.01	36.09	500213	
96	29.72	32.75	34.05	137280	
97	35.29	35.66	35.78	505754	
98	31.08	34.24	34.97	99198	
99	35.54	35.72	35.92	541061	
100	29.89	32.79	34.04	125539	3126061
101	33.29	34.11	34.36	481020	
102	30.08	33.27	33.98	96389	
103	34.95	35.24	35.44	516811	
104	30.21	33.38	34.41	132315	
105	35.57	35.91	36.00	510680	
106	29.55	32.63	33.92	141434	
107	35.47	35.87	35.91	495721	
108	29.80	32.03	33.41	140226	
109	35.75	36.14	36.17	467650	
110	30.24	32.76	33.85	163237	3145483
111	33.14	34.01	34.22	472379	
112	29.02	32.23	33.27	123352	
113	35.06	35.63	35.61	491815	
114	31.13	34.38	34.99	107905	
115	35.49	35.75	35.94	519601	
116	32.36	34.67	35.24	84987	
117	36.63	36.66	36.83	528387	
118	31.73	34.57	35.40	125843	
119	35.94	36.17	36.27	548234	
120	32.08	34.88	35.28	77822	3080325
121	34.64	35.16	35.17	576879	
122	30.09	33.46	34.22	124265	
123	35.44	35.88	35.84	492042	
124	32.33	34.84	35.14	68727	
125	36.38	36.66	36.73	532931	

Table 14 : Enhancement coder statistics picture by picture for Flower Garden at 9 Mbits/s

4.3. Table Tennis at 4 Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	31.66	31.91	32.46	30.97
	U	36.17	36.34	36.53	35.84
	V	37.28	37.65	37.82	36.77
Average QI		9.87	7.29	6.37	13.24
MBTYPE for MPEG-1 prediction	nCBP	3.30%	15.56%	3.49%	0.58%
	CBP	8.04%	41.08%	3.98%	4.39%
	nCBP+Q	0.03%	0.11%	0.05%	0.01%
	CBP+Q	0.04%	0.14%	0.03%	0.04%
	Fixed Tx	0.17%	0.01%	0.01%	0.33%
	Fixed nTx	0.29%	0.57%	0.01%	0.46%
MBTYPE for Frame prediction	MC,CBP	16.40%	0.00%	25.00%	12.91%
	MC	17.90%	0.00%	3.31%	33.41%
	noMC,CBP	9.02%	0.00%	18.59%	3.20%
	MC,CBP+Q	0.23%	0.00%	0.36%	0.17%
	noMC,CBP+Q	0.16%	0.00%	0.30%	0.09%
	Fixed Tx	1.08%	0.00%	0.18%	2.03%
	Fixed nTx	11.07%	0.00%	0.69%	21.77%
MBTYPE for Field prediction	MC,CBP	21.27%	32.80%	38.01%	5.34%
	MC	10.28%	8.81%	4.98%	14.85%
	noMC,CBP	0.27%	0.42%	0.45%	0.10%
	MC,CBP+Q	0.26%	0.33%	0.47%	0.08%
	noMC,CBP+Q	0.00%	0.00%	0.01%	0.00%
	Fixed Tx	0.08%	0.01%	0.02%	0.14%
	Fixed nTx	0.10%	0.15%	0.06%	0.13%
Number of Macroblock header bits	MB address	1534	1583	1590	1479
	MB Type	4318	3112	5091	3948
	MB Quant	58	45	97	30
	Motion Vectors	6970	3619	8475	6459
	CBP	4311	4985	6753	2199
Number of Coefficient bits	Y	86922	234755	132183	19424
	U	4624	13259	7444	539
	V	4427	10613	7269	837
	Total	95973	258627	146897	20800
Number of coefficients transmitted	Non-Zeros	14318	40346	21550	3029
	Zeros	54633	95590	95348	13210
Total bits per picture		114634	273441	170373	36385

Table 15 : Summary of the enhancement coder for 125 pictures of Table tennis at 4 Mbits/s

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	26.05	34.22	36.35	247961	
2	25.55	34.12	36.08	10161	
3	26.89	34.40	36.51	185536	
4	26.26	34.15	35.95	12551	
5	27.55	34.55	36.62	188373	
6	25.85	34.34	36.14	36417	
7	27.60	34.84	36.53	198946	
8	29.10	35.40	35.82	31809	
9	31.53	36.82	37.56	153985	
10	31.01	36.39	36.90	38305	1104044
11	34.23	38.73	39.74	312329	
12	32.06	37.34	37.93	42850	
13	33.66	38.16	39.06	152788	
14	32.25	37.28	37.63	40257	
15	33.97	38.13	38.89	151472	
16	32.69	37.16	37.36	40318	
17	34.39	38.33	39.12	153739	
18	33.06	37.23	37.42	44668	
19	34.56	38.35	39.02	153481	
20	33.12	37.37	37.34	43732	1135634
21	34.64	38.58	38.86	290230	
22	33.22	37.59	37.56	42536	
23	34.75	38.51	39.03	154602	
24	32.98	37.37	37.17	45475	
25	34.60	38.24	38.70	158752	
26	32.81	37.10	36.67	47051	
27	34.52	38.00	38.40	157217	
28	32.78	36.83	36.38	46870	
29	34.35	37.80	38.01	161388	
30	32.40	36.56	36.03	43644	1147765
31	33.83	37.57	37.57	218728	
32	32.06	36.27	35.74	43386	
33	34.07	37.62	37.76	171501	
34	32.11	36.35	35.84	47173	
35	34.11	37.60	37.72	173587	
36	31.97	36.18	35.49	46423	
37	34.02	37.33	37.60	174627	
38	31.88	35.97	35.41	45070	
39	33.96	37.26	37.50	174190	
40	31.81	35.92	35.33	46288	1140973
41	33.17	36.90	36.98	198433	
42	31.50	35.81	35.23	46720	
43	33.59	37.02	37.14	173212	
44	31.56	35.79	35.12	48512	
45	33.79	37.12	37.19	175678	
46	31.69	35.63	34.98	48251	
47	33.86	37.05	37.13	176041	
48	31.76	35.47	35.10	47393	
49	33.90	37.02	37.24	175376	
50	31.78	35.43	35.10	48438	1138054
51	33.58	36.84	37.07	225786	
52	31.59	35.32	35.11	47529	
53	33.60	36.70	36.98	167677	
54	27.22	32.96	34.18	80954	
55	29.89	34.34	35.32	170889	
56	29.61	34.24	35.10	18553	
57	31.42	35.35	36.56	169038	
58	30.95	35.15	36.18	28070	
59	32.28	35.99	37.23	180085	
60	31.60	35.72	36.85	38173	1126754
61	31.80	35.91	37.63	302194	
62	30.98	35.64	37.07	20414	
63	32.49	36.47	38.09	164670	
64	31.77	36.23	37.63	25780	
65	33.07	36.82	38.38	173775	
66	32.30	36.57	37.89	29764	
67	33.41	37.07	38.61	173394	
68	32.53	36.80	38.20	33000	
69	33.59	37.22	38.76	172155	
70	32.76	37.03	38.42	41327	1136473
71	31.85	35.94	37.59	304565	
72	31.13	35.75	37.17	17968	
73	32.66	36.57	38.25	167055	
74	32.04	36.42	37.85	25277	
75	33.28	37.02	38.55	173710	
76	32.57	36.80	38.16	25796	
77	33.65	37.29	38.86	177948	
78	32.85	37.04	38.38	29260	
79	33.88	37.46	39.05	177133	
80	32.97	37.14	38.55	41952	1140664
81	31.84	35.99	37.57	304042	
82	31.03	35.75	37.01	19541	
83	29.36	34.16	35.91	210402	
84	28.81	33.96	35.50	19767	
85	30.53	34.88	36.94	158826	
86	29.95	34.67	36.45	24854	
87	31.32	35.42	37.36	172077	
88	30.75	35.22	36.87	24514	
89	31.93	35.71	37.77	177685	
90	31.39	35.54	37.35	33322	1145030
91	30.86	35.35	37.79	314984	
92	30.31	35.21	37.31	17503	
93	31.84	35.90	38.21	167853	
94	31.25	35.73	37.75	22119	
95	32.34	36.19	38.45	178032	
96	31.34	35.99	38.03	24699	
97	32.35	36.22	38.43	177684	
98	30.48	35.95	37.93	33894	
99	31.91	36.03	38.21	175594	
100	30.65	35.70	37.61	30109	1142471
101	30.91	35.43	37.63	312694	
102	29.79	35.19	37.07	22532	
103	31.12	35.58	37.72	172995	
104	28.84	35.24	36.94	39910	
105	31.30	35.60	37.69	159745	
106	28.87	34.97	36.90	42765	
107	31.32	35.67	37.62	159137	
108	29.17	35.19	36.99	41261	
109	31.80	35.90	37.86	154697	
110	29.70	35.28	37.16	46834	1152570
111	30.70	35.25	37.25	237303	
112	29.92	35.14	36.83	29541	
113	31.53	35.70	37.60	173761	
114	29.85	35.28	37.20	40605	
115	31.96	35.99	37.83	173651	
116	31.16	35.87	37.43	31567	
117	32.86	36.46	38.29	181961	
118	30.51	35.97	37.64	48339	
119	32.80	36.46	38.25	170597	
120	30.78	35.59	37.66	44071	1131396
121	31.36	35.69	37.39	285478	
122	29.64	35.16	36.90	36336	
123	31.83	36.02	37.78	161221	
124	29.76	35.36	37.03	43665	
125	32.21	36.30	37.92	160703	

Table 16 : Enhancement coder statistics picture by picture for Table Tennis at 4 Mbits/s

4.4. Table tennis 9 Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	35.29	35.83	36.80	33.97
	U	38.79	39.00	39.60	38.10
	V	40.28	40.55	41.16	39.52
Average QI		4.51	3.45	2.88	6.06
MBTYPE for MPEG-1 prediction	nCBP	7.98%	42.49%	5.91%	2.42%
	CBP	3.33%	14.24%	1.07%	2.86%
	nCBP+Q	0.08%	0.05%	0.15%	0.04%
	CBP+Q	0.01%	0.01%	0.01%	0.02%
	Fixed Tx	0.00%	0.00%	0.00%	0.01%
	Fixed nTx	0.00%	0.00%	0.00%	0.01%
MBTYPE for Frame prediction	MC,CBP	25.29%	0.00%	28.27%	28.20%
	MC	8.15%	0.00%	0.10%	16.36%
	noMC,CBP	18.86%	0.00%	25.35%	17.58%
	MC,CBP+Q	0.49%	0.00%	0.63%	0.49%
	noMC,CBP+Q	0.45%	0.00%	0.55%	0.46%
	Fixed Tx	0.31%	0.00%	0.01%	0.62%
	Fixed nTx	6.89%	0.00%	0.02%	13.88%
MBTYPE for Field prediction	MC,CBP	24.87%	40.82%	36.45%	12.18%
	MC	2.42%	1.35%	0.22%	4.41%
	noMC,CBP	0.24%	0.36%	0.30%	0.17%
	MC,CBP+Q	0.58%	0.65%	0.96%	0.27%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.01%	0.00%	0.00%	0.02%
	Fixed nTx	0.02%	0.02%	0.00%	0.03%
Number of Macroblock header bits	MB address	1565	1584	1584	1546
	MB Type	4606	2650	5267	4483
	MB Quant	128	57	182	101
	Motion Vectors	5997	3434	7165	5592
	CBP	4786	3446	4881	4990
Number of Coefficient bits	Y	260947	559167	401851	84785
	U	19855	43205	33888	3641
	V	16118	32966	26043	4582
	Total	296920	635339	461782	93008
Number of coefficients transmitted	Non-Zeros	47089	100588	74664	13632
	Zeros	134085	170410	220871	56480
Total bits per picture		315472	647980	482330	111190

Table 17 : Summary of the enhancement coder for 125 pictures of Table tennis at 9 Mbits/s

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	30.61	35.58	37.86	599187	
2	29.09	35.26	37.43	33920	
3	33.11	36.86	38.93	500070	
4	31.29	36.36	38.34	93609	
5	34.62	37.70	39.65	510292	
6	29.76	36.57	38.60	138432	
7	32.43	36.55	38.75	515084	
8	30.94	36.41	37.83	101260	
9	35.58	39.08	40.53	467006	
10	33.46	37.95	39.29	128655	3087515
11	36.46	40.05	41.26	515053	
12	34.00	38.50	39.69	125197	
13	37.21	40.48	41.86	485504	
14	34.42	38.59	39.86	124509	
15	37.59	40.72	42.04	498422	
16	34.80	38.74	39.92	122731	
17	37.95	41.00	42.34	500019	
18	35.10	38.92	40.13	122966	
19	38.13	41.09	42.43	499648	
20	35.28	39.06	40.09	125146	3119195
21	37.45	40.70	41.67	494589	
22	35.30	39.14	40.06	124358	
23	38.29	41.20	42.41	503002	
24	35.30	39.07	40.03	128559	
25	38.24	41.14	42.32	505117	
26	35.16	38.83	39.59	127734	
27	38.21	41.03	42.16	505425	
28	35.15	38.71	39.41	126587	
29	38.10	40.91	41.96	508546	
30	34.90	38.51	39.09	124408	3148325
31	37.23	40.32	41.11	531778	
32	34.68	38.34	38.78	125525	
33	37.69	40.56	41.43	490287	
34	34.64	38.25	38.69	129994	
35	37.65	40.49	41.44	493238	
36	34.54	38.15	38.44	136692	
37	37.52	40.32	41.32	493305	
38	34.46	37.94	38.30	133482	
39	37.49	40.26	41.23	490292	
40	34.36	37.80	38.19	131876	3156469
41	36.11	39.31	39.92	447293	
42	34.13	37.58	37.76	140473	
43	37.28	40.10	41.04	491489	
44	34.29	37.67	37.97	139354	
45	37.46	40.20	41.14	494681	
46	34.46	37.77	38.08	142480	
47	37.48	40.19	41.04	500063	
48	34.47	37.79	38.16	138555	
49	37.45	40.09	41.14	500806	
50	34.53	37.66	38.24	138793	3133987
51	36.88	39.81	40.64	540466	
52	34.12	37.54	37.87	123376	
53	37.26	39.97	40.93	492260	
54	29.88	34.47	35.67	206612	
55	33.49	37.06	38.26	437377	
56	32.92	36.89	38.12	78689	
57	36.41	39.32	40.67	507203	
58	34.63	38.64	40.07	109734	
59	37.43	40.09	41.42	500319	
60	35.03	39.16	40.63	118358	3114394
61	36.43	39.54	41.26	823116	
62	34.19	38.63	40.20	71058	
63	37.16	40.12	41.78	463954	

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
64	34.91	39.29	40.90	97310	
65	37.52	40.32	41.94	453429	
66	35.22	39.52	41.06	107000	
67	37.76	40.51	42.07	454979	
68	35.26	39.62	41.27	108839	
69	37.71	40.48	42.12	453032	
70	35.27	39.67	41.35	107507	3140224
71	36.45	39.52	41.23	822265	
72	34.38	38.80	40.45	70776	
73	37.42	40.35	42.03	463218	
74	35.21	39.56	41.22	98140	
75	37.83	40.59	42.21	454104	
76	35.55	39.82	41.56	107696	
77	38.01	40.72	42.29	454097	
78	35.56	39.84	41.57	107604	
79	38.06	40.77	42.38	454930	
80	35.45	39.79	41.41	108575	3141405
81	36.49	39.64	41.31	820518	
82	34.26	38.75	40.18	70173	
83	33.26	36.60	38.56	527183	
84	32.34	36.30	38.20	60608	
85	35.48	38.13	40.05	453029	
86	33.94	37.58	39.42	88158	
87	36.62	38.88	40.68	473096	
88	34.64	38.14	39.90	89130	
89	37.08	39.26	41.03	455614	
90	35.14	38.56	40.36	106939	3144448
91	35.92	38.47	40.95	881496	
92	34.13	37.76	39.99	68071	
93	37.05	39.36	41.57	461823	
94	34.85	38.58	40.67	85649	
95	37.18	39.45	41.57	452883	
96	34.60	38.73	40.86	94379	
97	36.73	39.29	41.46	458917	
98	33.44	38.38	40.54	92138	
99	36.03	38.80	41.01	458622	
100	33.63	38.02	40.13	89810	3143788
101	34.98	37.84	39.93	670006	
102	32.99	37.33	39.24	82153	
103	35.65	38.31	40.36	498578	
104	32.40	37.33	39.26	117802	
105	36.00	38.46	40.48	475992	
106	32.41	37.00	39.06	118807	
107	35.97	38.56	40.51	477994	
108	32.80	37.37	39.36	115545	
109	36.72	39.13	41.06	477446	
110	33.15	37.31	39.57	120601	3154924
111	35.03	37.83	39.84	641142	
112	33.52	37.30	39.33	87133	
113	36.19	38.72	40.57	494335	
114	33.43	37.41	39.59	115602	
115	36.51	39.07	40.95	478159	
116	34.56	38.52	40.28	105178	
117	37.38	39.76	41.45	492449	
118	33.66	38.47	40.23	121594	
119	37.19	39.47	41.32	475349	
120	34.03	37.79	39.98	113056	3123997
121	35.69	38.37	40.24	636827	
122	33.04	37.10	39.27	105576	
123	36.43	39.14	41.00	484590	
124	33.28	37.42	39.41	119106	
125	36.86	39.44	41.21	479249	

Table 18 : Enhancement coder statistics picture by picture for Table Tennis at 9 Mbits/s

4.5. Calendar at 4 Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	27.39	27.80	28.36	26.51
	U	30.68	30.58	30.95	30.47
	V	32.05	32.02	32.32	31.84
Average QI		15.32	10.65	10.03	20.56
MBTYPE for MPEG-1 prediction	nCBP	4.97%	23.37%	6.05%	0.25%
	CBP	7.96%	37.37%	3.75%	5.18%
	nCBP+Q	0.02%	0.04%	0.05%	0.00%
	CBP+Q	0.03%	0.04%	0.02%	0.03%
	Fixed Tx	0.30%	0.02%	0.03%	0.58%
	Fixed nTx	0.09%	0.02%	0.00%	0.18%
MBTYPE for Frame prediction	MC,CBP	32.78%	0.00%	58.62%	18.82%
	MC	31.85%	0.00%	3.82%	61.13%
	noMC,CBP	0.20%	0.00%	0.16%	0.27%
	MC,CBP+Q	0.26%	0.00%	0.48%	0.13%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.05%	0.00%	0.00%	0.10%
	Fixed nTx	0.20%	0.00%	0.01%	0.40%
MBTYPE for Field prediction	MC,CBP	15.63%	34.63%	23.38%	5.41%
	MC	5.35%	4.06%	3.27%	7.30%
	noMC,CBP	0.09%	0.09%	0.12%	0.07%
	MC,CBP+Q	0.12%	0.25%	0.18%	0.03%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.06%	0.01%	0.03%	0.09%
	Fixed nTx	0.03%	0.09%	0.03%	0.03%
Number of Macroblock header bits	MB address	1587	1586	1585	1589
	MB Type	4597	2939	4793	4787
	MB Quant	34	26	58	16
	Motion Vectors	6128	2510	7517	5768
	CBP	4771	5722	7380	2468
Number of Coefficient bits	Y	85933	210290	139548	16621
	U	5996	15625	10588	273
	V	4269	10432	7631	265
	Total	96198	236347	157767	17160
Number of coefficients transmitted	Non-Zeros	14657	39654	23731	2099
	Zeros	64265	122604	109449	15593
Total bits per picture		114786	250599	180569	33257

Table 19 : Summary of the enhancement coder for 125 pictures of Mobile and Calendar at 4 Mbits/s

COSMIC

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	27.63	30.90	32.40	229455	
2	26.08	30.73	32.23	29444	
3	27.88	31.04	32.46	184529	
4	26.02	30.74	32.16	35009	
5	27.61	30.94	32.35	193047	
6	25.67	30.52	31.98	32179	
7	27.55	30.76	32.23	191451	
8	25.64	30.43	31.84	35546	
9	27.67	30.72	32.13	185498	
10	25.75	30.54	31.93	32011	1148169
11	27.46	30.82	32.19	236774	
12	25.76	30.67	32.08	31375	
13	28.22	31.12	32.48	174116	
14	26.58	30.69	32.01	33120	
15	28.90	31.64	32.95	168115	
16	27.07	31.01	32.39	40050	
17	29.29	31.89	33.23	174943	
18	27.48	31.25	32.57	37439	
19	29.33	32.00	33.34	182804	
20	26.71	31.17	32.58	42588	1121324
21	28.53	31.27	32.68	266827	
22	26.59	30.86	32.36	32837	
23	28.83	31.59	33.01	164312	
24	26.97	30.94	32.36	35520	
25	28.98	31.77	33.13	172177	
26	27.46	31.08	32.45	35758	
27	29.66	32.11	33.46	174483	
28	27.89	31.27	32.58	37771	
29	29.77	32.17	33.42	175513	
30	27.80	31.21	32.47	37649	1132847
31	28.58	31.28	32.58	271401	
32	27.04	30.84	32.15	29448	
33	28.87	31.62	32.86	170589	
34	27.38	30.96	32.25	31664	
35	29.26	31.84	33.12	175686	
36	27.26	31.27	32.67	39180	
37	29.09	31.78	33.10	178229	
38	27.67	31.31	32.64	30250	
39	29.39	31.93	33.15	178095	
40	28.35	31.53	32.84	27098	1131640
41	28.85	31.38	32.85	306703	
42	27.96	30.98	32.57	21457	
43	29.16	31.65	33.06	170649	
44	27.42	31.31	32.80	29485	
45	29.02	31.65	33.03	180838	
46	27.50	31.27	32.67	30139	
47	29.09	31.62	32.93	177376	
48	26.86	31.12	32.49	32793	
49	28.79	31.26	32.62	180862	
50	26.24	30.69	32.10	39763	1170065
51	27.53	30.49	31.95	238903	
52	25.69	30.23	31.66	31170	
53	27.78	30.66	32.04	185024	
54	25.26	30.03	31.39	37886	
55	27.69	30.53	31.96	182982	
56	25.63	29.86	31.32	33965	
57	27.69	30.51	31.90	185376	
58	25.89	29.94	31.31	30389	
59	27.91	30.65	32.03	183679	
60	26.58	30.22	31.56	27487	1136861
61	27.52	30.29	31.77	244138	
62	25.91	30.11	31.54	28200	
63	27.98	30.63	32.03	181125	

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
64	25.96	30.20	31.57	36403	
65	28.00	30.67	32.02	183188	
66	26.00	30.07	31.43	35378	
67	28.06	30.78	32.15	181612	
68	26.08	30.15	31.49	36814	
69	28.07	30.70	32.12	182994	
70	26.11	30.22	31.60	36184	1146036
71	27.52	30.26	31.72	240021	
72	25.75	30.01	31.41	32907	
73	27.99	30.47	31.85	176124	
74	26.01	30.13	31.42	36212	
75	28.20	30.54	31.91	177910	
76	26.20	30.07	31.34	38017	
77	28.28	30.77	32.10	178050	
78	26.19	30.24	31.52	41912	
79	28.16	30.62	31.97	180856	
80	26.09	30.19	31.53	38115	1140124
81	27.49	30.23	31.62	241749	
82	25.80	29.99	31.35	31108	
83	28.00	30.46	31.86	176576	
84	26.64	30.18	31.43	31779	
85	28.14	30.53	31.90	183211	
86	26.38	30.20	31.46	34306	
87	27.91	30.45	31.81	191156	
88	26.47	30.16	31.46	27772	
89	28.01	30.50	31.90	183498	
90	26.55	30.33	31.75	30499	1131654
91	27.62	30.31	31.75	241651	
92	26.46	30.13	31.57	27665	
93	28.15	30.66	32.03	177003	
94	26.97	30.46	31.76	26914	
95	28.53	30.95	32.27	181719	
96	27.42	30.73	31.99	30959	
97	28.78	31.14	32.41	190479	
98	26.89	30.76	32.01	34599	
99	28.54	31.01	32.34	192609	
100	26.61	30.53	31.89	36235	1139833
101	27.62	30.28	31.72	241427	
102	25.84	30.05	31.45	31137	
103	27.75	30.41	31.81	180609	
104	25.88	30.05	31.38	36319	
105	27.89	30.36	31.75	181989	
106	26.08	29.97	31.29	36687	
107	27.98	30.29	31.69	182330	
108	26.18	29.96	31.26	35779	
109	28.01	30.32	31.71	185855	
110	26.33	29.86	31.21	32379	1144511
111	27.50	30.00	31.45	246298	
112	26.03	29.73	31.15	29926	
113	27.82	30.17	31.60	180396	
114	26.13	29.73	31.17	34819	
115	28.00	30.31	31.75	179477	
116	26.33	30.07	31.46	34271	
117	28.08	30.37	31.80	180760	
118	26.63	30.13	31.53	31407	
119	28.18	30.35	31.78	182732	
120	26.88	30.34	31.76	27864	1127950
121	27.52	30.03	31.51	252436	
122	26.15	29.89	31.33	27956	
123	28.04	30.31	31.72	178956	
124	26.71	30.13	31.49	30956	
125	28.15	30.31	31.71	186872	

Table 20 : Enhancement coder statistics picture by picture for Mobile and Calendar at 4 Mbits/s

4.6. Calendar at 9 Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	31.96	32.97	33.84	30.23
	U	34.16	34.25	34.98	33.49
	V	35.44	35.46	36.15	34.86
Average QI		6.97	4.99	4.35	9.50
MBTYPE for MPEG-1 prediction	nCBP	9.67%	49.61%	7.52%	3.03%
	CBP	1.69%	8.95%	0.18%	1.38%
	nCBP+Q	0.05%	0.08%	0.09%	0.01%
	CBP+Q	0.01%	0.01%	0.00%	0.01%
	Fixed Tx	0.00%	0.00%	0.00%	0.00%
	Fixed nTx	0.00%	0.00%	0.00%	0.00%
MBTYPE for Frame prediction	MC,CBP	52.35%	0.00%	66.42%	51.98%
	MC	15.43%	0.00%	1.03%	30.28%
	noMC,CBP	0.42%	0.00%	0.21%	0.67%
	MC,CBP+Q	0.51%	0.00%	0.69%	0.47%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.03%	0.00%	0.02%	0.04%
	Fixed nTx	0.14%	0.00%	0.03%	0.25%
MBTYPE for Field prediction	MC,CBP	17.74%	39.33%	22.30%	9.53%
	MC	1.59%	1.41%	1.09%	2.04%
	noMC,CBP	0.17%	0.16%	0.17%	0.16%
	MC,CBP+Q	0.12%	0.30%	0.18%	0.04%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.05%	0.00%	0.04%	0.06%
	Fixed nTx	0.04%	0.15%	0.02%	0.03%
Number of Macroblock header bits	MB address	1586	1586	1585	1587
	MB Type	4559	2545	4804	4784
	MB Quant	54	31	75	42
	Motion Vectors	5563	2549	6775	5218
	CBP	5195	3310	5596	5267
Number of Coefficient bits	Y	254110	547454	382728	88878
	U	25254	62641	42625	3406
	V	18197	44926	30635	2562
	Total	297561	655021	455987	94846
Number of coefficients transmitted	Non-Zeros	50525	116191	78852	13912
	Zeros	122013	157676	183596	64871
Total bits per picture		315989	666513	476293	113214

Table 21 : Summary of the enhancement coder for 125 pictures of Mobile and Calendar at 9 Mbits/s

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	32.21	33.90	35.15	574437	
2	29.13	33.17	34.62	98497	
3	32.95	34.45	35.60	485378	
4	29.37	33.41	34.81	110010	
5	32.88	34.41	35.62	523074	
6	29.24	33.25	34.73	116665	
7	32.60	34.08	35.37	503489	
8	28.97	33.11	34.47	126928	
9	32.85	34.05	35.30	491149	
10	29.32	33.31	34.70	121661	3151288
11	32.07	33.80	35.08	582869	
12	28.79	33.11	34.50	102253	
13	33.37	34.66	35.90	457345	
14	30.13	33.38	34.80	111316	
15	34.97	36.15	37.17	488141	
16	30.80	34.04	35.48	125369	
17	35.24	36.44	37.51	473289	
18	31.54	34.36	35.82	137437	
19	35.07	36.38	37.54	493457	
20	30.05	33.85	35.44	133194	3104670
21	32.94	34.33	35.44	593563	
22	29.74	33.27	34.65	108372	
23	34.12	35.38	36.44	453977	
24	30.63	33.58	34.98	125941	
25	34.71	36.00	37.10	483573	
26	31.50	34.08	35.54	126853	
27	35.69	36.83	37.86	480871	
28	31.84	34.27	35.75	131767	
29	35.54	36.63	37.73	491526	
30	31.40	34.05	35.40	139088	3135531
31	33.90	35.02	36.12	679888	
32	30.32	33.38	34.76	94335	
33	34.42	35.71	36.75	462173	
34	31.29	33.84	35.19	120116	
35	35.18	36.40	37.40	470786	
36	30.89	34.47	35.89	123474	
37	34.55	36.01	37.09	470852	
38	31.99	34.61	35.97	107256	
39	35.14	36.36	37.37	484302	
40	32.78	34.96	36.31	102563	3115745
41	34.41	35.51	36.73	852022	
42	32.21	34.11	35.69	58850	
43	34.88	36.10	37.23	453284	
44	31.47	34.72	36.24	105573	
45	34.24	35.76	36.98	455930	
46	31.42	34.64	36.05	111214	
47	34.13	35.45	36.63	457404	
48	30.30	34.03	35.49	109657	
49	33.85	34.81	36.15	466499	
50	29.42	33.29	34.84	126851	3197284
51	32.09	33.62	34.86	584180	
52	28.68	32.71	34.05	102945	
53	32.96	34.25	35.38	487918	
54	28.55	32.52	33.94	132317	
55	32.87	34.25	35.43	489732	
56	28.82	32.46	33.93	124836	
57	32.90	34.23	35.38	489797	
58	29.46	32.73	34.11	124245	
59	33.10	34.44	35.67	467697	
60	30.28	33.14	34.42	103481	3107148
61	33.24	34.43	35.63	718029	
62	29.49	33.31	34.67	95632	
63	33.49	34.82	36.03	455071	

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
64	29.50	33.35	34.69	125051	
65	33.27	34.58	35.78	475071	
66	29.59	32.94	34.30	122096	
67	33.23	34.66	35.86	452312	
68	29.61	32.95	34.30	118873	
69	33.44	34.74	35.93	475439	
70	29.68	33.21	34.55	120377	3157951
71	32.38	33.62	34.82	604287	
72	28.94	32.63	33.92	101996	
73	33.18	34.23	35.42	463793	
74	29.58	32.98	34.31	127053	
75	33.58	34.38	35.55	477297	
76	29.74	32.97	34.19	122711	
77	33.80	34.82	35.96	490697	
78	29.64	33.21	34.54	128605	
79	33.70	34.59	35.77	488592	
80	29.63	33.18	34.49	124790	3129821
81	32.42	33.75	34.82	615229	
82	29.14	32.79	33.96	105533	
83	33.28	34.39	35.50	451791	
84	30.80	33.40	34.50	117829	
85	33.71	34.63	35.78	496338	
86	30.26	33.31	34.56	121733	
87	33.49	34.41	35.62	516483	
88	30.60	33.39	34.71	90793	
89	33.74	34.66	35.81	493797	
90	31.24	33.90	35.22	115005	3124531
91	33.32	34.49	35.72	707200	
92	30.71	33.52	34.83	72748	
93	34.04	35.19	36.30	470637	
94	31.78	34.19	35.47	101145	
95	34.66	35.71	36.73	487869	
96	32.58	34.68	35.84	103937	
97	34.99	35.98	37.06	489551	
98	31.38	34.48	35.69	117732	
99	33.98	35.13	36.39	483470	
100	30.01	33.50	34.89	114570	3148859
101	33.25	34.37	35.65	701993	
102	29.45	33.23	34.64	107888	
103	33.06	34.28	35.58	455780	
104	29.44	33.04	34.47	124375	
105	33.18	34.08	35.42	458608	
106	29.59	32.90	34.33	116561	
107	33.35	34.11	35.41	476380	
108	29.66	32.92	34.28	114120	
109	33.42	34.19	35.40	480517	
110	29.93	32.76	34.13	103653	3139875
111	33.27	34.27	35.57	723186	
112	29.74	32.97	34.39	101955	
113	33.18	34.25	35.57	446617	
114	29.66	32.88	34.30	120524	
115	33.36	34.23	35.52	458566	
116	29.94	33.23	34.59	110063	
117	33.58	34.33	35.63	481780	
118	30.65	33.52	34.88	107175	
119	33.61	34.32	35.62	478268	
120	31.22	33.93	35.31	104789	3132923
121	33.12	34.17	35.44	727782	
122	29.88	33.33	34.70	87270	
123	33.53	34.50	35.71	447670	
124	30.67	33.70	34.94	109618	
125	33.74	34.48	35.74	480613	

Table 22 : Enhancement coder statistics picture by picture for Mobile and Calendar at 9 Mbits/s

4.7. Popple at 9Mbits/s

		All	Intra	Predicted	Extrapolated
SNR	Y	31.96	32.97	33.84	30.23
	U	34.16	34.25	34.98	33.49
	V	35.44	35.46	36.15	34.86
Average QI		6.97	4.99	4.35	9.50
MBTYPE for MPEG-1 prediction	nCBP	9.67%	49.61%	7.52%	3.03%
	CBP	1.69%	8.95%	0.18%	1.38%
	nCBP+Q	0.05%	0.08%	0.09%	0.01%
	CBP+Q	0.01%	0.01%	0.00%	0.01%
	Fixed Tx	0.00%	0.00%	0.00%	0.00%
	Fixed nTx	0.00%	0.00%	0.00%	0.00%
MBTYPE for Frame prediction	MC,CBP	52.35%	0.00%	66.42%	51.98%
	MC	15.43%	0.00%	1.03%	30.28%
	noMC,CBP	0.42%	0.00%	0.21%	0.67%
	MC,CBP+Q	0.51%	0.00%	0.69%	0.47%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.03%	0.00%	0.02%	0.04%
	Fixed nTx	0.14%	0.00%	0.03%	0.25%
MBTYPE for Field prediction	MC,CBP	17.74%	39.33%	22.30%	9.53%
	MC	1.59%	1.41%	1.09%	2.04%
	noMC,CBP	0.17%	0.16%	0.17%	0.16%
	MC,CBP+Q	0.12%	0.30%	0.18%	0.04%
	noMC,CBP+Q	0.00%	0.00%	0.00%	0.00%
	Fixed Tx	0.05%	0.00%	0.04%	0.06%
	Fixed nTx	0.04%	0.15%	0.02%	0.03%
Number of Macroblock header bits	MB address	1586	1586	1585	1587
	MB Type	4559	2545	4804	4784
	MB Quant	54	31	75	42
	Motion Vectors	5563	2549	6775	5218
	CBP	5195	3310	5596	5267
Number of Coefficient bits	Y	254110	547454	382728	88878
	U	25254	62641	42625	3406
	V	18197	44926	30635	2562
	Total	297561	655021	455987	94846
Number of coefficients transmitted	Non-Zeros	50525	116191	78852	13912
	Zeros	122013	157676	183596	64871
Total bits per picture		315989	666513	476293	113214

Table 23 : Summary of the enhancement coder for 125 pictures of Popple at 9 Mbits/s

No.	snr Y	snr U	snr V	Bits/pic	Bits/GOP
1	34.92	37.71	38.44	395957	
2	32.70	35.88	36.91	103489	
3	36.90	40.10	40.66	497083	
4	34.13	37.31	38.33	139775	
5	37.34	40.50	41.10	514331	
6	34.13	37.56	38.55	130943	
7	37.50	40.83	41.33	522974	
8	34.22	37.72	38.64	125510	
9	37.60	41.01	41.51	524286	
10	34.21	37.67	38.78	131243	3085591
11	36.53	39.85	40.49	568328	
12	33.08	36.50	37.79	90522	
13	37.04	40.48	41.12	485086	
14	33.92	37.27	38.59	120959	
15	37.33	40.67	41.27	504011	
16	33.90	37.35	38.62	120861	
17	37.38	40.67	41.33	505246	
18	33.93	37.38	38.57	120475	
19	37.35	40.58	41.25	503086	
20	33.97	37.41	38.51	122328	3140902
21	36.45	39.77	40.34	571268	
22	32.80	36.04	37.29	90394	
23	36.93	40.25	40.85	486679	
24	33.61	36.87	38.08	119162	
25	37.10	40.45	41.06	501882	
26	33.82	37.26	38.39	121374	
27	37.20	40.62	41.10	504110	
28	33.84	37.37	38.34	120758	
29	37.25	40.65	41.12	503205	
30	33.82	37.33	38.22	124133	3142965
31	36.48	39.76	40.35	566991	
32	32.86	36.32	37.32	92143	
33	37.00	40.50	41.01	484861	
34	33.72	37.27	38.27	122078	
35	37.09	40.64	41.08	500824	
36	33.76	37.35	38.27	125315	
37	37.22	40.70	41.22	498921	
38	33.73	37.40	38.42	125846	
39	37.08	40.65	41.18	500145	
40	33.55	37.35	38.44	126085	3143209
41	35.83	39.04	39.68	485351	
42	32.57	36.10	37.32	95194	
43	36.84	40.29	40.76	513289	
44	32.64	36.77	37.91	136948	
45	36.39	39.84	40.43	527724	
46	31.88	36.19	37.22	116226	
47	36.32	39.65	40.22	520275	
48	32.08	36.25	37.22	128103	
49	36.22	39.51	40.26	533740	
50	31.13	35.28	36.71	151743	3208593
51	34.80	37.70	38.49	352593	
52	31.79	35.14	36.35	149854	
53	36.48	39.83	40.44	489255	
54	32.32	35.62	36.75	148140	
55	36.86	40.30	40.79	513215	
56	31.92	35.51	36.67	143505	
57	36.96	40.45	40.69	512950	
58	32.66	36.21	36.81	136412	
59	37.31	41.11	41.17	505701	
60	33.69	37.15	37.60	144773	3096398
61	36.15	39.30	39.53	360089	
62	34.67	37.78	38.26	164998	
63	37.64	41.65	41.77	480498	
64	34.82	37.88	38.50	160308	
65	37.85	42.00	42.10	491424	
66	34.82	37.91	38.54	150743	
67	38.01	42.21	42.30	503335	
68	34.93	37.72	38.38	152751	
69	38.07	42.28	42.42	503059	
70	35.04	37.92	38.39	152412	3119617
71	36.97	40.92	41.05	357167	
72	35.39	38.29	38.74	175856	
73	37.87	42.11	42.15	472773	
74	35.34	38.49	38.81	173558	
75	37.86	42.21	42.11	489987	
76	34.95	38.02	38.36	159101	
77	37.85	42.19	42.09	499761	
78	34.87	37.89	38.21	162691	
79	37.83	42.32	42.10	496128	
80	34.83	37.69	38.04	164687	3151709
81	36.73	40.72	40.84	350034	
82	34.80	37.49	37.87	178641	
83	37.36	41.35	41.34	476943	
84	34.32	36.75	37.21	173534	
85	37.27	41.10	41.14	489473	
86	33.81	36.05	36.43	182128	
87	37.07	40.70	40.77	479659	
88	33.45	35.57	35.94	185849	
89	36.72	40.01	40.12	475677	
90	33.25	35.36	35.69	190344	3182282
91	35.39	38.23	38.32	375886	
92	32.81	34.75	34.98	177659	
93	35.82	38.68	38.77	461613	
94	32.82	34.71	35.06	188954	
95	35.72	38.44	38.58	462308	
96	32.39	34.49	34.77	198449	
97	35.45	37.97	38.13	456380	
98	31.94	34.07	34.34	207603	
99	35.25	37.48	37.73	443838	
100	31.72	33.87	34.10	211762	3184452
101	33.84	36.06	36.33	352575	
102	31.08	32.94	33.15	177731	
103	34.63	36.86	36.99	439321	
104	31.72	33.57	33.76	203098	
105	34.69	36.81	36.93	451342	
106	31.92	33.67	33.90	201786	
107	34.87	36.92	37.02	456835	
108	31.77	33.54	33.80	203483	
109	34.87	36.86	37.04	460484	
110	31.52	33.48	33.78	200135	3146790
111	33.92	35.83	36.13	361062	
112	31.14	32.92	33.22	174099	
113	34.85	36.72	37.02	427045	
114	31.90	33.67	33.97	207933	
115	34.77	36.80	37.01	455735	
116	31.83	33.45	33.85	198860	
117	34.73	36.63	36.86	464510	
118	31.43	33.16	33.40	197366	
119	34.73	36.56	36.82	454650	
120	31.29	33.19	33.56	207913	3149173
121	33.62	35.51	35.80	360443	
122	30.97	32.80	33.06	174292	
123	34.55	36.46	36.73	437960	
124	31.69	33.40	33.88	193793	
125	34.72	36.62	36.91	461362	

Table 24 : Enhancement coder statistics picture by picture for Popple at 9 Mbits/s

5. Implementation description

5.1. Overview

Figure 7 shows the functionality of the encoder and decoder systems.

The encoder consists of a MPEG-1 coder and an enhancement coder. The CCIR601 input pictures are immediately converted to 4:2:0 format. These are down-sampled to SIF and coded by the MPEG-1 coder. The resulting coded pictures are up-sampled to 4:2:0 format and are used as one prediction mode for the enhancement coder.

The decoder consists of a MPEG-1 decoder and an enhancement decoder. An up-sampling process is used to obtain the MPEG-1 prediction for the enhancement decoder. The display pictures are subsequently converted back to 4:2:2.

Except for the motion estimation process, the MPEG-1 coder and the enhancement coder are implemented, by time sharing, in a single chip. The same single chip is used in the decoder for both the MPEG-1 decoding and enhancement decoding processes. This chip is referred to as the coder chip.

The motion estimation process is performed in parallel by four prediction chips. Each chip processes one macroblock at a time. It firstly chooses the best full pel motion vector and then performs a half pel search around this vector. It then chooses the best prediction mode and passes this information to the coder chip.

The up-sampling and down-sampling processes are both implemented in single chips. The same chip, configured differently, is used for both processes. This chip is referred to as the up/down-sampling chip.

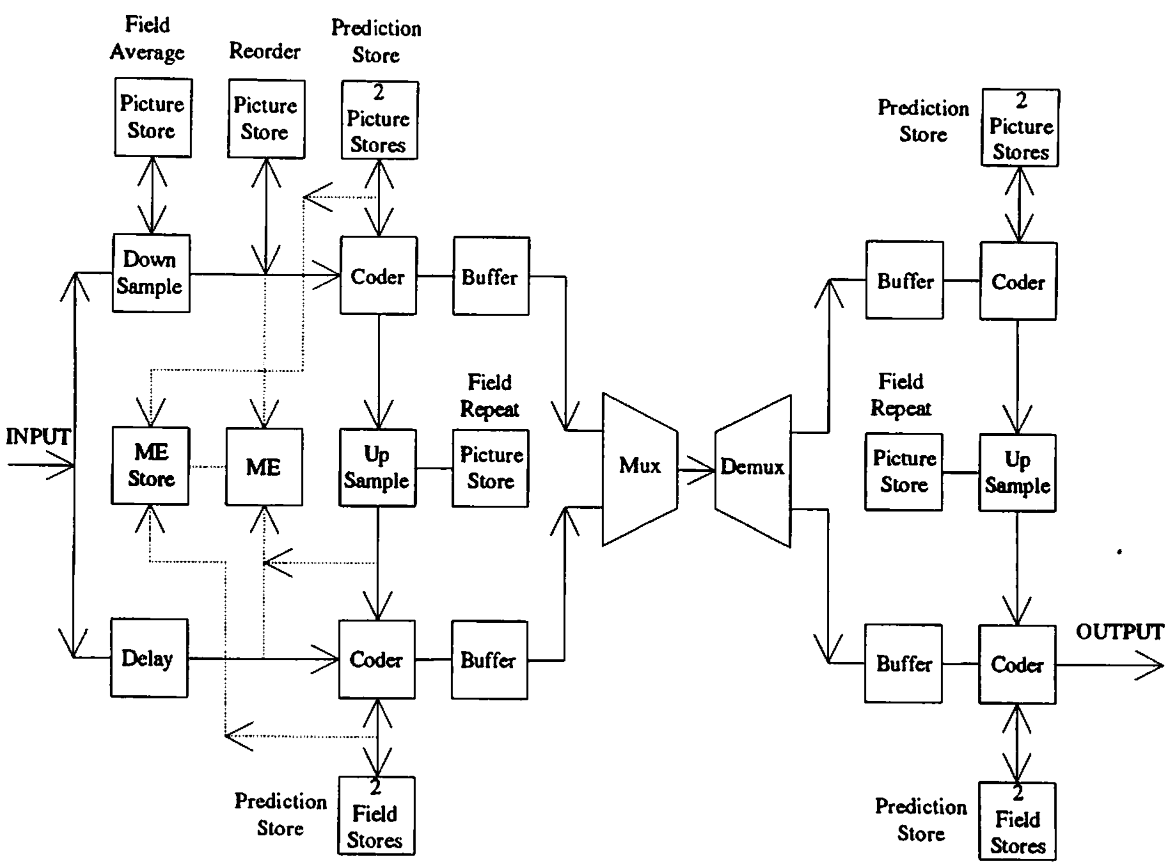


Figure 7. Block diagram showing the data paths for the encoder and decoder system.

5.2. Timing and memory requirements

5.2.1. System timing

All stages of processing incur some amount of delay. This section describes the major delays in the system, that is, delays measured in units of field periods (20ms).

The following diagram shows the system timing. O, E represent odd and even fields, I, P and B represent MPEG-1 intra, predicted and interpolated pictures.

```
Input             O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
Field Ave.            I1      B1      P1      B2      P2
Reordered             I1      B0      P1      B1      P2      B2
MP1 coded             I1      B0      P1      B1      P2      B2
Ordered                       B0      I1      B1      P1      B2      P2
Up-sampled                    B0  B0  I1  I1  B1  B1  P1  P1  B2  B2  P2  P2
Delayed Input                         O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
Enhanced coded                        O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
MP1 buffered                                              I1      B0      P1      B1      P2      B2
MP1 decoded                                               I1      B0      P1      B1      P2      B2
Enhanced buffered                                     O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
Enhanced delayed                                                          O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
Ordered                                                                   I1      B1      P1      B2      P2
Up-sampled                                                                I1  I1  B1  B1  P1  P1  B2  B2  P2  P2
Enhanced decoded                                                          O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
Output                                                                    O1  E1  O2  E2  O3  E3  O4  E4  O5  E5
```

The only significant delay in the down-sampling process is a field delay caused by field averaging. Interpolated pictures are reordered and delayed by two frame periods (4 field periods). Coding incurs no significant delay. Ordering delays intra and predicted pictures by two frame periods. Up-sampling incurs no delay. The MPEG-1 prediction is therefore ready for use by the enhancement coder after a delay of 5 field periods.

The MPEG-1 coded data buffer incurs a delay of 5 frame periods (10 field periods). Decoding incurs no delay. Ordering delays intra and predicted pictures only. Up-sampling incurs no delay. The MPEG-1 prediction is therefore ready for use by the enhancement decoder after a further delay of 10 field periods.

The enhancement coded data buffer causes a delay of 5 field periods. Decoding incurs no delay. A further delay of five field periods is required to synchronize with the MPEG-1 decoder. This delay can occur in the coded data buffer and be split between the encoder and decoder buffer in any way; it is determined by the multiplexing scheme.

A total delay of 15 field periods, equal to 300ms, occurs between encoder input and decoder output. This delay is primarily due to two factors. The reordering of MPEG-1 pictures incurs a delay of 4 field periods, equal to 80ms. The MPEG-1 coded data buffer incurs a delay of 10 field periods, equal to 200ms.

When the coding scheme is used for communication applications, the MPEG-1 process is replaced by the H.261 process. This eliminates the 80ms reorder delay. The need for intra pictures is also removed. It is the intra pictures which cause the need for such a large coded data buffer. Elimination of intra pictures should allow the coded data buffer to be halved. This would reduce the total delay by 80+100 = 180ms to a total of only 120ms.

5.2.2. Delay store

This is only present in the encoder. It is used to compensate for the delays caused by the MPEG-1 coder. Its size is significantly reduced when no interpolated pictures are coded in the MPEG-1 process.

The store is required to delay the input pictures by 5 field periods. It is also used to perform the line to macroblock scan conversion. The required memory is therefore:

$$5*704*288*1.5 = 1.5\text{Mbyte}$$

This is configured as two ping-pong RAMs of 0.75M by 8. It is required to read or write one field in a field period. The cycle rate required is therefore:

$$704*288*1.5*50 = 15.2\text{MHz}$$

5.2.3. Prediction store

This is present in the encoder and in the decoder. For simplicity of language this section describes the operation only for the decoder. The prediction store stores all pictures and fields needed for prediction. It therefore has to store two SIF pictures for the MPEG-1 process and two fields for the enhancement process. The memory required is therefore:

$$2*352*288*1.5 + 2*704*288*1.5 = 912 \text{ kbytes}$$

This is configured as 256k by 32. Data is stored in line format with four consecutive pels along a line stored at the same address.

The system is clocked so that in one field period (20ms), one MPEG-1 picture and one enhancement field are decoded. During the next period, no MPEG-1 picture is decoded, and one enhancement field is decoded. This requires two MPEG-1 macroblocks to be decoded in the same time interval as four enhancement macroblocks. This implies that a total of six blocks must be processed in one MPEG-1 block period in the worst case.

Four consecutive pels along a line are stored at each RAM address. 16 cycles are therefore required to access a block. To access a 9 by 9 area for half pel prediction, three cycles are always needed for each row of 9 pels, so 3*9 = 27 cycles are needed to access the whole prediction area.

To decode a MPEG-1 block, the worst case memory access requirements occur when decoding predicted blocks. In this case it is necessary to read the prediction data and the data for up-sampling and to write the decoded pels. In the worst case of half pel motion compensation, 81 pels need to be read to form the prediction; this takes 27 clock cycles. 16 cycles are needed to read the data for up-sampling and 16 for writing the decoded pels. A total of 27+16+16 = 59 cycles are therefore needed.

To decode an enhancement block, the worst case memory access requirements occur when decoding prediction blocks. In this case it is necessary to read the prediction data and write the decoded data. This takes a total of 27+16 = 43 cycles.

The minimum cycle rate is therefore given by:

$$(2*59 + 4*43) * 6 * 396 * 25 = 17.2\text{MHz}$$

Every MPEG-1 block period, four enhancement blocks and up to two MPEG-1 blocks are processed. Data flow to and from the prediction store is bursty. For example, data for up-sampling is read from the store in two bursts of 16 cycles in each block period of every other field. Block buffers are needed in the coder and up/down-sampling chips to smooth this burstiness. These and other compensating delays have been ignored in this implementation study.

5.2.4. Picture repeat/ field average store

This type of store occurs once in the decoder and twice in the encoder. It is used for picture repeating in the up-sampling process and for field averaging in the down-sampling process. In both cases it must store one SIF picture. Its size is:

$$352*288*1.5 = 152\text{ kbytes.}$$

It is configured as 256k by 8. In both cases it is necessary to transfer one SIF picture in a field period. This requires a cycle rate of:

$$352*288*1.5*50 = 7.6\text{MHz}$$

5.2.5. Picture reorder store

This store occurs once in the encoder. It is used to delay interpolated pictures prior to coding. Its size depends on the number of interpolated pictures between intra and predicted pictures. In this implementation this number is one. The required memory size is equal to one SIF picture, that is:

$$352*288*1.5 = 152\text{ kbytes.}$$

It is configured as 256k by 8. It is necessary to write one SIF picture and read one SIF picture in a field period. This requires a cycle rate of:

$$2*352*288*1.5*50 = 15.2\text{MHz}$$

5.2.6. Coded data buffer

This must store 0.2s of MPEG-1 coded data and 0.1s of enhancement data. The worst case occurs when the MPEG-1 bit rate is 2.5Mbit/s and the enhancement bit rate is 7.5Mbit/s. The required memory is:

$$0.2*2500000 + 0.1*7500000 = 1250000\text{ bits} = 150\text{ kbytes}$$

However, the additional 0.1s delay in the MPEG-1 coded data buffer is compensated in the enhancement coded data buffer. This can be split between encoder and decoder, 0.05s in each. The required memory is therefore:

$$0.2*2500000 + 0.15*7500000 = 1625000\text{ bits} = 200\text{ kbytes}$$

The bandwidth required is the same in the encoder as in the decoder. For the decoder it is evaluated as follows. It is required to be able to read one symbol of length 28 bits at the total pel rate and to write at the total data rate. It is configured as 64K by 32. The required cycle rate is therefore:

$$352 * 288 * 1.5 * 25 * (1+4) + 10000000/32 = 19.3\text{MHz}$$

5.2.7. Motion estimation store

This must store the search area for the motion estimation process. It is necessary to store two MPEG-1 pictures and two enhancement fields. As motion estimation is only performed on luminance pels, it is only necessary to store luminance pels. The total memory requirement is:

$$2*352*288 + 2*704*288 = 609\text{ kbytes}$$

It is configured as 192K by 32.

The vector range is +/- 7 for MPEG-1 and +/- 15 vertically and +/- 30 horizontally for enhancement coding. It is required to read a 48 pel high strip for the enhancement search area and a 32 pel high strip for the MPEG-1 search area for each row of macroblocks. It is required to write six macroblocks every MPEG-1 macroblock period. Noting that chrominance data is not used for motion estimation, that the MPEG-1 motion estimation must be done in a field period, and that two prediction images (forward/backward and field/frame) must be searched, the required read cycle rate is:

$$2*(704*48+352*32)*18*50/4 = 20.3\text{MHz}$$

The required write cycle rate is:

256 * (4+2) * 396 * 25 / 4 = 3.8MHz

The total cycle rate is therefore:

20.3 + 3.8 = 24.1MHz

5.3. Architecture

5.3.1. Coder chip

A block diagram of the coder chip is shown in figure 8. It performs either the MPEG-1 encoding and the enhancement encoding process or the MPEG-1 decoding and the enhancement decoding process. The following sections explain how the chip functions when configured for the decoding process and when configured for the encoding process.

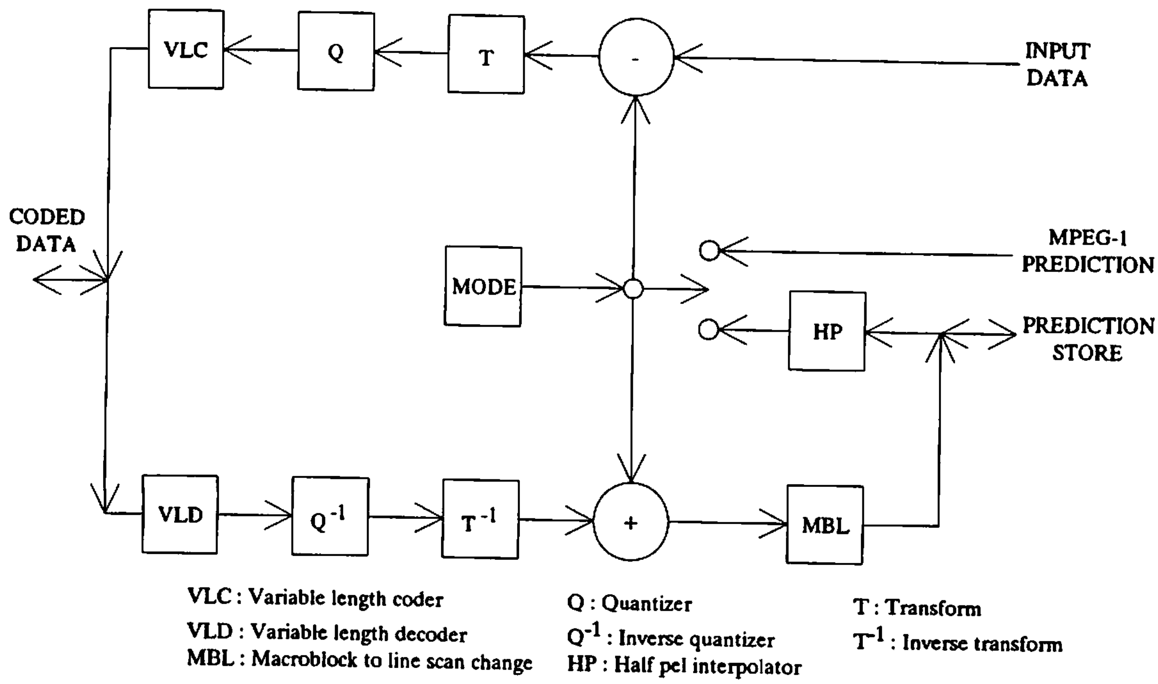


Figure 8. Block diagram of the coder chip.

5.3.1.1. Decoder operation

The chip is clocked at the total pel rate. This is equal to the sum of the MPEG-1 pel rate and the enhancement pel rate:

clock rate = 352 * 288 * 1.5 * 25 * (1 + 4) = 19MHz

Coded data is read from the coded data buffer into the variable length code decoder (VLD) along a 32 bit bus. The VLD can decode a symbol every clock cycle if required. The reverse scan and inverse quantization module converts blocks to vertical scan and performs the inverse quantization process. After processing a RUN/LEVEL pair, another is fetched from the VLD which then decodes the next symbol from the bitstream. The transform module performs the transform process and transposes the block.

The prediction multiplexer and pel adder module selects the correct prediction mode and performs the adder function. The scan is changed from macroblock scan to line scan. For display, 4:2:2 format is restored by line repeating chrominance data.

All intra and predicted MPEG-1 pictures and all intra and predicted enhancement fields are written to the store. Prediction pictures and fields are read from the store and the half pel interpolation function is performed. MPEG-1 pictures are also read from the store and directed to the up-sampling chip.

5.3.1.2. Encoder operation

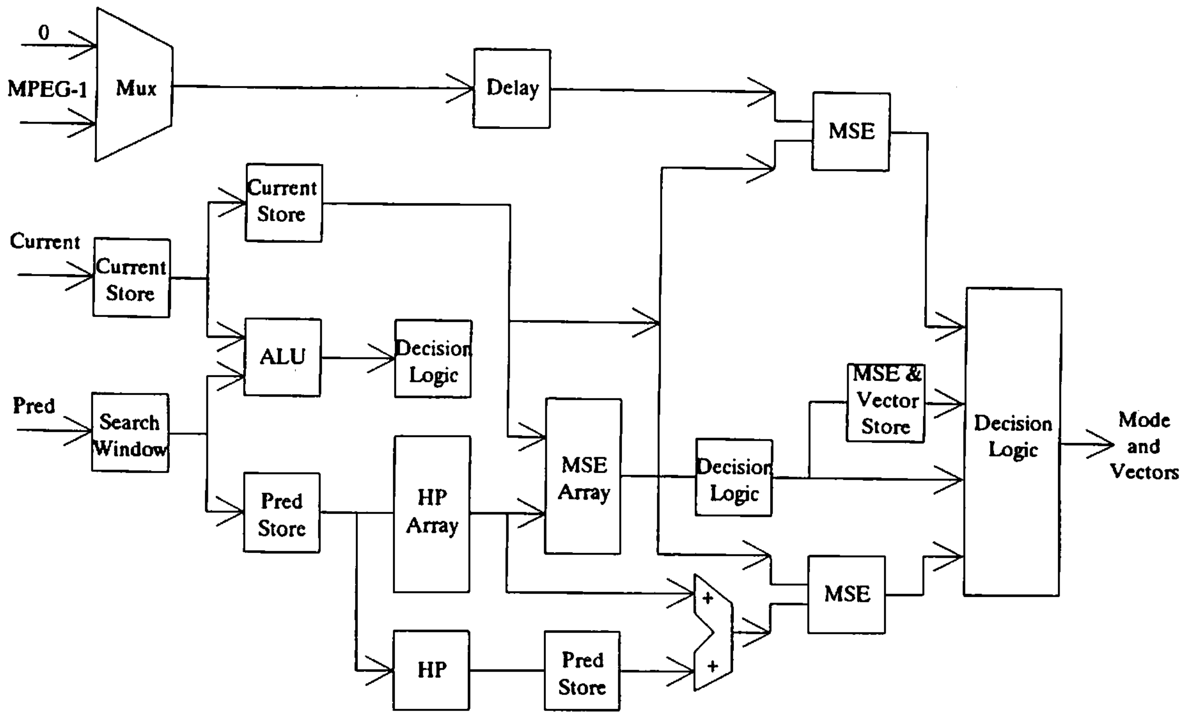
The chip is clocked at the total pel rate.

Input data is in 4:2:2 format. It is converted to 4:2:0 format by dropping every second chrominance line. Data is then passed to the subtractor module. The mode decision module chooses a prediction from the valid prediction modes. The transform module performs the transform process and changes the block scan to vertical scan. The quantization and scan module performs the quantization process and generates RUN/LEVEL pairs. These are passed to the variable length code encoder (VLC) which is capable of coding one RUN/LEVEL pair per clock cycle. Coded data is written to the coded data buffer along a 32 bit bus.

The other modules function as in the decoder description above.

5.3.2. Prediction chip

A block diagram for the prediction chip is shown in figure 9. This chip performs the motion estimation and mode decision functions.



MUX : Multiplexer HP : Half pel interpolator MSE : Mean square error

Figure 9. Block diagram of prediction chip.

An integer pel full search is performed on the search area. For the MPEG-1 macroblocks the translational motion between two consecutive MPEG-1 frames is estimated. The worst case is for interpolated pictures when the full search is performed for both forward and backward vectors. For the enhancement macroblocks the translational motion between two consecutive like fields (frame prediction) and two consecutive unlike fields (field prediction) are estimated.

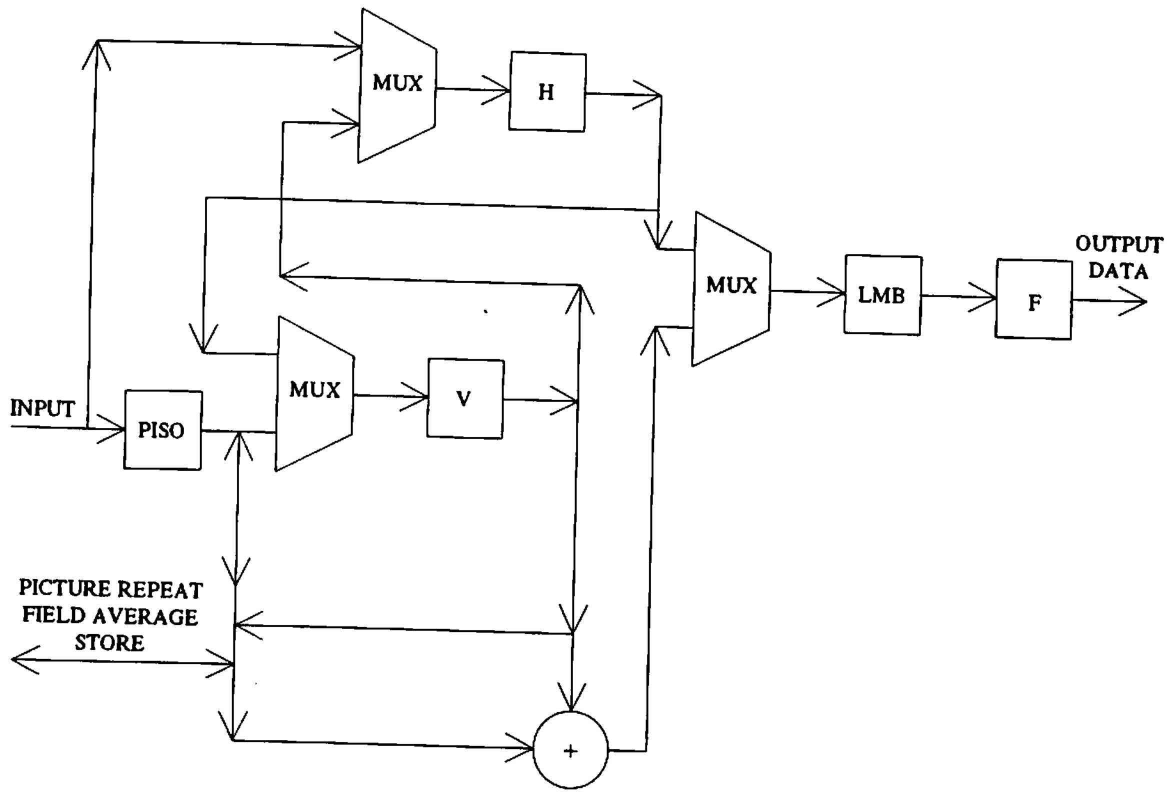
The current picture macroblock (16x16) is compared with the data in the search window from the reference picture. For MPEG-1 macroblocks the search range is +/-7 in both the horizontal and vertical direction. For enhancement macroblocks the search range is +/-30 horizontally and +/-15 vertically.

The eight half pel displacements centred on the full pel vectors are searched to obtain a half pel vector and error term for each prediction mode.

The possible prediction modes are compared with each other and the intra mode. The best mode and the chosen vector(s) are putput to the coder chip.

5.3.3. Up/down-sampling chip

A block diagram for the up/down sampling chip is shown in figure 10. It performs either the up-sampling process or the down-sampling process. The following sections explain how the chip functions when configured for the up-sampling process and when configured for the down-sampling process.



MUX : Multiplexer
H : Horizontal filter/interpolator
LMB : Line to macroblock scan change
PISO : 32 to 8 bit converter
V : Vertical line shifter
F : Prediction filter

Figure 10. Block diagram of up/down-sampling chip.

5.3.3.1. Up-sampling operation

The chip is clocked at the total pel rate of 19MHz.

Data is clocked into the chip in line scan along a 32 bit bus. Four consecutive pels along a line are therefore clocked in during a clock cycle. This is passed through a parallel to serial type converter to separate into 8 bit pels.

The timing of the system as defined above implies that one MPEG-1 picture is clocked into the chip in a field period (20ms), and no data is clocked in during the next field period. During the period when data is clocked in, it is immediately written to the picture repeat store. During the period when no data is clocked in, data is retrieved from the picture repeat store. This achieves the temporal up-sampling.

Data is then passed to the vertical line shift module. This alternatively shifts fields up and down a quarter of a line. This reintroduces the interlace. Data is then passed to the horizontal filter/interpolator module. This interpolates one pel between each input pel.

The line to macroblock module changes the line scan to macroblock scan. The filter function performs the prediction filtering process.

5.3.3.2. Down-sampling operation

The chip is clocked at the total pel rate.

Data is clocked into the chip in line scan on the least significant 8 bits of a 32 bit bus. It is then passed to the horizontal filter/interpolator module. This filters and sub-samples the data to reduce the horizontal resolution to 352 pels per line. It is then passed to the vertical line shift module. This alternatively shifts fields up and down a quarter of a line so as to remove the interlace.

The timing of the system as defined above implies that one MPEG-1 picture is clocked out of the chip in a field period (20ms), and no data is clocked out during the next field period. During the period when no data is clocked out, data is written to the field average store. During the period when data is clocked out, data is retrieved from the field average store and added to the current data. This achieves the temporal down-sampling.

The line to macroblock module changes the line scan to macroblock scan. The filter function is by-passed.

5.4. Functional description

This section considers the operation of the coder, prediction and up/down-sampling chips in more detail. The operation of each module is described. For each module, the following statistics are given: the rate at which the module is clocked, the memory required by the module, the width of additions and multiplications, the number of additions and multiplications needed per clock cycle, the size of any look-up table required and the number of accesses to such a table per clock cycle. The complexity of control logic and short compensating delays are not considered.

5.4.1. Coder chip

A block diagram for the coder chip is shown in figure 2.

5.4.1.1. Variable length decoder

A block diagram for this module is shown in figure 11. 32 bits are read from the coded data buffer at a time. They are stored in a barrel shifter and input to a set of 5 PLAs. The PLAs are used to decode the variable length codes: macroblock address, MTYPE, vectors, CBP and RUN/LEVEL pairs. The output of the PLAs is a 16 bit symbol representing the decoded value and a 5 bit number indicating the number of bits in the variable length code. This number is fed back to the barrel shifter, which then shifts by this number. If less than 32 bits are left in the barrel shifter, another 32 are read in. The finite state machine (FSM) controls the selection of the correct PLA to use and generates flags needed by other modes.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	-
Width of additions	-
Additions per clock cycle	-
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

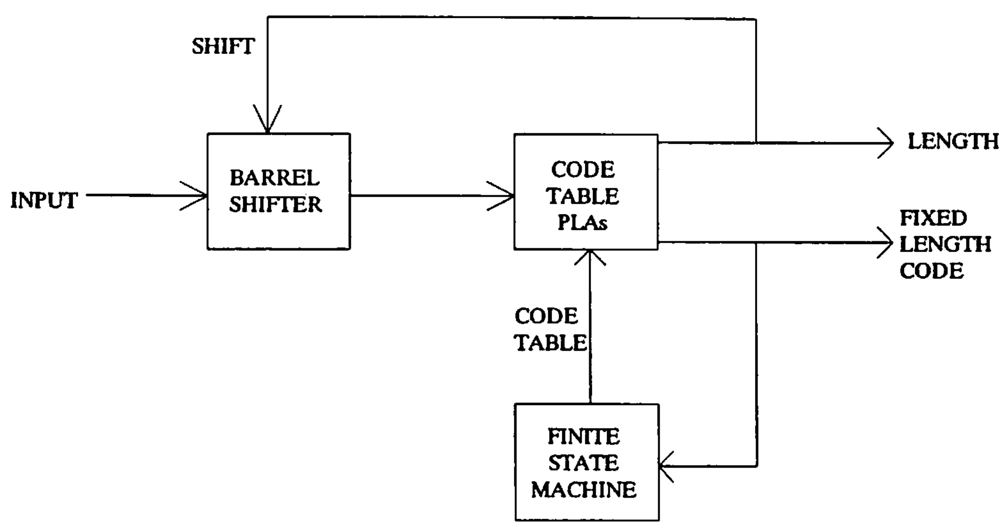


Figure 11 Block diagram of variable length decoder.

5.4.1.2. Reverse scan and inverse quantization

A block diagram of this module is shown in figure 12. The module can be split into two parts: the inverse quantization block and the reverse scan block. A RAM of size 128 x 12 bits is used to interface to the inverse transform module. This module writes to one half while data is read from the other half.

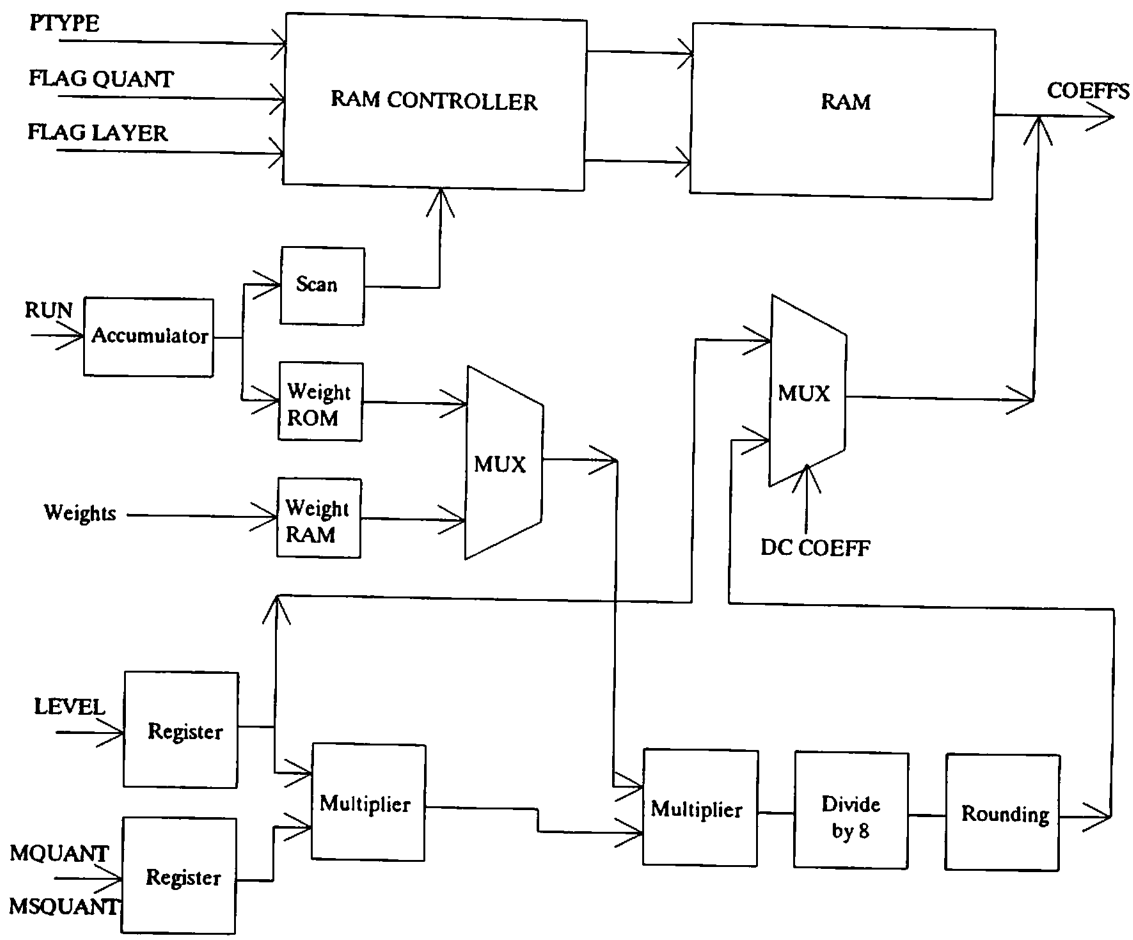


Figure 12. Block diagram showing reverse scan and inverse quantization.

The reverse scan block consists of an accumulator to track the RUNs of zeros. It is used to address the scan ROM and the weighting ROM that have been collapsed into a single 64 x 12 bit ROM and weight RAM used to store downloaded weighting matrices. When used for MPEG-1 blocks, the scan ROM is used to address the RAM but when used for enhancement blocks, which are already in up/down scan, the accumulator is used directly to address the RAM.

The inverse quantization block requires two multipliers, to perform inverse quantization and inverse weighting, a half adder to perform rounding and a clipper to clip to 12 bits.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	128 x 12 & 128 by 6
Width of additions	6
Additions per clock cycle	1
Width of multiplications	16x5 & 6x21
Multiplications per clock cycle	1 of each
Table size	64 x12
Table lookups per clock cycle	1

5.4.1.3. Inverse transform

A block diagram for this module is shown in figure 13. The transform function is performed by two monodimensional transforms performed sequentially. An intermediate array is used for transposition. Butterflies are used to reduce the amount of coefficient ROM required.

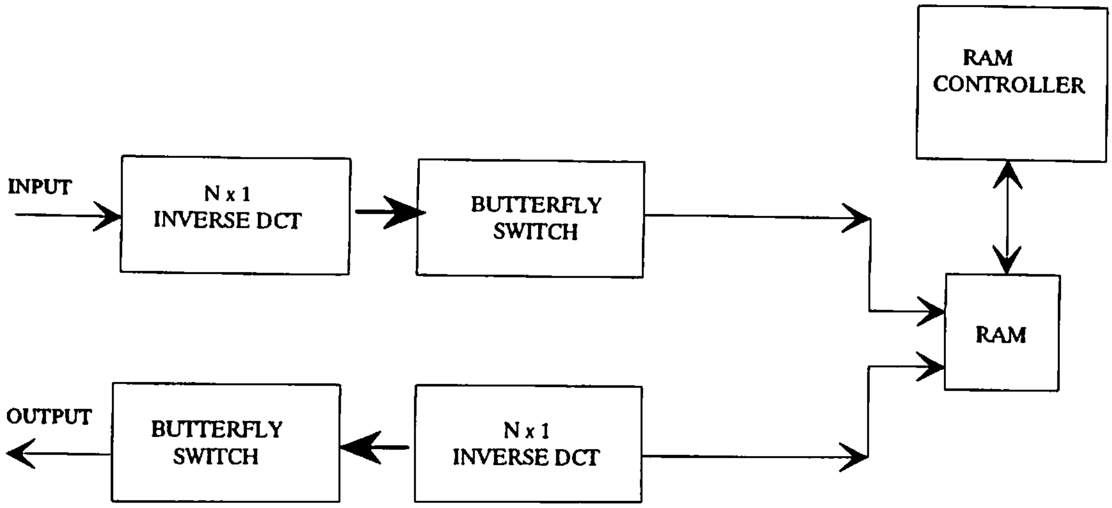


Figure 13. Block diagram of inverse transform.

The transposition memory has size 64 by 12 bits. It is alternatively accessed by each monodimensional transform in row and column fashion.

Figure 14 shows the monodimensional N transform. A row of N samples of n bits each are shifted into the input register (IR) and then loaded in parallel into the bus register, BR. It is shifted serially, 1 bit for each sample, to form a N-bit bus, CB. This bus is used by each ROM And Accumulator (RAC) to address the coefficient ROM, 2^N by k bits, to produce a partial sum of products. Each partial result is shifted, by means of its own accumulator, m bits wide, and added to the next stored coefficient due to the new address on CB. This process is iterated n times, in parallel for all RACs, to produce the output vector. The output register, OR, composed of N by m bits, outputs the transformed array.

In this implementation a value of k equal to 12 is used. N has the value 12 and n the value 8.

The statistics for the module are as follows.

Clock rate (MHz)	38
Memory size	64 x 12
Width of additions	16 of 1 & 16 of 12
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	16 of 16 x12
Table lookups per clock cycle	1

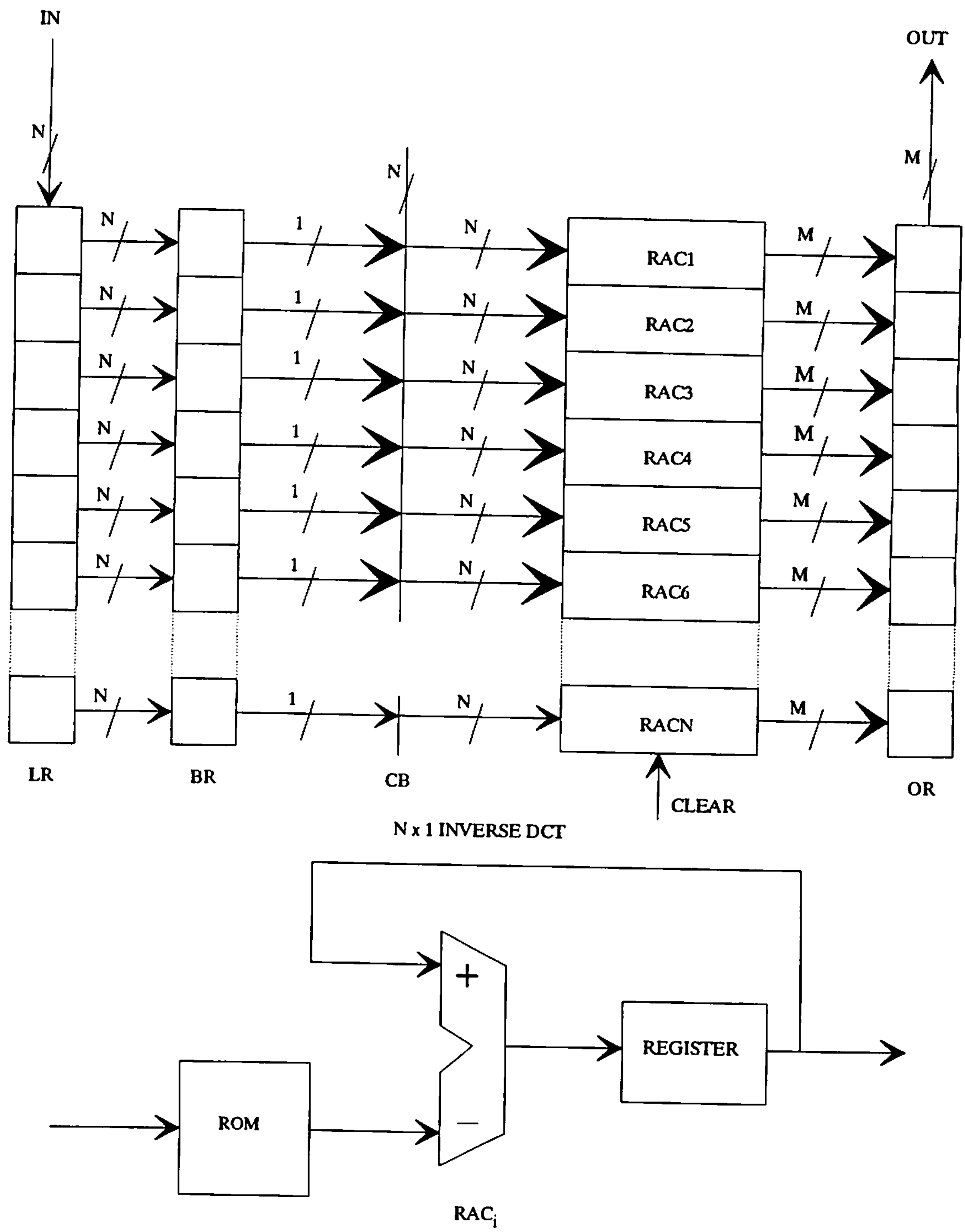


Figure 14. Block diagram of monodimensional N transform.

5.4.1.4. Pel adder

The function of this module is to reconstruct pels. It is composed of an adder to perform the addition, if required, and a clipper to clip to the range 0 to 255. A block diagram for the module is shown in figure 15.

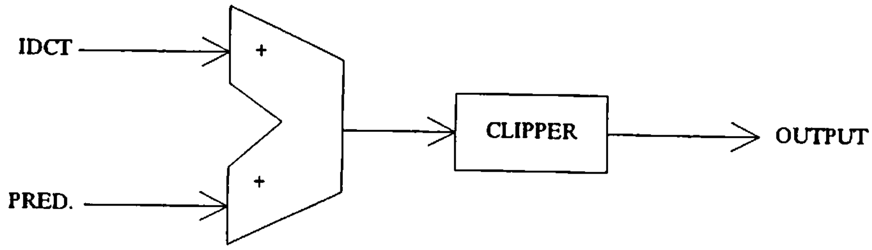


Figure 15. Block diagram showing pel adder.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	-
Width of additions	9
Additions per clock cycle	1
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.1.5. Motion compensation

This stage is responsible for prediction store access. It has to store and retrieve luminance and chrominance pels from the prediction store in order to perform the motion compensation function. To simplify the diagram, this function is not shown in figure 2, the block diagram of the coder chip.

A block diagram of the module is given in figure 16. It is mainly composed of three differential address computation units, labelled accumulator, two 20 bit luminance address registers (LADDR_RAM0, LADDR_RAM1), two 19 bit chrominance address registers (CADDR_RAM0, CADDR_RAM1) and a ping-pong RAM control unit (RAMC).

The differential address computation stage stored the differential input address (MBADDR, VVEC and HVEC) and determines the new value. The operation of the module is controlled by RAMC.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	128 x 8
Width of additions	17 of up to 19
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.1.6. Half pel interpolator

This performs the half pel interpolation function. The worst case is for MPEG-1 interpolated blocks when two interpolations must be performed. A block diagram of the module is shown in figure 17. The half pel interpolator consists of three adders to average four neighbouring pels. A 64 by 8 RAM is used to store the first (forward) block while the second (backward) block is interpolated. The two predictions are added.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	64 x 8
Width of additions	3 of 8
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

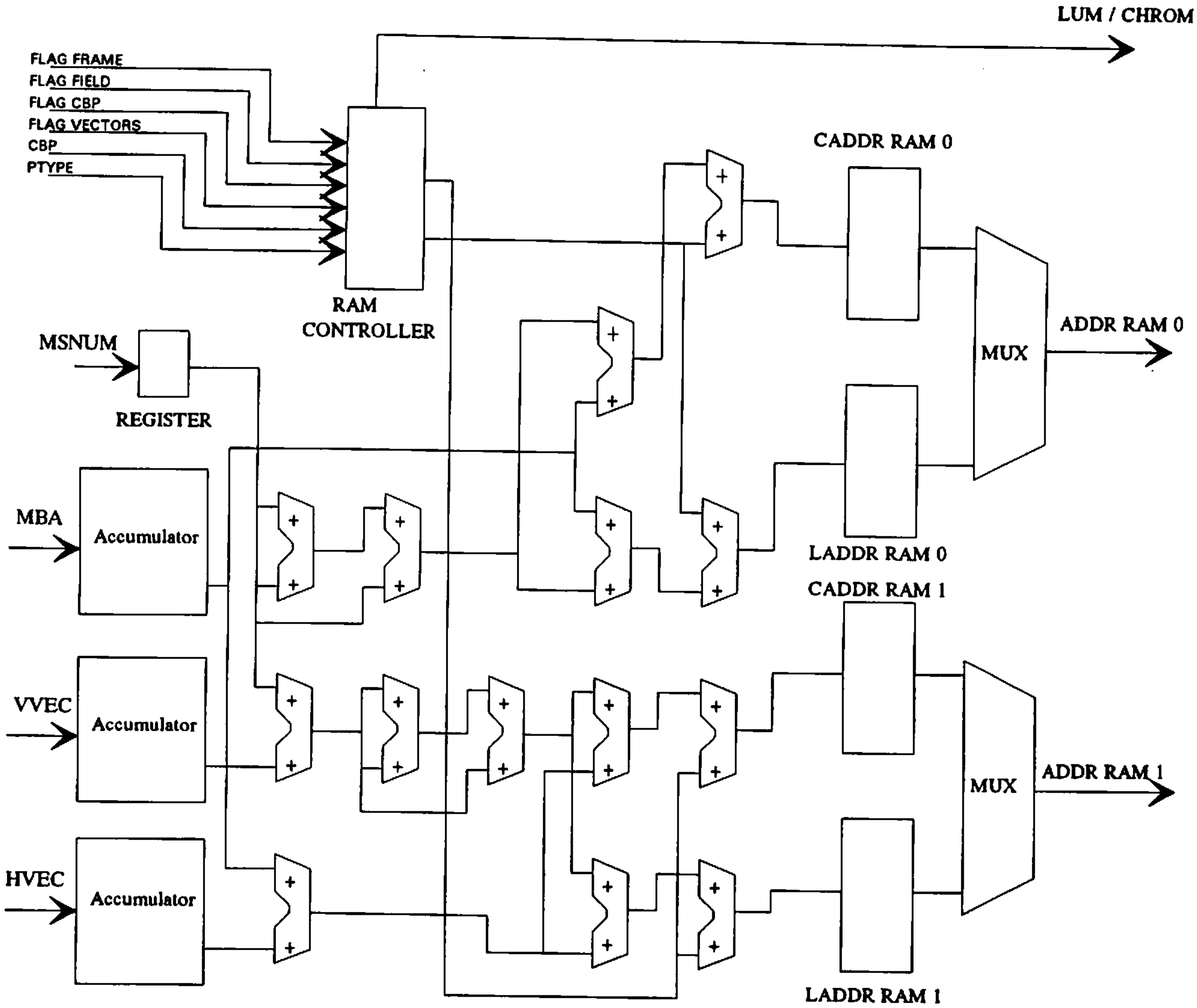


Figure 16. Block diagram of motion compensation.

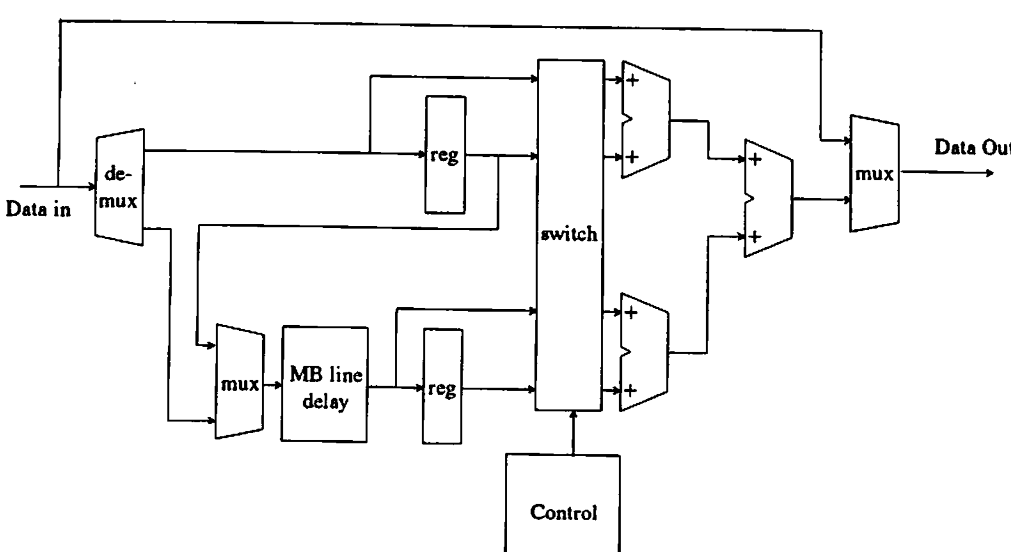


Figure 17. Block diagram of half pel interpolator. Reg indicates a register.

5.4.1.7. Prediction multiplexer and pel subtractor

A block diagram for this module is shown in figure 18. There is a maximum of four possible prediction modes. Forward, backward, interpolated and intra for MPEG-1 and field, frame and MPEG-1 for enhancement macroblocks. The prediction mode is decision is made by the prediction chip. The selected prediction mode is subtracted from the input, either SIF or CCIR601.

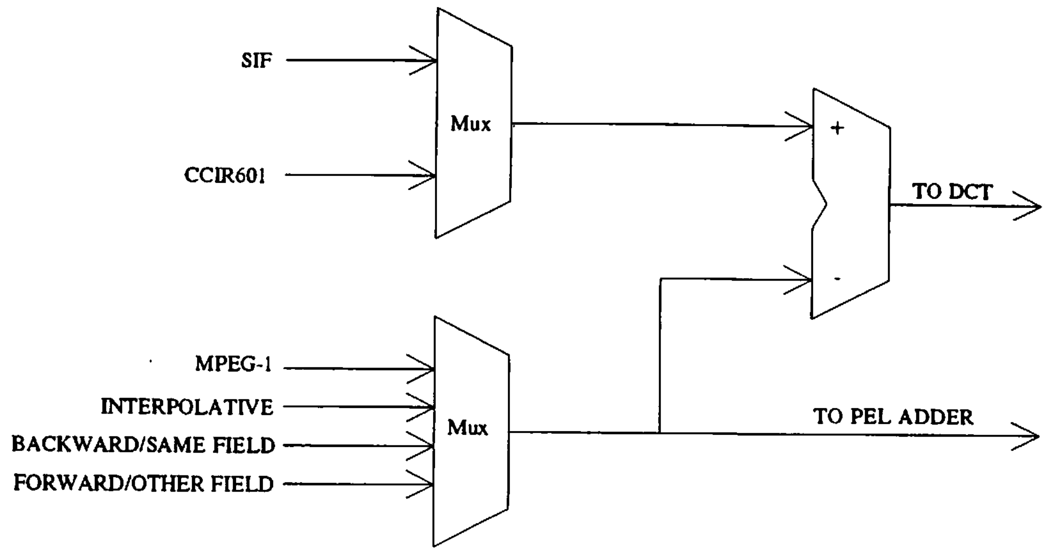


Figure 18. Block diagram showing prediction multiplexer and pel subtractor.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	-
Width of additions	1 of 8
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.1.8. Forward transform

The forward transform function is similar to the inverse transform function except that the butterflies are located before the RACs and the lookup table contents are different.

The statistics for the module are as follows.

Clock rate (MHz)	38
Memory size	64 x 12
Width of additions	16 of 1 & 16 of 12
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	16 of 16 x12
Table lookups per clock cycle	1

5.4.1.9. Scan and quantization

This module performs the scan, weighting, thresholding and quantization functions. Figure 19 shows a block diagram for the scan and variable threshold functions and the calculation of the weights. Figure 20 shows a block diagram for the weighting and quantization functions.

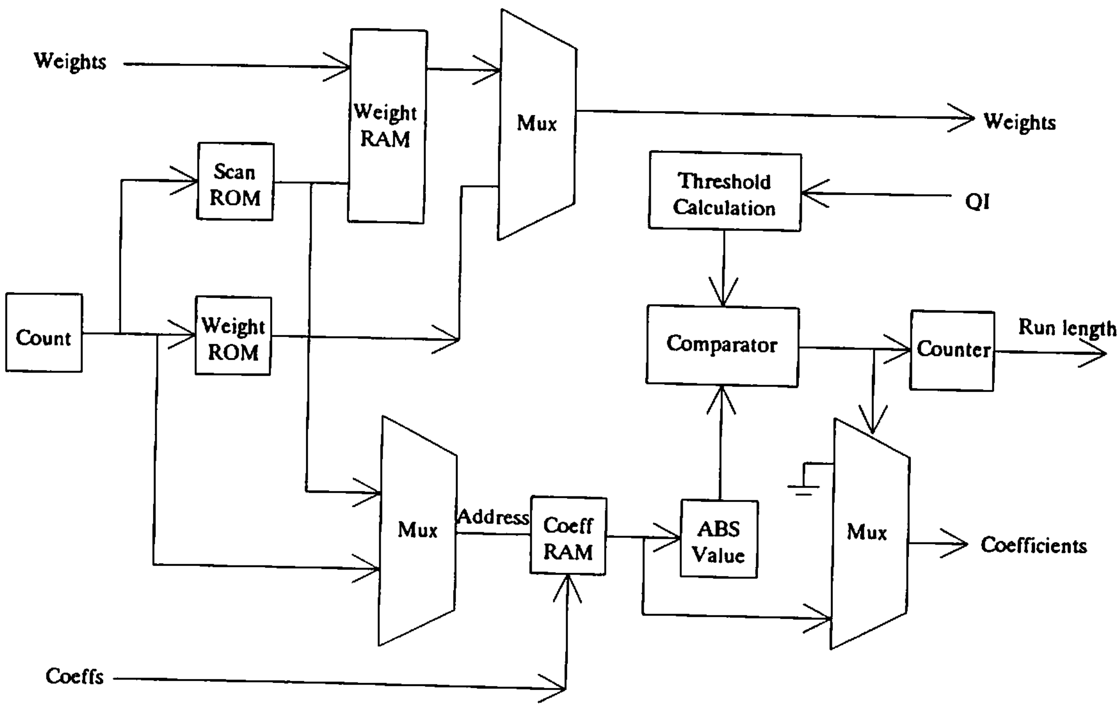


Figure 19. Block diagram showing scan and variable thresholding.

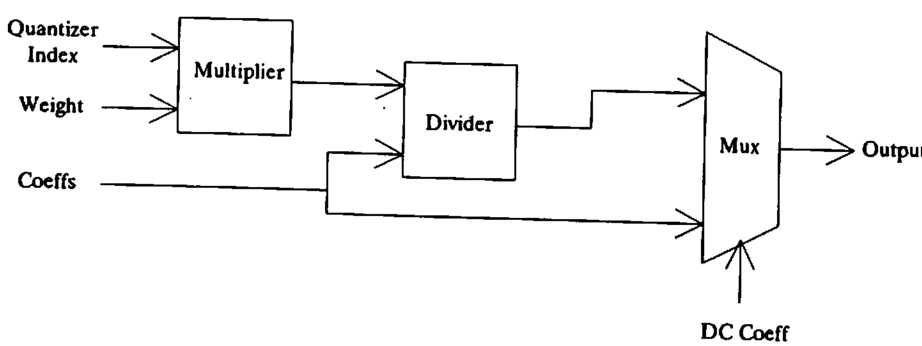


Figure 20. Block diagram showing quantization and weighting.

A RAM of size 128 x 12 bits is used to interface to the forward transform module. This module reads from one half while data is written to the other half.

The scan type chosen is zigzag for the MPEG-1 signal and is performed using a 64 by 6 scan ROM, addressed by a counter counting coefficients. For enhancement blocks no scan change is needed. The scan address is used to access coefficients in the RAM as well as the ROM containing the weight stores. Two 64 by 6 RAMs are needed to store downloadable MPEG-1 weights; a 64 by 6 ROM is needed for the enhancement weights.

A zero detector and a counter are needed to calculate the RUNs of zeros. The quantization block requires a multiplier and a divider to perform quantization and weighting.

Figure 21 shows a block diagram for the calculation of coded block pattern. A block contains no non-zero coefficients if the run length indicator is equal to 64. A six bit shift register stores which blocks have non-zero coefficients. A macroblock delay is required as the coded block pattern must be inserted in the bitstream before the coefficient data.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	128 x 8 & 128 by 6 & 384 by 15
Width of additions	-
Additions per clock cycle	-
Width of multiplications	16x5 & 6x21
Multiplications per clock cycle	1 of each
Table size	2 of 64x6
Table lookups per clock cycle	1

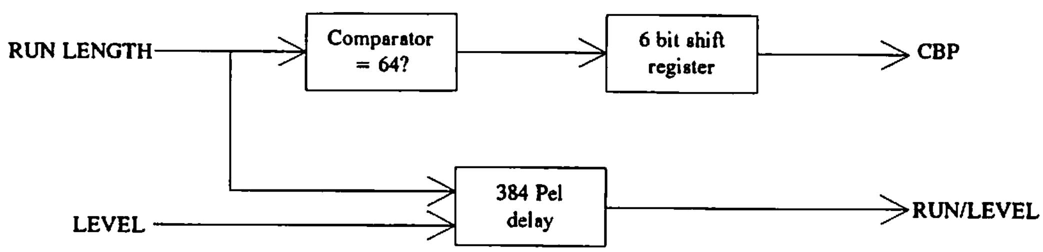


Figure 21. Block diagram of coded block pattern calculator.

5.4.1.10. Variable length encoder

A block diagram for this module is shown in figure 22. The input to the PLAs is a 16 bit symbol representing the symbol to be encoded. The PLAs are used to encode the variable length codes: macroblock address, MTYPE, vectors, CBP and RUN/LEVEL pairs. The output of the PLAs is the variable length code and a 5 bit number indicating the number of bits in the variable length code. This number is fed back to the barrel shifter, which then shifts by this number. If at least 32 bits are in the barrel shifter, the most significant 32 are written to the coded data buffer. The finite state machine (FSM) controls the selection of the correct PLA to use.

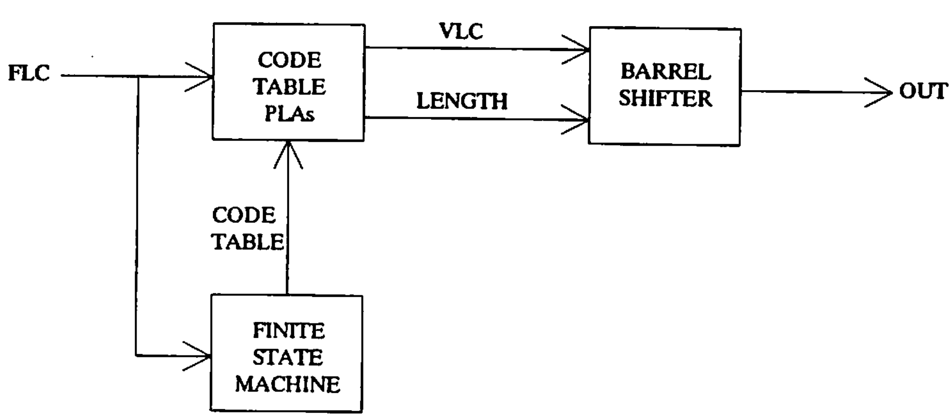


Figure 22. Block diagram of variable length encoder.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	-
Width of additions	-
Additions per clock cycle	-
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.1.11. Rate control

A block diagram for this module is shown in figure 23. This module is based on a micro-code state machine. Its function is primarily to choose the quantizer index to optimise picture quality and avoid buffer underflow and overflow. It accepts information from the buffer, performs a calculation and outputs the quantizer index. It is based on a programmable logic array equipped with a multiplier/accumulator, a program ROM and a data RAM.

The C simulation of this function required 6 integer variables and was implemented in 15 lines of code, involving about 50 operations. The size of the program ROM was chosen to be 128 x 16 and the data RAM to be 16 x 16.

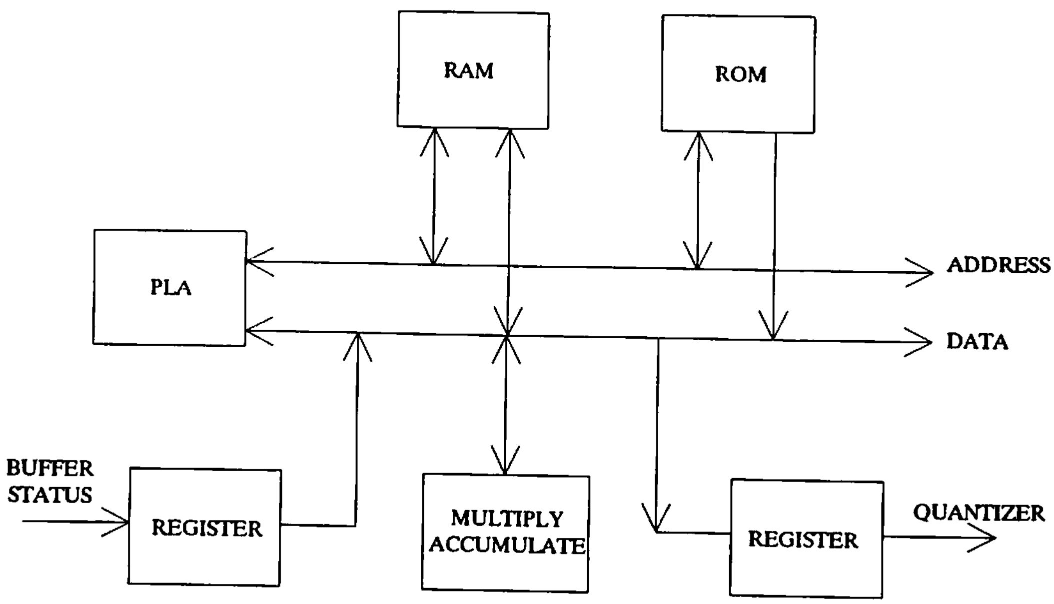


Figure 23. Block diagram for rate control.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	128 x 16
Width of additions	16
Additions per clock cycle	1
Width of multiplications	16
Multiplications per clock cycle	1
Table size	16 x 16
Table lookups per clock cycle	1

5.4.1.12. Macroblock to line scan change

This module performs a conversion from macroblock scan to line scan. This function is performed by suitably addressing the prediction store. No additional memory is required.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	-
Width of additions	-
Additions per clock cycle	-
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.2. Prediction chip

A block diagram for the prediction chip is shown in figure 9.

5.4.2.1. Integer pel motion estimation

For the MPEG-1 macroblocks the translational motion between two consecutive MPEG-1 frames is estimated. The worst case is for interpolated pictures when the full search is performed for both forward and backward vectors. For the enhancement macroblocks the translational motion between two consecutive like fields (frame prediction) and two consecutive unlike fields (field prediction) are estimated.

The current picture macroblock (16x16) is compared with the data in the search window from the reference picture. For MPEG-1 macroblocks the search range is +/-7 in both the horizontal and vertical direction. For enhancement macroblocks the search range is +/-30 horizontally and +/-15 vertically.

During each MPEG-1 row of macroblocks period the search must be done for one enhancement row of macroblocks and one MPEG-1 row of macroblocks. Data is therefore read from the motion estimation store at the following cycle rate:

$$2*(704*48+352*32)*18*50/4 = 20.3\text{MHz}$$

The computation of the error values for all the search positions are performed by an array of four identical processing units. Each processing unit consists of two input register arrays for the current and previous picture of size 512x8 and 768x8 respectively for shuffling of data. There is an arithmetic unit consisting of 256 parallel 8 bit subtractors followed by an adder tree which maintains full precision throughout (255 additions in total). The computed error output is 16 bits.

The error for a search position is computed as follows:

$$\text{error}_{(i,j)} = \sum_{y=0}^{15} \sum_{x=0}^{15} \text{abs}\Big(PRV(x+i,y+j) - CUR(x,y)\Big)$$

where CUR(x,y) and PRV(x,y) are the 8 bit current picture and search window pels at position (x,y), and abs(x) denotes the absolute value of x. The minimum error is obtained by exhaustively searching all the search positions. The motion vector for the minimum error, the minimum error itself and the zero offset error are determined and a simple decision process is performed between the zero offset and the displaced block.

Each processor unit runs at the prediction pel rate of 81.2MHz. This is fast enough for the array of processors to provide the motion vectors for the CCIR601 pictures (704x576) and the SIF pictures (352x288) at a frame rate of 25Hz.

The statistics for the module are as follows.

Clock rate (MHz)	81.2
Memory size	768 x 8 & 512 x 8
Width of additions	256 of 8 & 255 of 16
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.2.2. Half pel motion estimation

The current macroblock used in the integer pel estimation store is copied and stored in a 256 by 8 RAM. The 18 by 18 block around the best integer displacement is transferred from the search window RAM to the prediction store. (324 x 8). This data is clocked into an array of eight half.pel interpolators, as shown in figure 17. The predictions generated by these together with the integer position are clocked into an array of nine mean square error (MSE) units to calculate the mean square error of each prediction compared to the current data. The MSE unit is shown in figure 24.

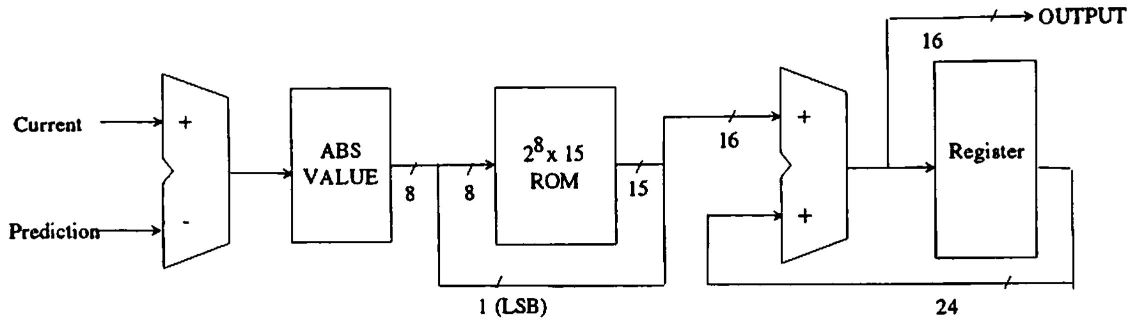


Figure 24. Block diagram of mean square error (MSE) unit.

Figure 24 shows a block diagram for the MSE unit. Twos complement 9 bit numbers are converted to 8 bit unsigned numbers. These are squared in a look up table, 256 by 15, and summed in an accumulator. The least significant bit of the squared data does not need to be calculated as it is the same as the original least significant bit.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	256 x 8 & 324 x8
Width of additions	12 of 8 & 9 of 16
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	9 of 256x15
Table lookups per clock cycle	1 of each

5.4.2.3. Mode decision

There is a maximum of four possible prediction modes. Forward, backward, interpolated and intra for MPEG-1 and field, frame and MPEG-1 for enhancement macroblocks. The decision is based on the minimum mean square error (MSE) of the luminance prediction error.

Data in the best prediction store in the half pel motion estimation module is copied to a similar store, also of size 324 by 8. A half pel interpolator, as shown in figure 17, is used to recalculate the best half pel prediction using the decision made in the half pel motion estimation module. This is done for the interpolation mode of MPEG-1.

As the motion estimation process is performed on a row of macroblocks basis, it is necessary to store all the predictions for one row of macroblocks for use in deciding whether to choose the interpolated mode during the second pass. As four prediction chips are used in parallel, only one quarter (11) of the macroblock predictions need to be stored. This requires 11*256 = 2816 bytes of memory. Similarly, 11 vectors and 11 MSEs need to be stored; this requires a RAM of size 11 by 30.

The forward and backward predictions are added and the mean square error calculated in an MSE unit, as shown in figure 24.

A multiplexer chooses whether zero or MPEG-1 should be used as the prediction for intra coding. This is delayed for three macroblock periods in a 768 byte RAM. The error between this and the current is calculated in another MSE unit.

A decision based on minimum MSE is made between up to four possible prediction modes: intra, forward/field, backward/frame and interpolated.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	2816 x 8 & 768 x 8 & 11 x 30
Width of additions	6 of 8 & 2 of 16
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	2of 256 x15
Table lookups per clock cycle	1 of each

5.4.3. Up/down-sampling chip
A block diagram for the up/down-sampling chip is shown in figure 10.

5.4.3.1. Horizontal filter/interpolator
A block diagram for this module is shown in figure 25. It implements an eight tap interpolator/filter. Multiplication of data by taps is performed in 8 ROMs of size 2048 by 16. Different taps are used for up and down sampling and for luminance and chrominance. For up-sampling there are two sets of chrominance taps. Cross over switches are used in the up-sampling to reverse the order of taps and hence double the number of pels. The outputs of these ROMs are summed using 7 adders.

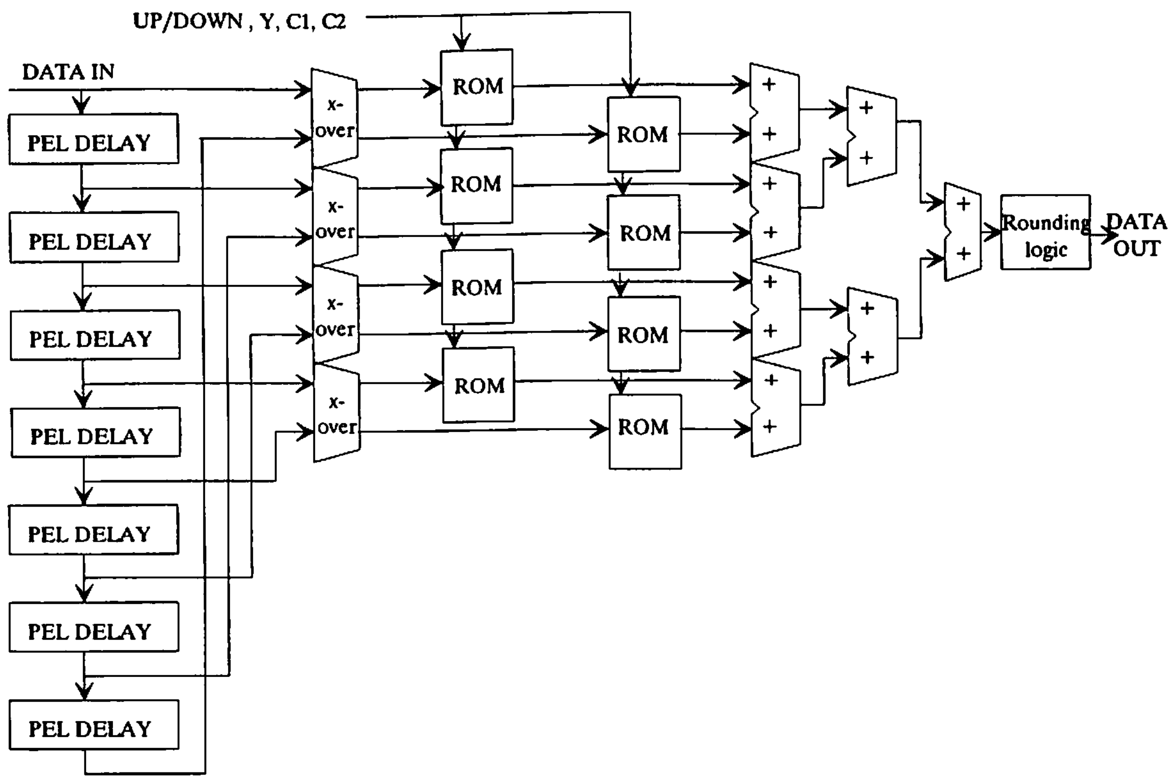


Figure 25. Block diagram for horizontal filter/interpolator.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	-
Width of additions	7 of 16
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	8 of 2048x16
Table lookups per clock cycle	1 of each

5.4.3.2. Vertical line shift
A block diagram for this module is shown in figure 26. It implements a five tap +/- 1/4 line shifter. Multiplication of data by taps is performed in 5 ROMs of size 2048 by 16. Different taps are used for up and down sampling and for luminance and chrominance. For up-sampling there are two sets of chrominance taps, which shift +/- 1/8 and +/- 3/8. Multiplexers are used in the up-sampling to reverse the order of taps and hence double the number of pels. A different set of taps are used for the up and down-sampling processes. The outputs of these ROMs are summed using 4 adders. Four line stores are needed for luminance and chrominance, this requires 4*(352+176+176) = 2816 bytes of RAM.

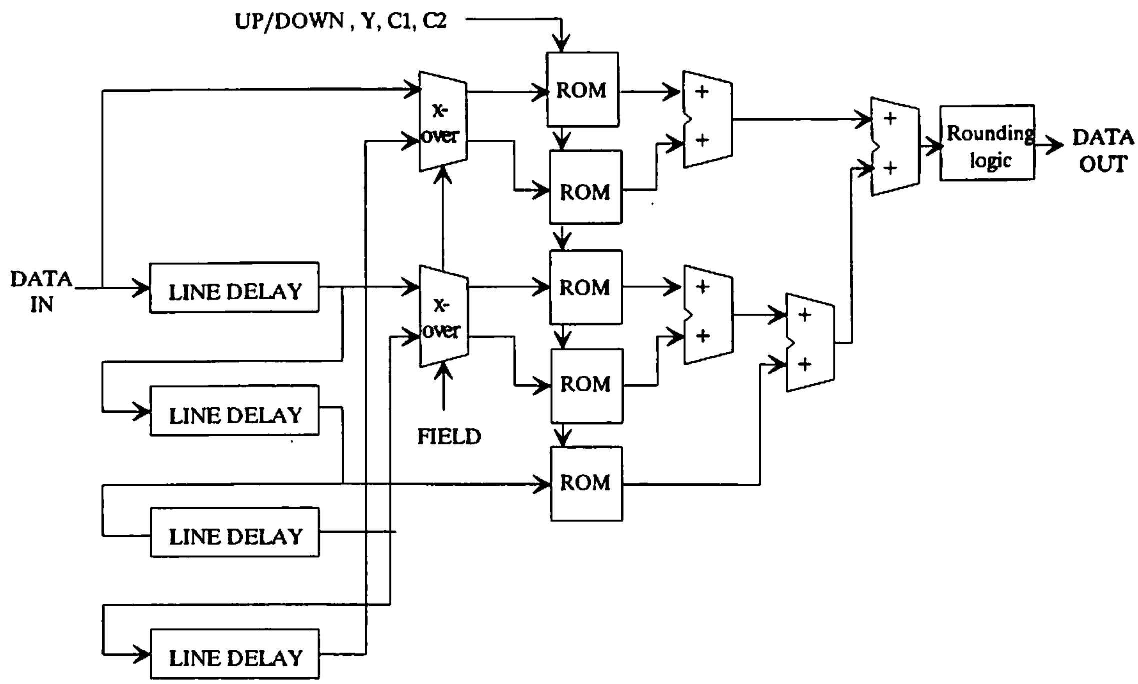


Figure 26. Block diagram of vertical line shift module.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	2816 x 8
Width of additions	4 of 16
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	5 of 2048 x16
Table lookups per clock cycle	1 of each

5.4.3.3. Line to macroblock scan change

This module performs a conversion from line scan to macroblock scan. To do this it must store two rows of macroblock data. This requires 2*(352*16 + 2*176*8) = 16896 bytes of RAM.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	16896 x 8
Width of additions	-
Additions per clock cycle	-
Width of multiplications	-
Multiplications per clock cycle	-
Table size	-
Table lookups per clock cycle	-

5.4.3.4. Prediction filter

A block diagram for this module is shown in figure 27. An accumulator is used to calculate the mean of an 8 by 4 sub-block. Pels are squared using a 256 by 15 ROM, the least significant bit does not need to be calculated as it is the same as the original least significant bit. The sum of squares is accumulated. The square of the mean is subtracted from the final result to give the variance of the sub-block. This is compared with a threshold, and if less the data in the block is set to the mean value. A 32 by 8 RAM is needed to delay the original data until the calculations are done.

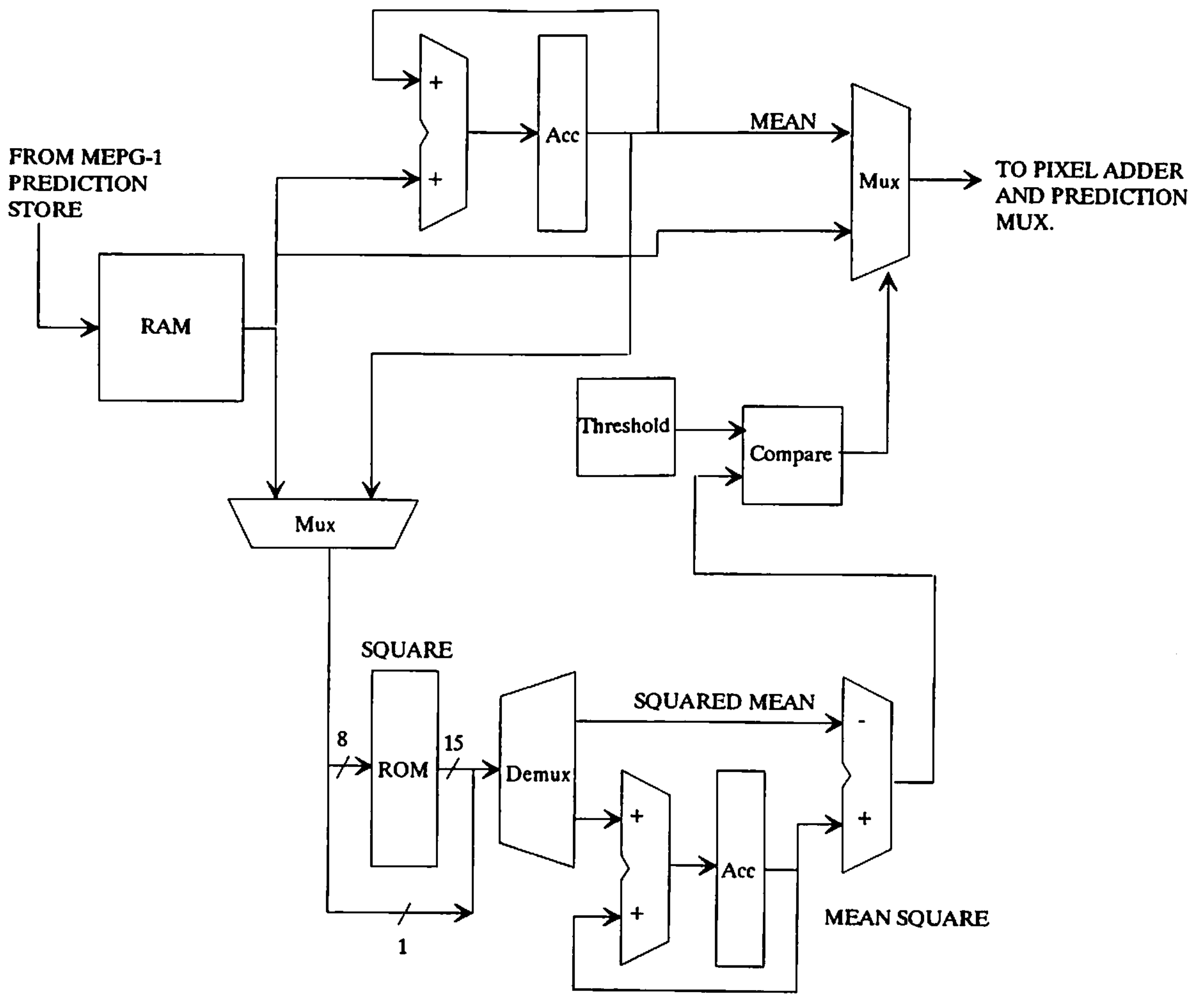


Figure 27. Block diagram of prediction filter.

The statistics for the module are as follows.

Clock rate (MHz)	19
Memory size	32 x 8
Width of additions	8 & 16
Additions per clock cycle	1 of each
Width of multiplications	-
Multiplications per clock cycle	-
Table size	256 x15
Table lookups per clock cycle	1

5.5. Summary

The requirements of the implementation of the whole system are described in this section.

The encoder consists of one coder chip, four prediction chips and two up/down-sampling chips, one configured for down-sampling, the other for up-sampling, memory and some form of system control, for example, a microprocessor.

The decoder consists of one coder chip, configured for decoding, and one up/down-sampling chips, configured for up-sampling, memory and some form of system control, for example, a microprocessor.

The following table shows the total requirements of each chip based on the depth of study given in this document:

Requirement	Coder	Prediction	Up/down-sampling
Clock rate (MHz)	19	81.2	19
On chip memory (bytes)	1872	5488	19744
Number of additions	88	540	19
Number of multiplications	5	0	0
Table size (bytes)	992	5280	53728

The encoder off chip memory requirements are as follows:

Store	Size (kbyte)
Field average	256
Picture reorder	256
Prediction store	1024
Delay	1536
Field repeat	256
Motion estimation	768
Coded data buffer	256
Total	4352

The decoder off chip memory requirements are as follows:

Store	Size (kbyte)
Prediction store	1024
Field repeat	256
Coded data buffer	256
Total	1536

The encoder off chip memory requirements are significantly decreased when the MPEG-1 layer does not include interpolated and intra pictures, for example, when used for communication applications. The requirements are then:

Store	Size (kbyte)
Field average	256
Picture reorder	0
Prediction store	1024
Delay	0
Field repeat	256
Motion estimation	768
Coded data buffer	256
Total	2560

The total system delay is 300ms when the MPEG-1 layer contains one interpolated picture between intra and predicted pictures and when intra pictures are coded. This delay is reduced to 120ms when no intra and no interpolated pictures are coded.

6. Further Information

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