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Wang et al.

[45] Reissued Date of Patent: Nov. 21, 1995

[54] SYSTEMS AND METHODS FOR CODING EVEN FIELDS OF INTERLACED VIDEO SEQUENCES

5,001,559 3/1991 Gonzales ..... 348/400
5,008,746 4/1991 Bernard et al. .... 348/429
5,049,991 9/1991 Niihara ..... 348/416
5,134,480 7/1992 Wang ..... 348/620

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FOREIGN PATENT DOCUMENTS

0374548 6/1990 European Pat. Off. .

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Attorney, Agent, or Firm—Brumbaugh, Graves, Donohue & Raymond

[21] Appl. No.: 353,968

[57] ABSTRACT

[22] Filed: Dec. 9, 1994

In accordance with the invention, a method, for coding multi-mode predictive interpolative coded fields of video, includes the steps of:

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: 5,193,004
Issued: Mar. 9, 1993
Appl. No.: 621,343
Filed: Dec. 3, 1990

U.S. Applications:

[63] Continuation of Ser. No. 218,970, Mar. 25, 1994, abandoned.

[51] Int. Cl. H04N 7/36

[52] U.S. Cl. 348/413; 348/420

[58] Field of Search 348/402, 413, 348/420; H04N 7/133, 7/36

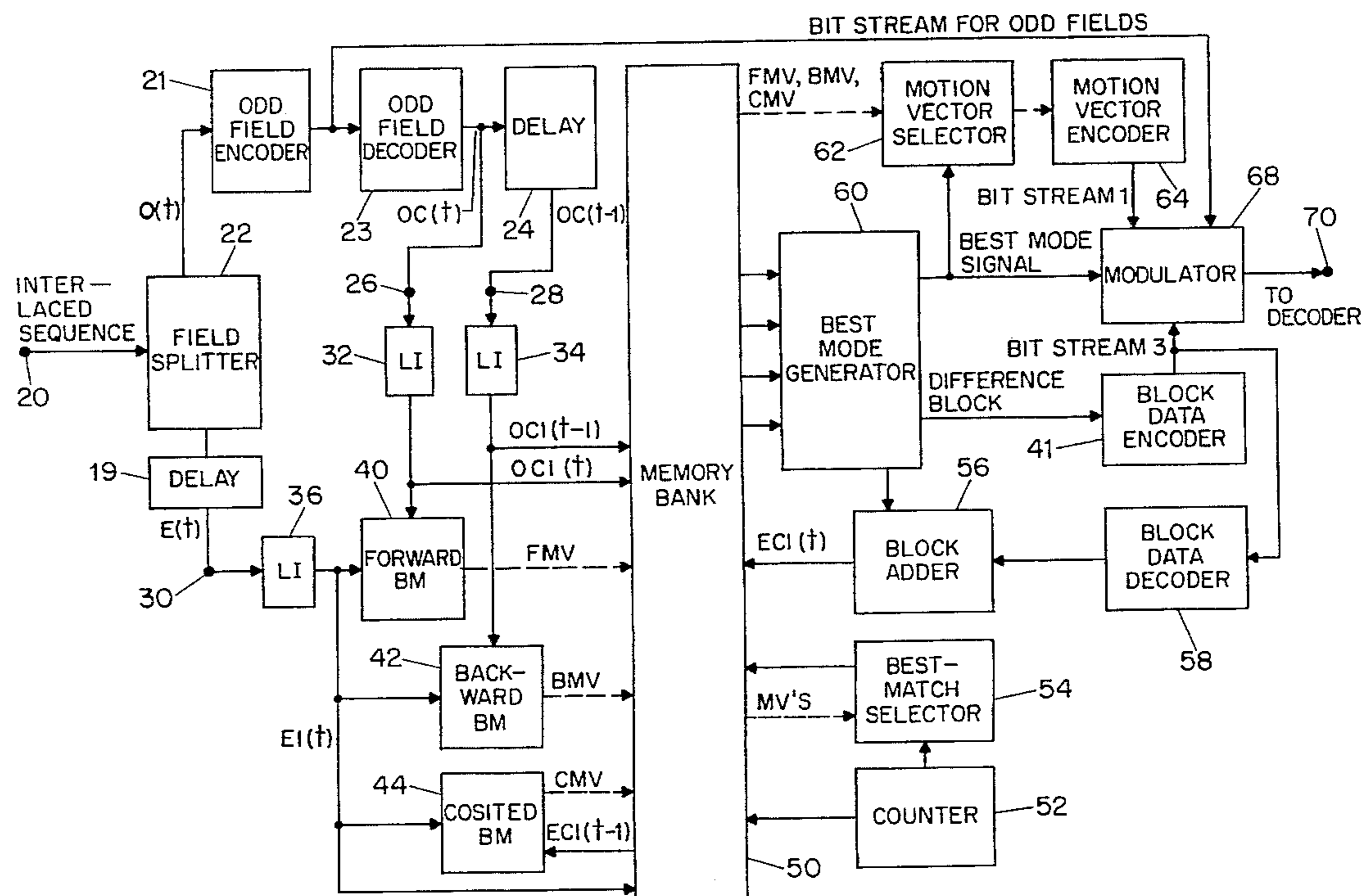
- (a) providing a current field of interlaced pixel data, and past and future fields of such data;
(b) providing estimated pixel data at omitted line positions in the past and future fields of data to form enhanced fields of pixel data;
(c) comparing a block of pixel data from the current field with corresponding blocks of data from such past and future fields to derive motion vector signals indicative of best matched blocks of data;
(d) developing pixel error signals representing pixel by pixel errors based on utilization of best matched blocks in different modes for comparison with the block of pixel data from the current field and developing best mode signals indicative of which of such modes represents the least overall error; and
(e) providing the best mode signals, motion vector signals, pixel error signals, and the future odd field of data for transmission for use by a decoder.

[56] References Cited

U.S. PATENT DOCUMENTS

4,821,119 4/1989 Gharui ..... 348/402
4,873,573 10/1989 Thomas et al. .... 348/416
4,897,720 1/1990 Wu et al. .... 348/412
4,999,705 3/1991 Puri ..... 348/412

56 Claims, 9 Drawing Sheets



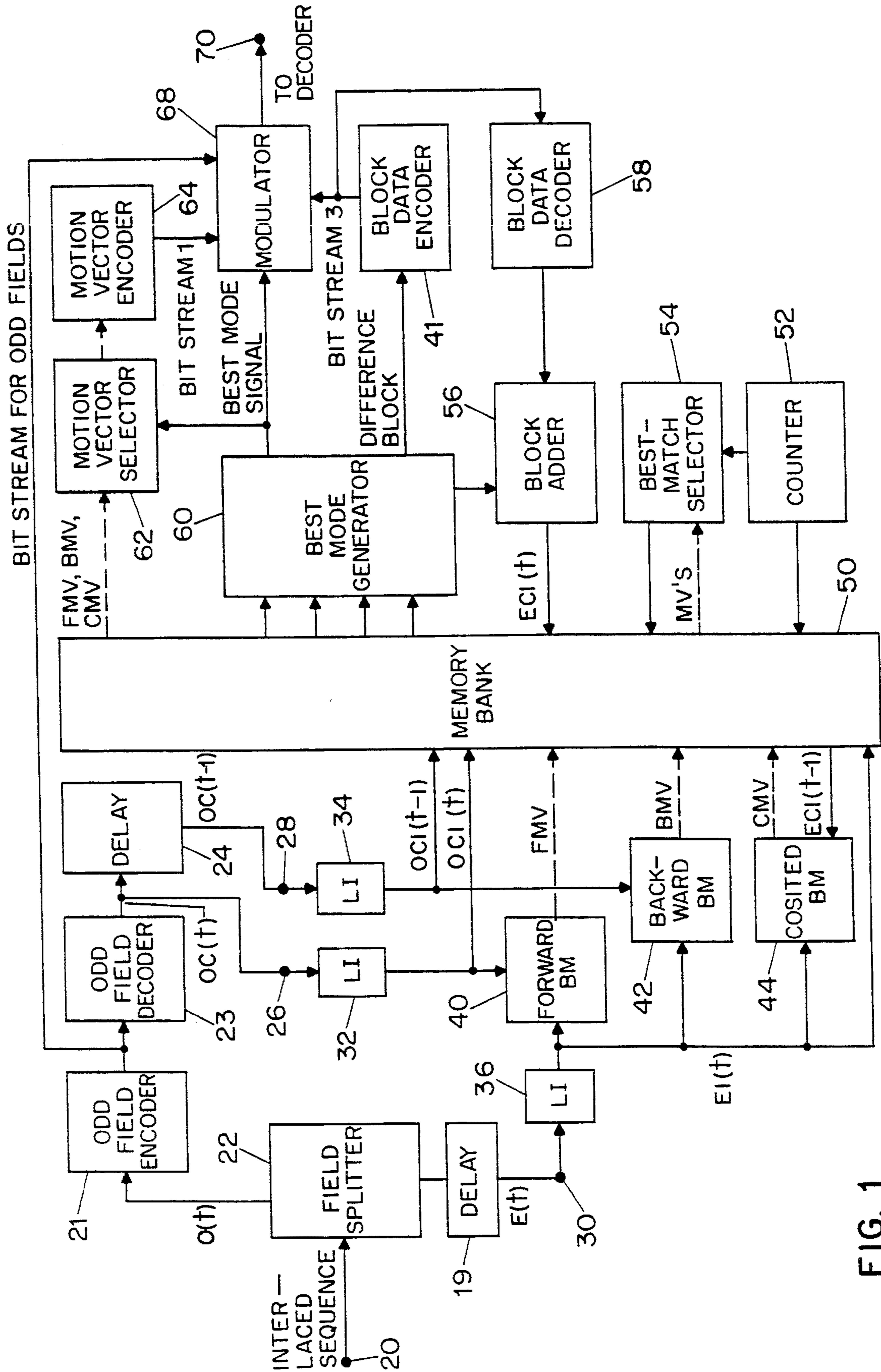


FIG. 1

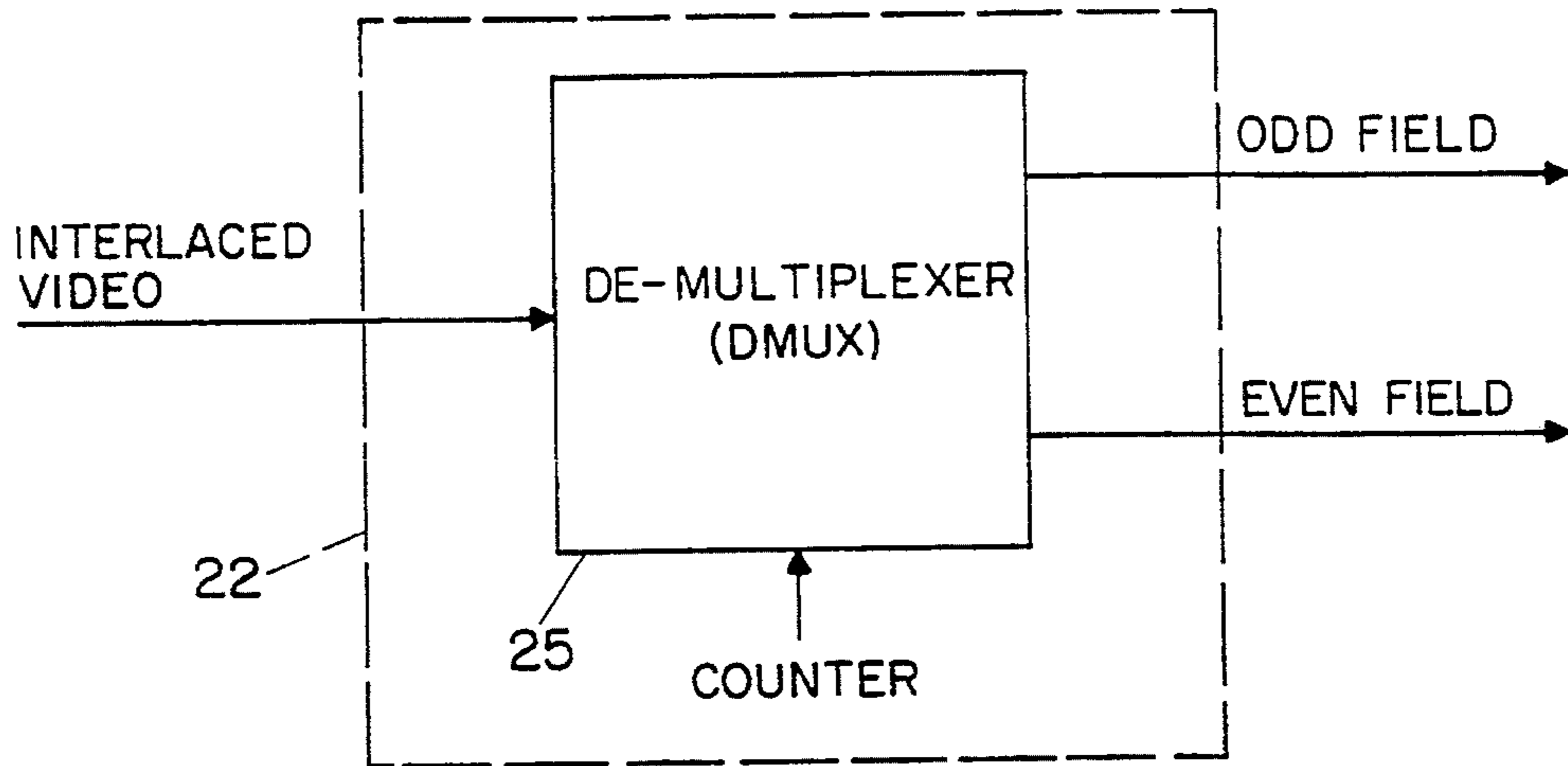


FIG. 2

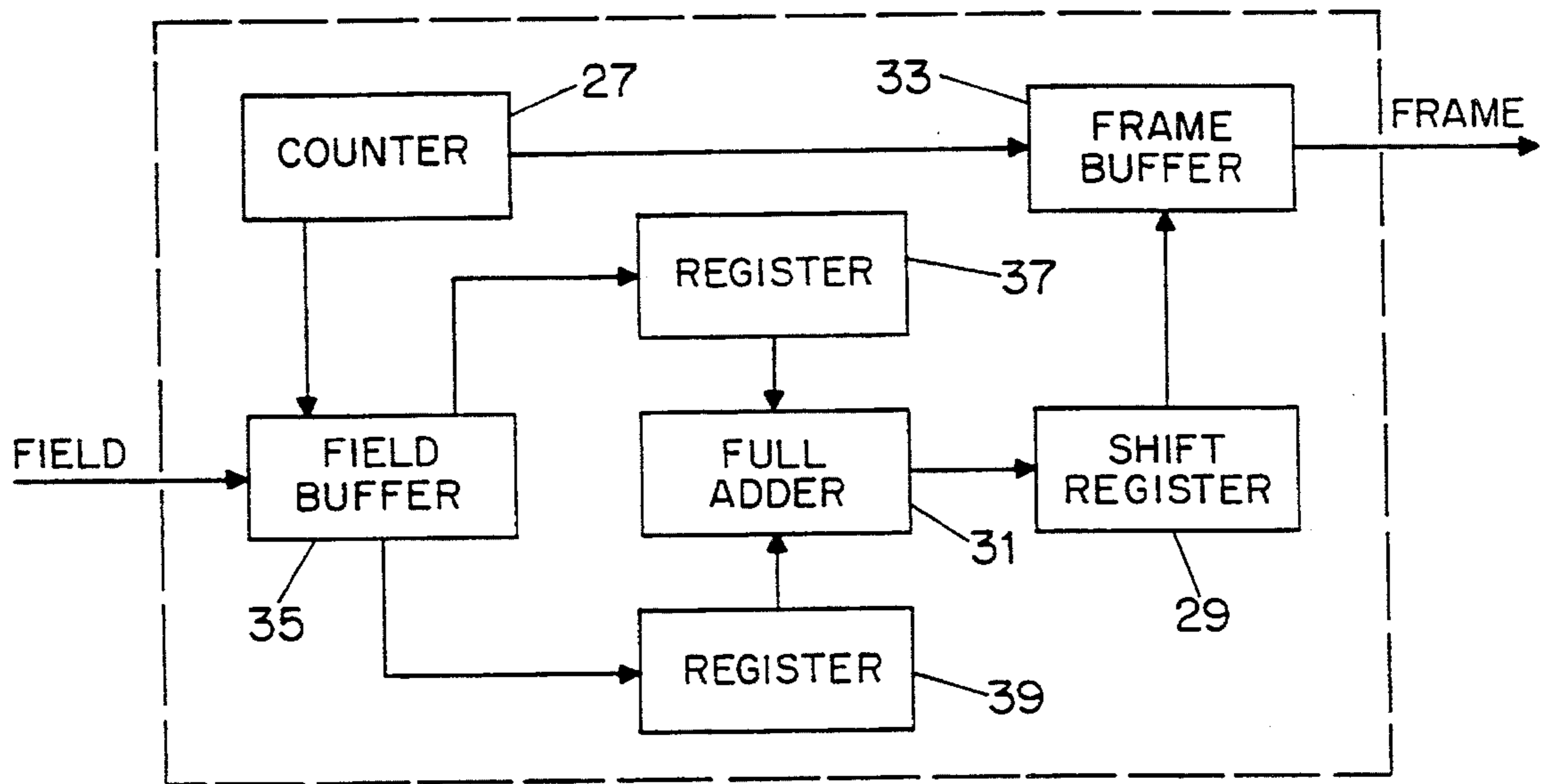


FIG. 3

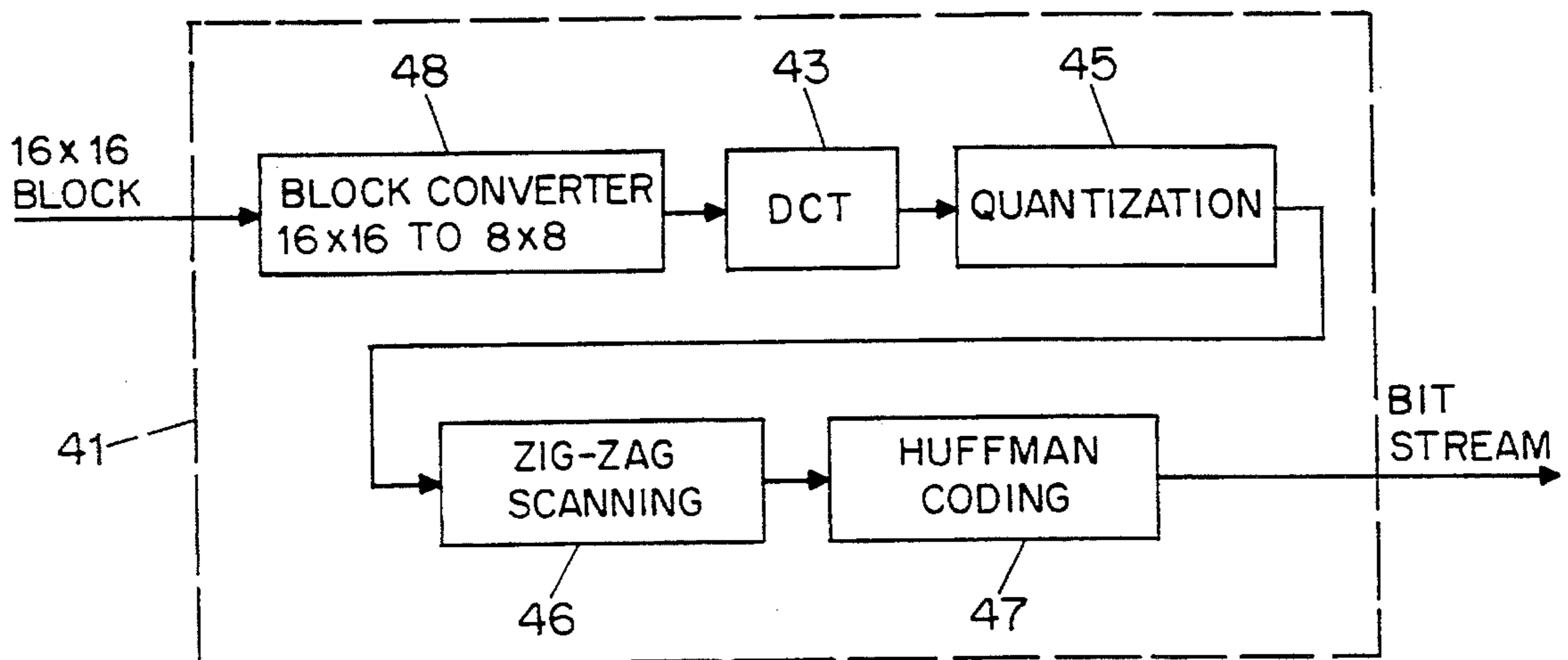


FIG. 4

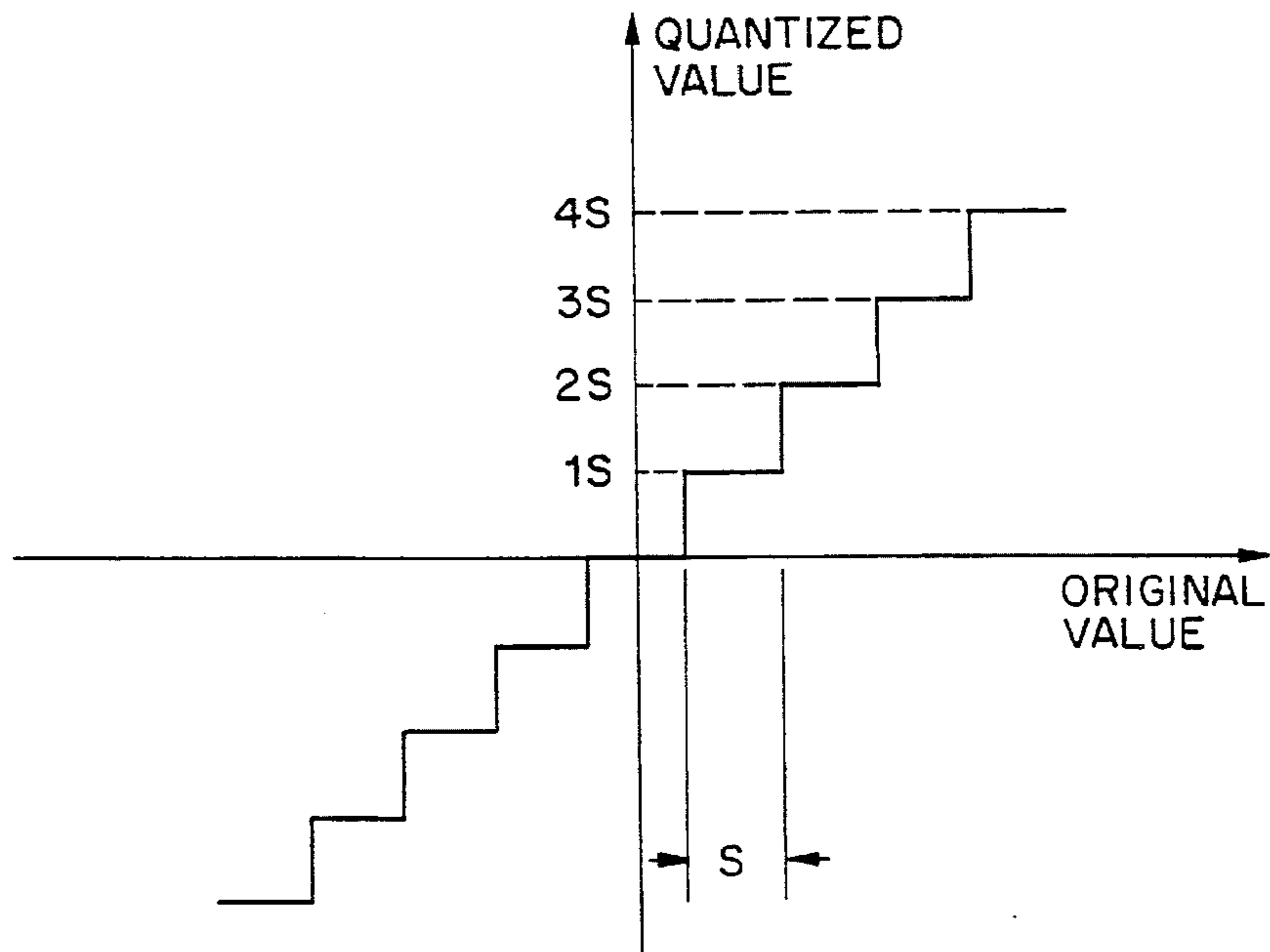
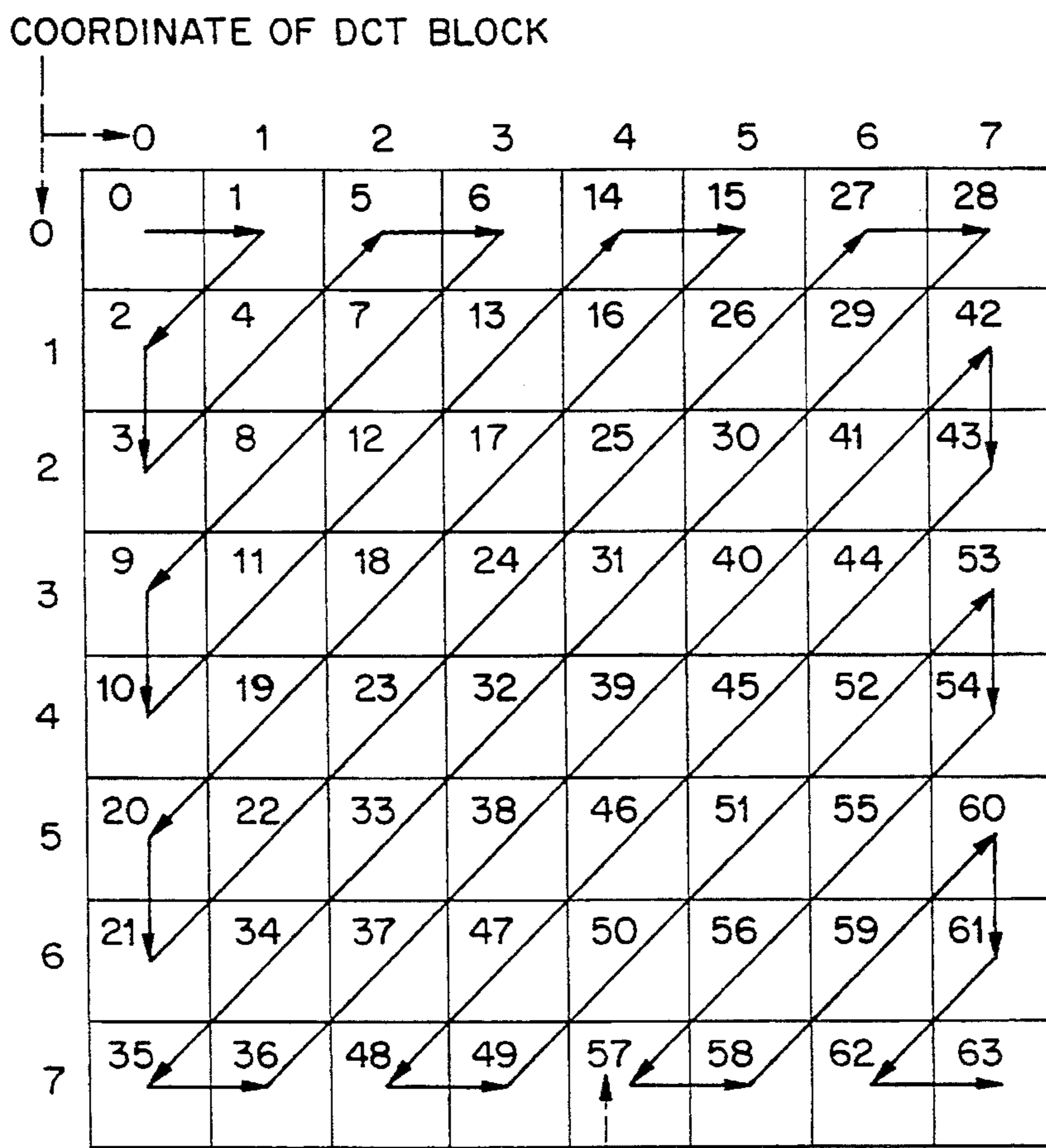


FIG. 5



ZIG-ZAG ORDER

FIG. 6

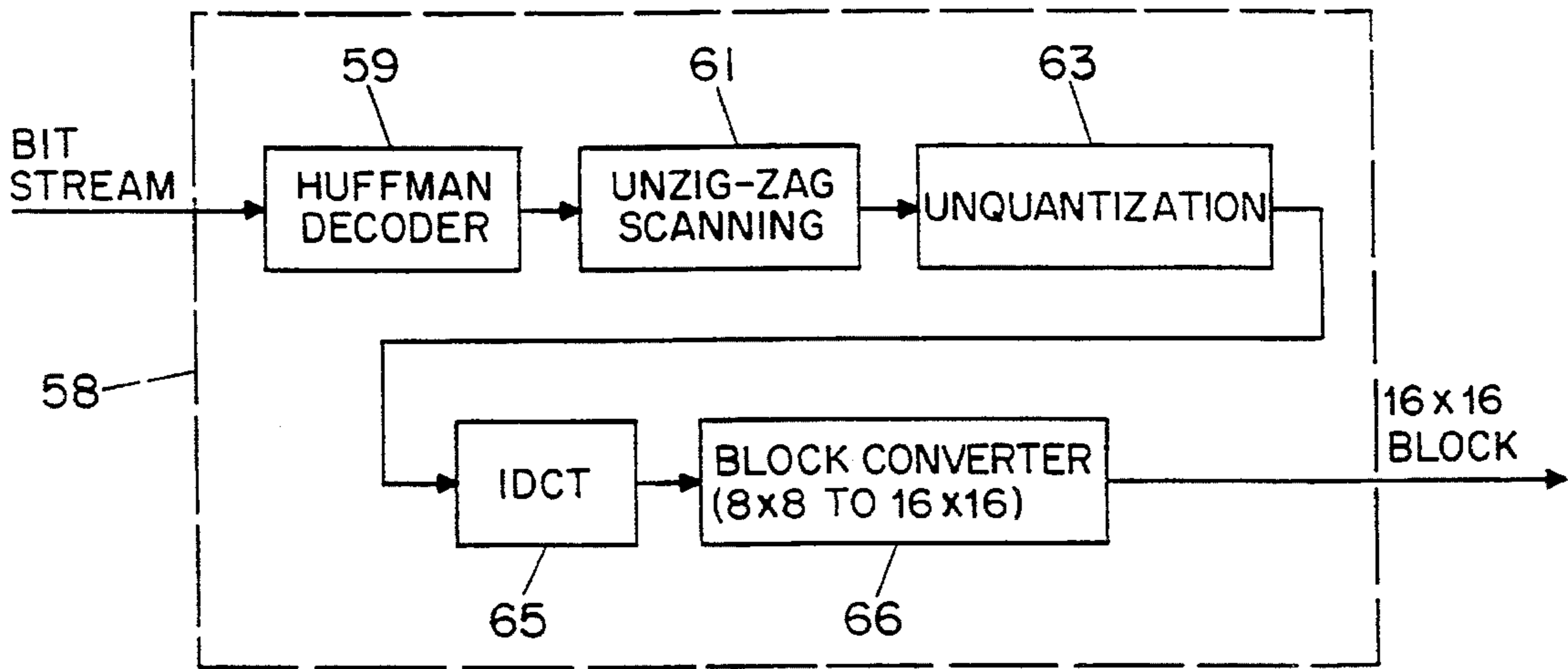


FIG. 7

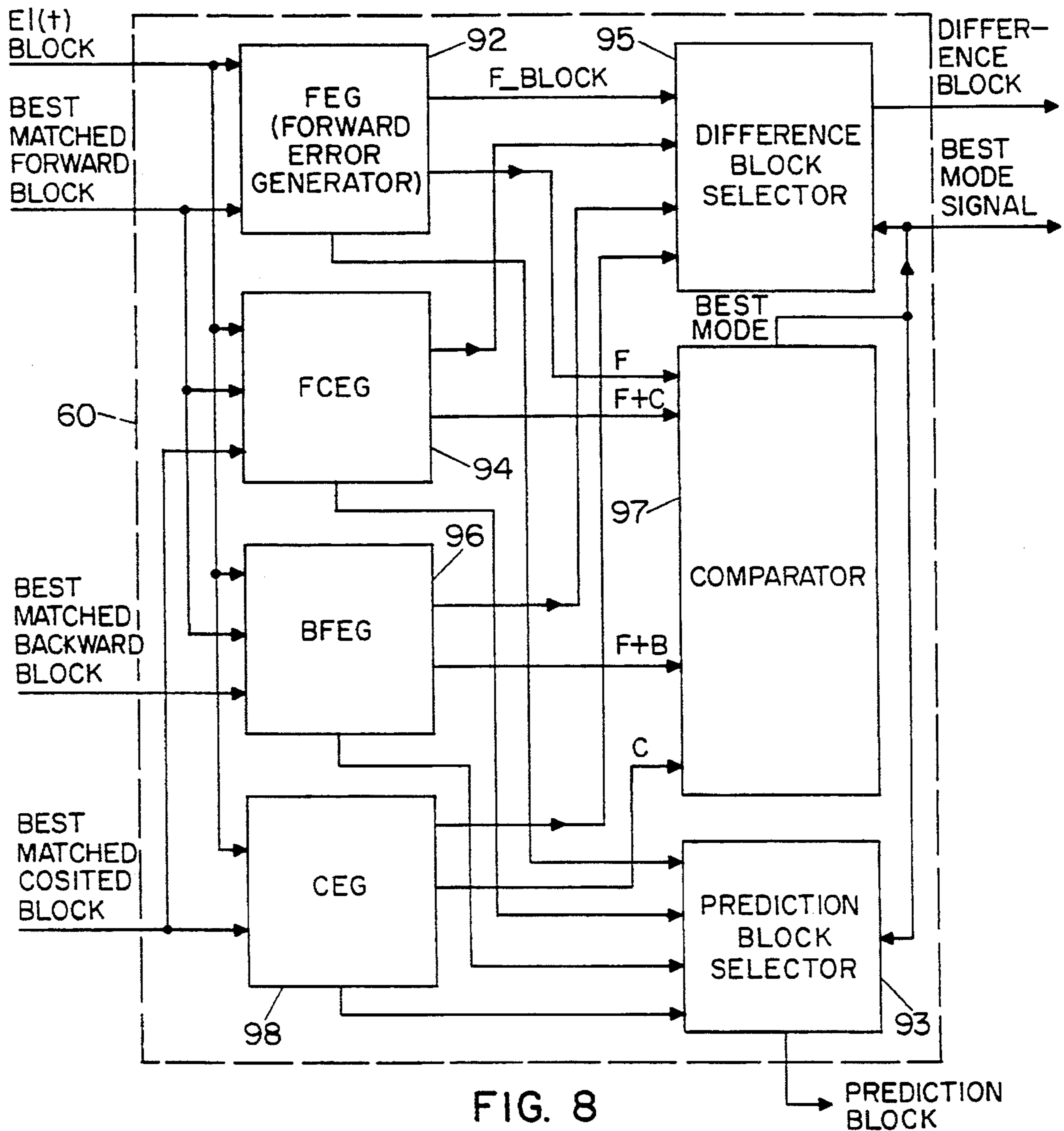


FIG. 8

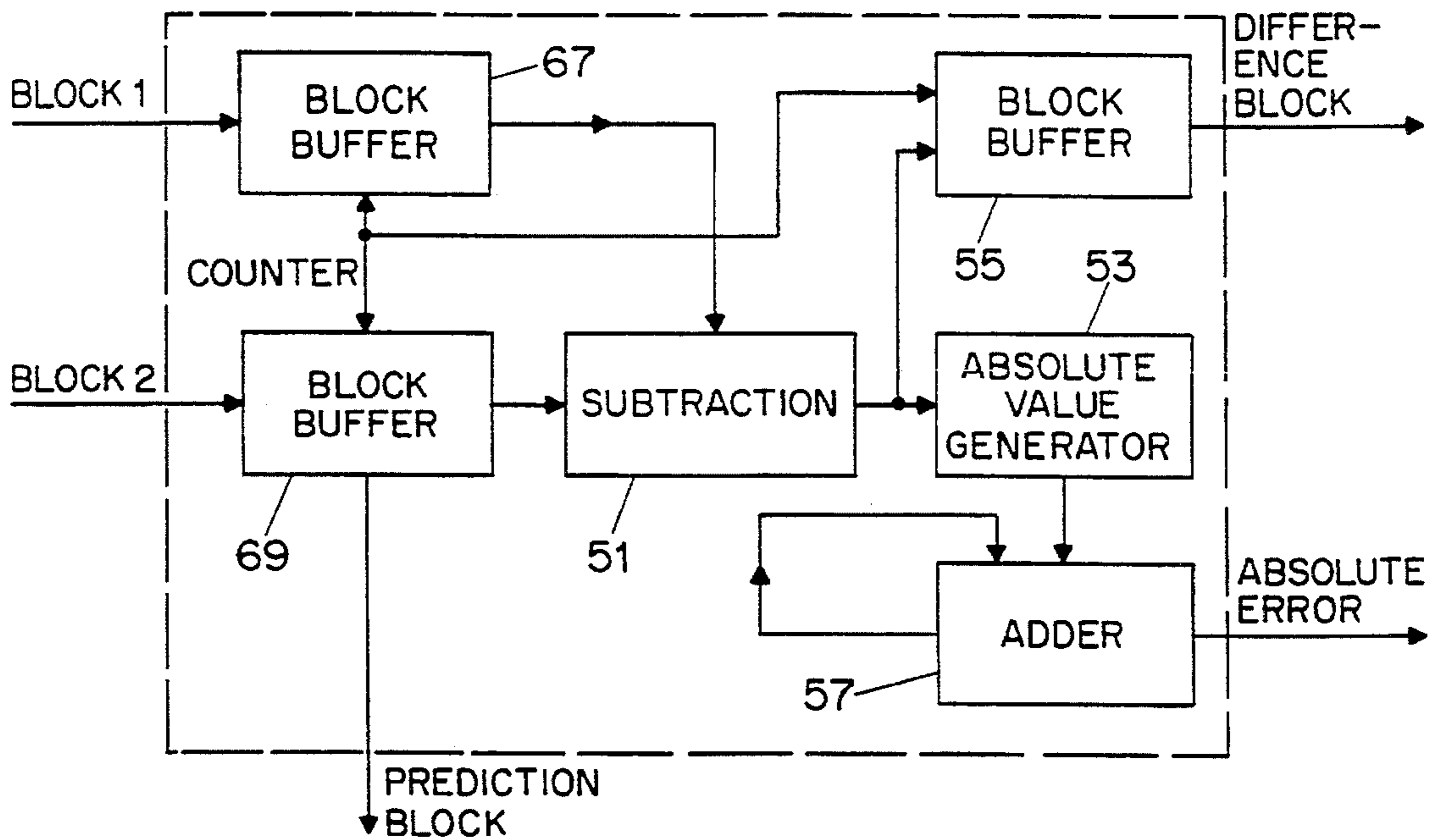


FIG. 9

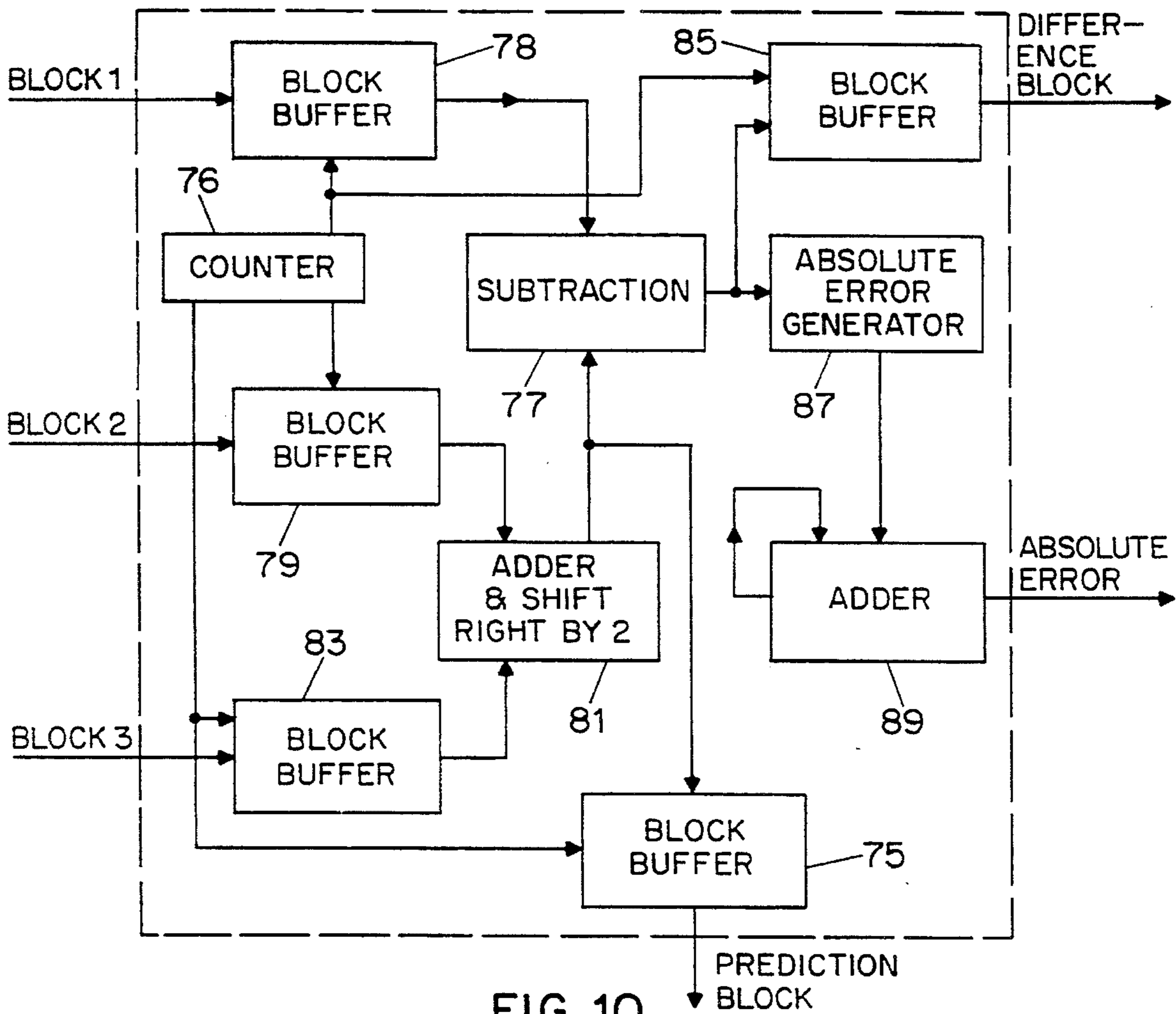


FIG. 10

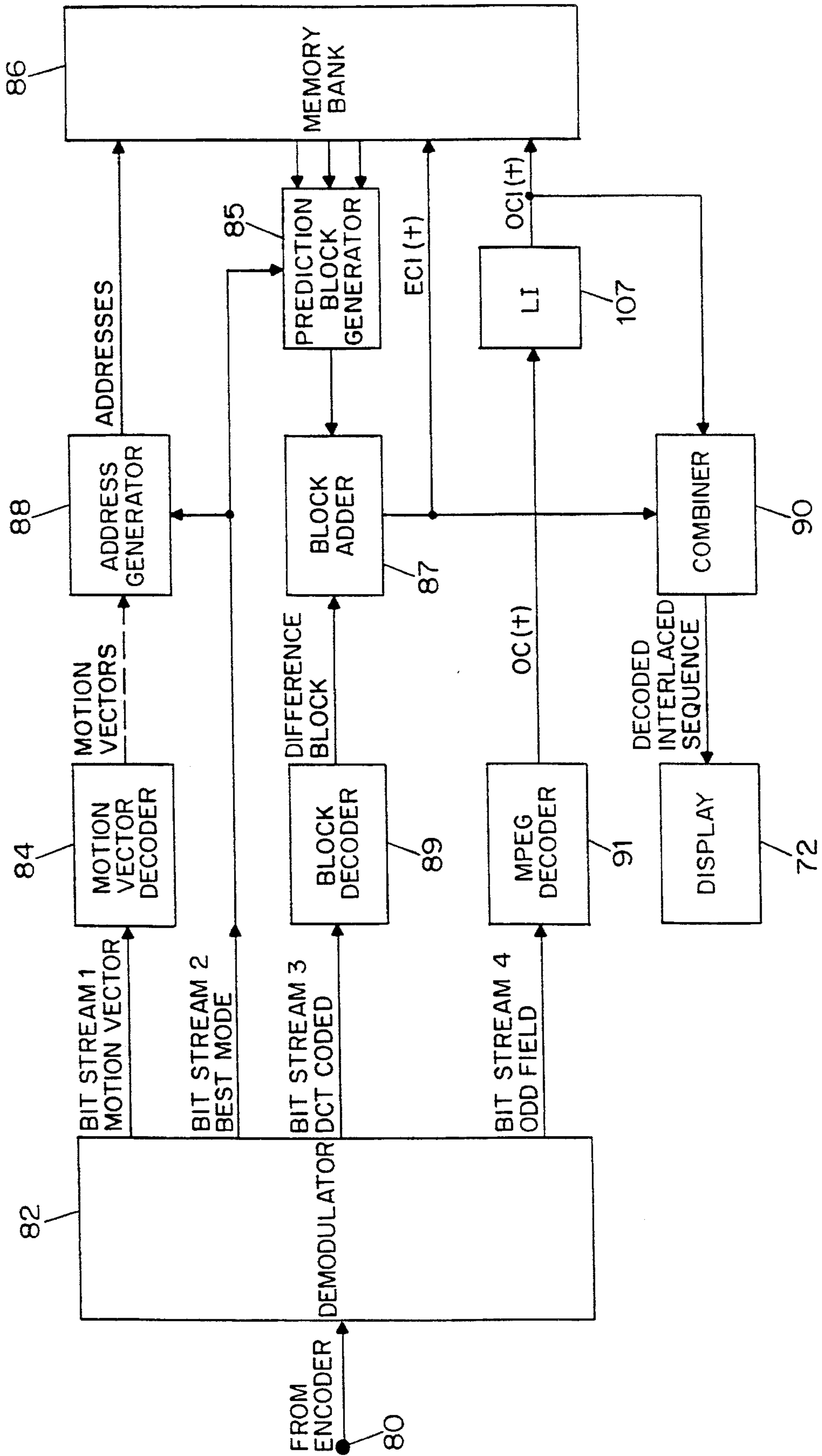


FIG. 13

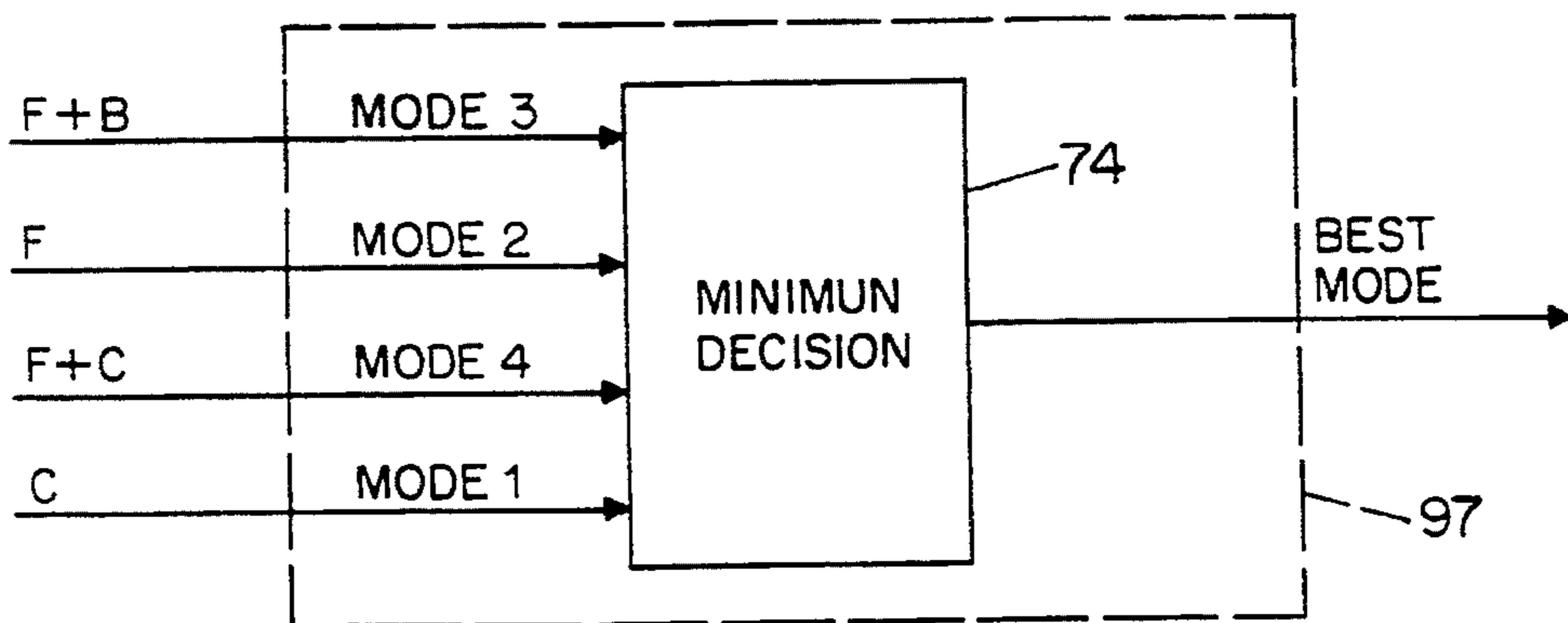


FIG. 11

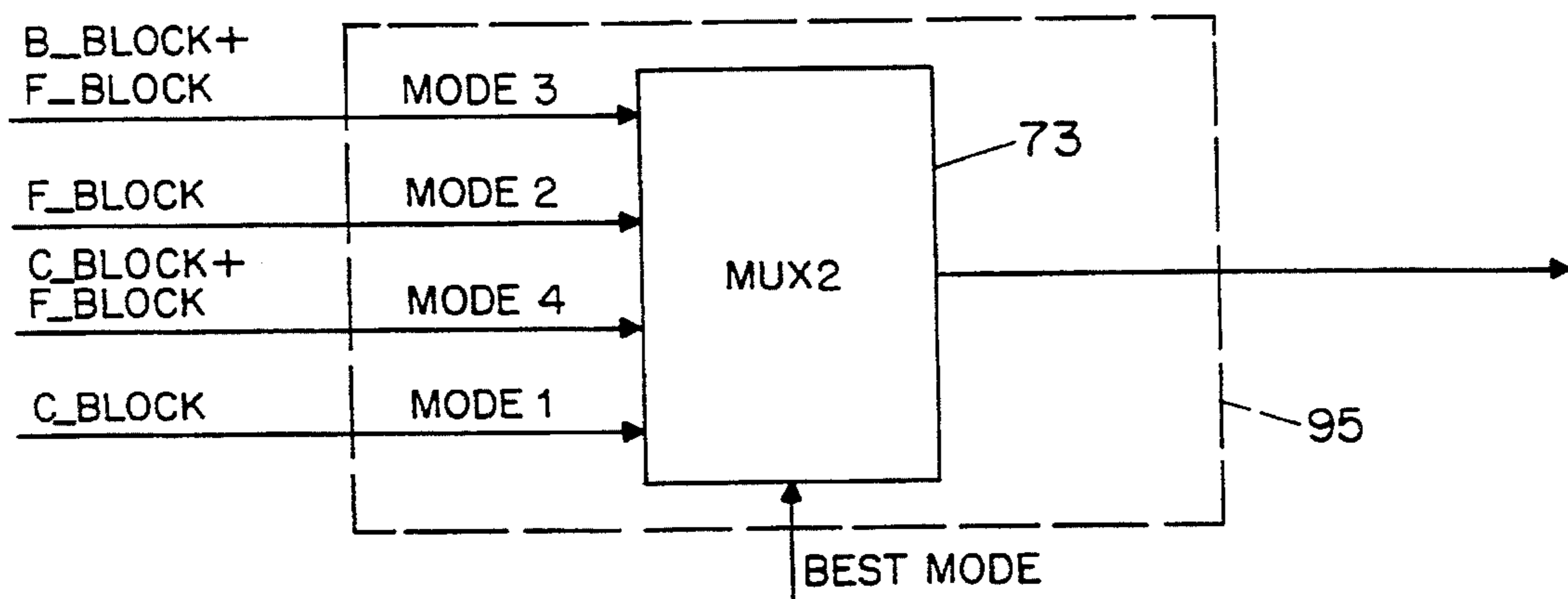


FIG. 12

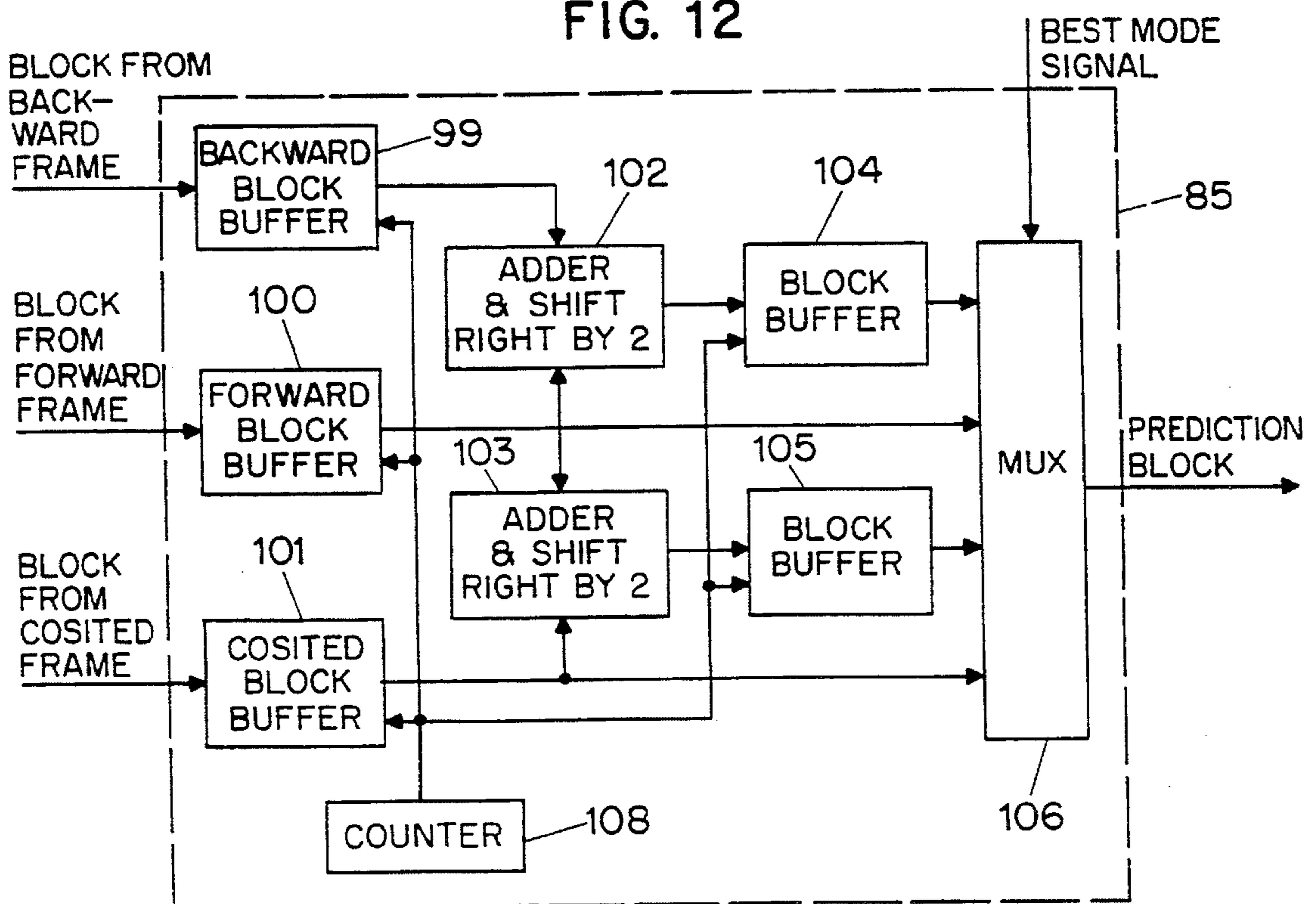


FIG. 14



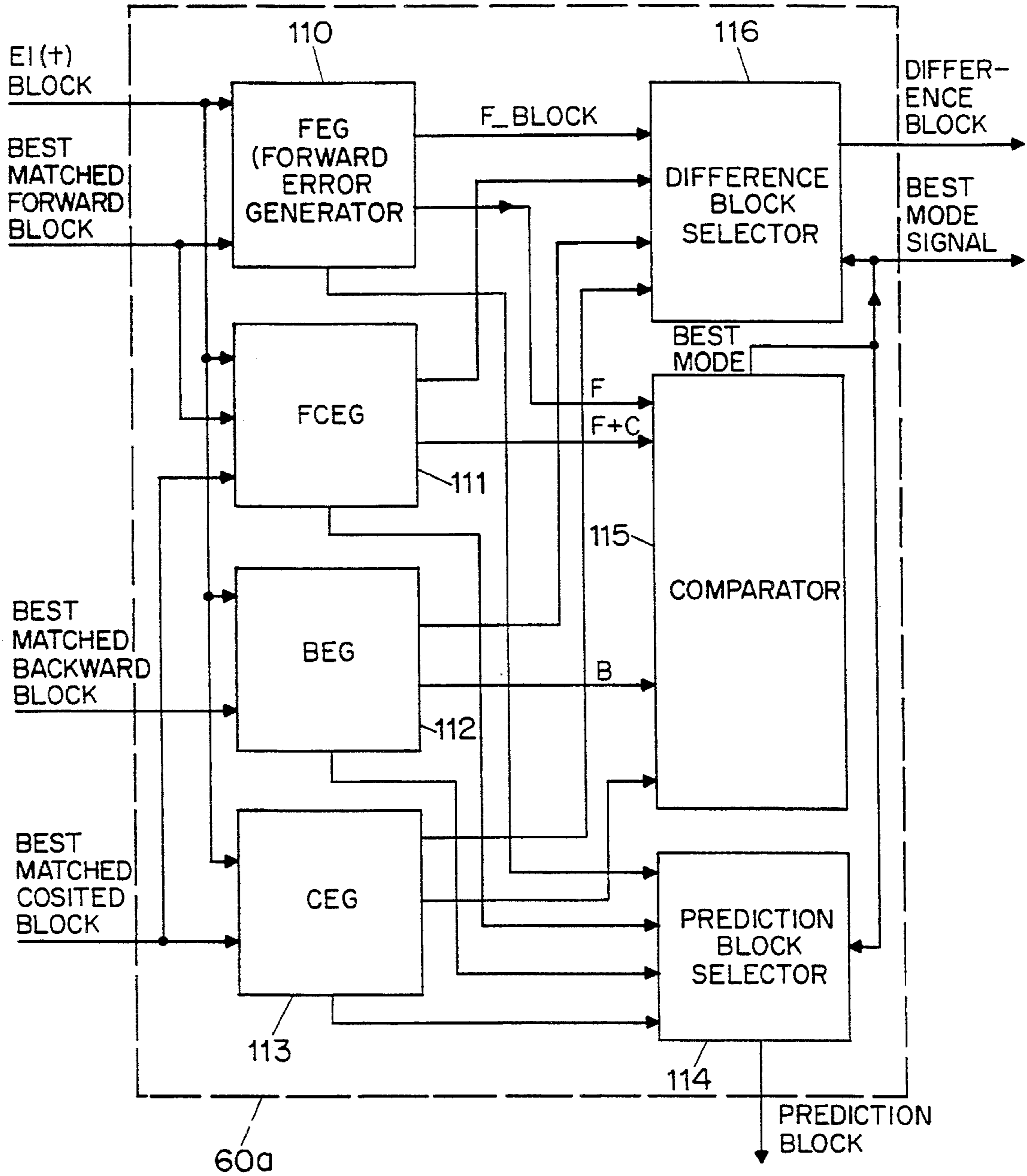


FIG. 15 (a)

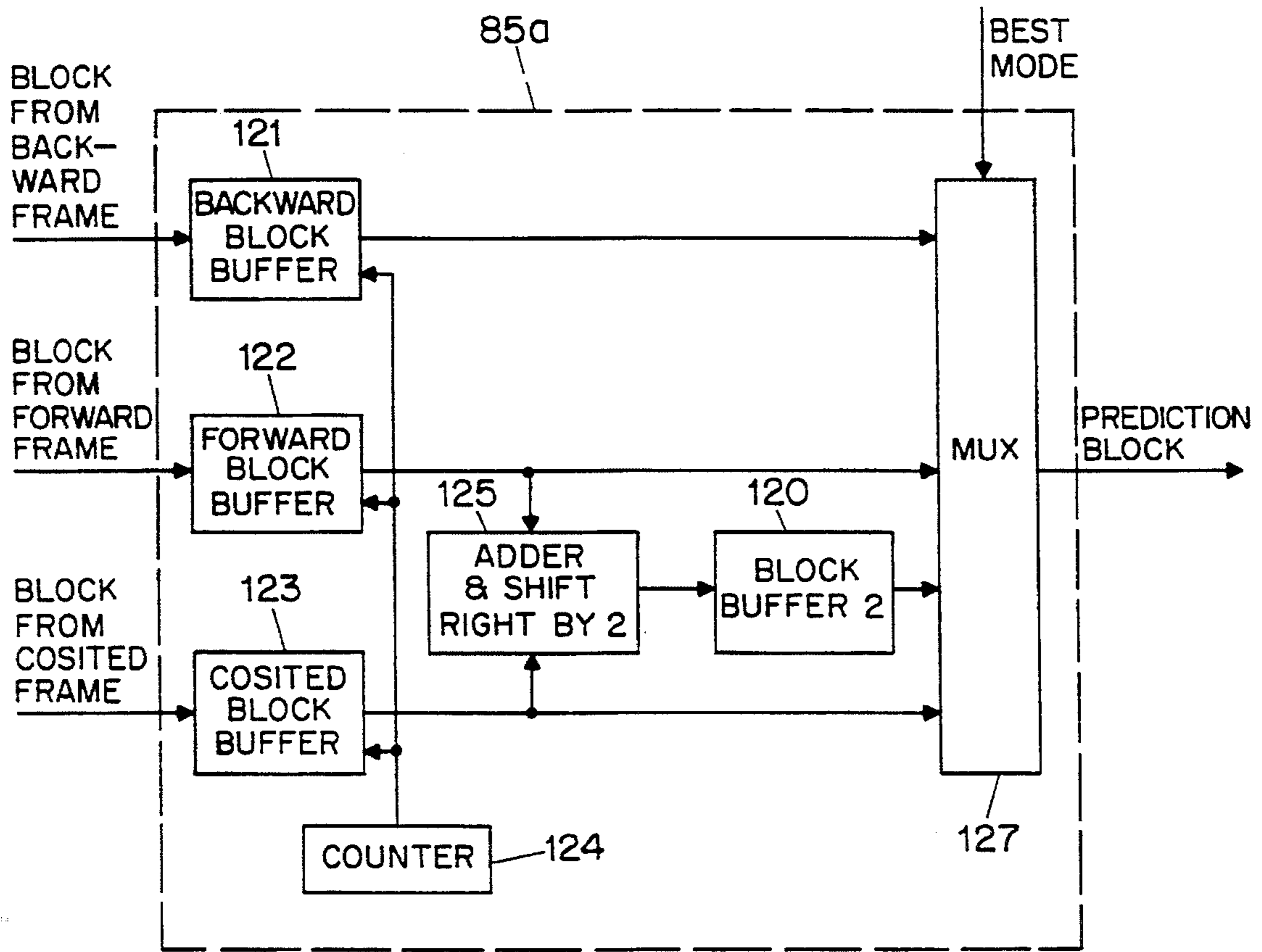


FIG. 15 (b)

**SYSTEMS AND METHODS FOR CODING  
EVEN FIELDS OF INTERLACED VIDEO  
SEQUENCES**

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

*The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of contract No. CDR-88-1111 awarded by the National Science Foundation.*

*This application is a continuation of application Ser. No. 08/218,970, filed on Mar. 25, 1994, now abandoned, and is a reissue of U.S. Pat. No. 5,193,004.*

**BACKGROUND OF THE INVENTION**

This invention relates to methods and systems for coding alternate fields of an interlaced video format and has particular applicability to arrangements wherein the other fields have already been coded.

Interlaced scanning is an efficient method of bandwidth compression for television transmission. Further bandwidth compression can be achieved by downsampling the interlaced video sequence by deleting either all the even or all the odd fields. This scheme is used, for example, in the current Motion Picture Experts Group (MPEG) proposal relating to coding and decoding protocols for the compression of video data. In that proposed format only the odd fields of an interlaced video sequence are encoded and transmitted. The present invention, utilizing the fact that even and odd fields are highly correlated, makes it possible to code the missing even fields very efficiently.

It is therefore the object of this invention to provide methods and systems for efficiently coding one field of an interlaced video.

It is a further object of this invention to provide methods and systems for coding interlaced video data so as to permit efficient and accurate decoding using methods and systems also in accordance with the invention.

**SUMMARY OF THE INVENTION**

In accordance with the present invention, a system, for multi-mode predictive interpolative coding of fields of video, includes input means for coupling current and later fields of interlaced data, such fields including even fields having pixel data for line positions at which pixel data is omitted in prior and later odd fields, separator means for separating even fields of data from odd fields of data and delayed coupling means for providing past odd field data. The system also includes storage means for storing data and for providing past even field data from storage and interpolation means, coupled to receive current even, future odd and past odd fields of data, for deriving and coupling to the storage means enhanced fields of data corresponding to each of such fields of data and having estimated pixel data at omitted line positions. Block matching means are included for comparing current even enhanced field data with each of the future odd and past odd enhanced fields and past even field data to develop motion vector signals indicative of location of best matched blocks of future odd, past odd and past even data, and for coupling motion-vector signals to the storage means. The system further includes comparator means for utilizing blocks of pixel data retrieved from

storage in response to motion vector signals for performing a plurality of mode comparisons of a block of current even pixel data with different ones of the best matched blocks alone or on an averaged basis for deriving a best mode signal representative of a single best mode block having the least error and deriving pixel error signals representing pixel by pixel errors in the best mode block, and output means for providing pixel error signals, best matched block location signals based on motion vector signals corresponding to the best mode signal, and odd field pixel data signals for transmission for use by a decoder.

Also in accordance with the invention a system, for decoding coded fields of video, includes input means for coupling location signals providing location data for best matched blocks, pixel error signals representative of pixel value errors in a best mode block relative to a current even field of pixel data, and odd field pixel data signals, and storage means for storing fields of pixel data, including a future odd field and past odd and even fields. Address generator means are included for providing address signals for retrieving one or more blocks of pixel data from stored future odd and past odd and even fields, and block coupling means provide a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved, and includes means for averaging simultaneously retrieved blocks of pixel data. Also included are block adder means for combining pixel error signals with the single best mode data block to provide a block of current even field pixel data, and combiner means for providing video signals including alternating odd and even fields of data.

Further in accordance with the invention, a method, for coding multi-mode predictive interpolative coded fields of video, includes the steps of:

- (a) providing a current field of interlaced pixel data, and past and future fields of such data;
- (b) providing estimated pixel data at omitted line positions in the past and future fields of data to form enhanced fields of pixel data;
- (c) comparing a block of pixel data from the current field with corresponding blocks of data from such past and future fields to derive motion vector signals indicative of best matched blocks of data;
- (d) developing pixel error signals representing pixel by pixel errors based on utilization of best matched blocks in different modes for comparison with the block of pixel data from the current field and developing best mode signals indicative of which of such modes represents the least overall error; and
- (e) providing the best mode signals, motion vector signals, pixel error signals, and the future odd field of data for transmission for use by a decoder.

Also in accordance with the invention a method, for decoding coded fields of video, includes the steps of:

- (a) receiving location signals providing location data for best matched blocks of data, pixel error signals representative of pixel value errors in a best mode block relative to a current even field of data, and odd field pixel data signals;
- (b) storing fields of pixel data which, relative to the current even field, include a future odd field and past odd and even fields;
- (c) deriving, with use of location signals, address signals used in retrieving from storage one or more blocks of pixel data from stored future odd and past odd and even fields;

- (d) providing an averaging function, responsive to blocks of pixel data retrieved in step (c), to provide a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved from storage;
- (e) combining the best mode data block with such pixel error signals to derive a block of current even field pixel data; and
- (f) assembling even fields of data for combination with the odd fields of data to provide video signals including alternating odd and even fields.

For a better understanding of the present invention, together with other and further objects, reference is made to the following description, taken in conjunction with the accompanying drawings, and its scope will be pointed out in the appended claims.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the a system diagram of an encoder in accordance with the invention.

FIG. 2 shows a field splitter useful in the FIG. 1 encoder.

FIG. 3 shows a linear interpolator useful in the FIG. 1 encoder.

FIG. 4 shows a block data encoder useful in the FIG. 1 encoder.

FIG. 5 shows a uniform quantization table used for coding block data.

FIG. 6 shows a zig-zag scanning diagram of an 8x8 DCT block.

FIG. 7 shows a block data decoder useful in the FIG. 1 encoder and the FIG. 13 decoder.

FIG. 8 shows a best mode generator useful in the FIG. 1 encoder.

FIG. 9 shows an error generator useful in the FIG. 8 best mode generator.

FIG. 10 shows an average error generator useful in the FIG. 8 best mode generator.

FIG. 11 shows a comparator useful in the FIG. 8 best mode generator.

FIG. 12 shows a block selector useful in the FIG. 8 best mode generator.

FIG. 13 is a system diagram of a decoder according to the invention.

FIG. 14 is a block coupling unit useful in the FIG. 13 decoder.

FIG. 15(a) shows an alternative arrangement of a best mode generator useful in the FIG. 1 encoder.

FIG. 15(b) shows a coupling unit corresponding to the FIG. 15(a) best mode generator.

### DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, there is illustrated a system for coding alternate fields of an interlaced video sequence for transmission to a decoder. Thus, for frames of video made up of successive odd and even fields of video data, the FIG. 1 system is useable for coding the even fields for example.

As used herein:

"field" refers to an incomplete frame of data, for example, the alternate fields of an NTSC television signal;

"frame" refers to a complete frame of data, for example, the composite of two fields of NTSC data;

In FIG. 1 the encoder includes input means shown as terminal 20 for receiving an interlaced video sequence and separator means, shown as field splitter 22, for separating odd fields of data  $O(t)$  from even fields of data  $E(t)$ . FIG. 2 is an illustration of a suitable field splitter. A de-multiplexer, shown as DMUX unit 25 takes an interlaced video sequence and uses a counter as a control signal. When the output of the counter is even, the "Even" output port of the 2-to-1 DMUX is selected, otherwise the "Odd" output port is selected.

The odd field data is encoded by unit 21 and provided to modulator unit 68. Encoded odd field data is decoded by unit 23. In this way any errors introduced by coding and decoding will be taken into account during the block matching process. Decoded odd field data is designated  $O_c(t)$ .

Delayed coupling means, including delay units 19 and 24 are arranged so that when an odd field of data, denoted as  $O_c(t)$  for reference timing purposes, is supplied to a point 26, the previous odd field of data denoted as  $O_c(t-1)$  and the even field of data  $E(t)$  are simultaneously supplied to points 28 and 30. Thus at any given iteration of the system's operation, the fields  $O_c(t)$ ,  $O_c(t-1)$  and  $E(t)$  are simultaneously available at 26, 28 and 30 respectively.

The encoder also includes interpolation means, shown as linear interpolators (LI) 32, 34, and 36 which may be separate channels of a single interpolation unit, effective to fill in an approximation of the pixel data at missing lines of each individual field of data by interpolation of pixel data at corresponding positions in preceding and succeeding lines of the same individual field. This provides full frames of alternating lines of actual input pixel data and interleaved lines of interpolated data, at the frame rate. These interpolated fields will be referred to as enhanced fields. Non-linear interpolation is also possible. As shown, unit 32 receives the current odd field input data  $O_c(t)$  from the separator means, via encoder unit 21 and decoder unit 23, and its output is an enhanced field version  $O_{ci}(t)$ . Similarly, unit 34 receives past odd field  $O_c(t-1)$  from delay unit 24 and its output is an enhanced field version  $O_{ci}(t-1)$ . Similarly, interpolation unit 36 receives the current even field of input data  $E(t)$  from the separator and its output is an enhanced field version  $E_i(t)$ . The interpolation means provide  $O_{ci}(t)$ ,  $O_{ci}(t-1)$  and  $E_i(t)$  to memory bank 50 and to block matching means.

Referring to FIG. 3, there is illustrated an embodiment of an interpolation circuit suitable for units 32, 34 and 36. In FIG. 3, linear interpolations are performed between two scanning lines of one field to generate the missing intermediate line. This is done by a full adder means 31 and a shift register 29 for each missing pixel. As shown, the input field containing only even or odd lines of a frame is input to field buffer 35. Under the control of values provided by counter means, two pixels are selected which are at the same horizontal position on two consecutive lines (i.e., the lines before and after the missing line position) and stored separately in the two registers 37 and 39. The values of the two pixels are then added in means 31 and shifted to the right by one bit one bit in shift register 29, which is the equivalent to dividing the sum of the two pixel values by a factor of two. The same process is applied for every missing pixel of the field, sequentially. In practice, this sequence of operations is performed in parallel through use of additional adder and register combinations. The output signal of units 32, 34 and 36 are linearly interpolated enhanced fields. As indicated, inputting  $O_c(t)$  to unit 32 results in the interpolated output  $O_{ci}(t)$  and similarly, interpolating of input  $O_c(t-1)$  results in interpolated output  $O_{ci}(t-1)$  and interpolating of  $E(t)$  results in interpolated output  $E_i(t)$ .

Block matching means, shown as forward, backward and

cosited block matching (BM) units **40**, **42** and **44**, may also be separate channels of a single unit. The block matching means receive as input the enhanced fields of data  $E_i(t)$ ,  $O_{ci}(t)$ ,  $O_{ci}(t-1)$  and  $E_{ci}(t-1)$ .  $E_{ci}(t-1)$ , the previous even field of data, is received from memory bank **50** where it has been stored after having been derived in the previous iteration of the encoder.

The block matching means finds for each given block of pixels in  $E_i(t)$ , the corresponding blocks in  $O_{ci}(t)$ ,  $O_{ci}(t-1)$  and  $E_{ci}(t-1)$  which match the given block in  $E_i(t)$  most closely. These can be referred to as the best matched forward, backward and cosited blocks. The block matching means then calculates an appropriate motion vector to each of the identified best matching blocks and outputs that data to memory bank **50**. Thus "fmv" is the appropriate motion vector indicating which block in  $O_{ci}(t)$  best matches the appropriate block in  $E_i(t)$ . Similarly "bmv" is the appropriate motion vector indicating which block in  $O_{ci}(t-1)$  best matches the appropriate block in  $E_i(t)$ . Finally, "cmv" represents the appropriate motion vector indicating which block in  $E_{ci}(t-1)$  best matches the appropriate block in  $E_i(t)$ . In the present embodiment, blocks of  $16 \times 16$  pixels are used for motion compensated block matching. Block matching techniques are known and block matching units **40**, **42**, and **44** may appropriately use block matching as shown in U.S. Pat. No. 4,897,720 by Wu and Yang.

The counter **52** and best-match selector **54** use the motion vector information to generate addresses for the best matched blocks in memory bank **50** corresponding to block in  $E_i(t)$  being matched.

Memory bank **50** can be composed of random access memory (RAM) chips which have to be big enough to hold five  $M \times N$  images ( $M$  and  $N$  are the width and height in terms of pixels of one image) and three sets of  $N/16 \times M/16$  motion vectors.

Best mode generator means **60** receives as input each block of  $E_i(t)$  and the best matched forward, backward and cosited blocks found by the block matching means. Concurrently, motion vector selector, shown as unit **62**, receives the motion vector values for each of the best matched blocks. The best mode generator determines which of the best matched blocks most closely matches the appropriate block in  $E_i(t)$ . These different comparisons are known as modes. Thus there can be a forward mode, a backward mode and a cosited mode based on a comparison of a specific block of pixel data from  $E_i(t)$  with the best matched blocks of future odd, past odd and past even pixel data, respectively. The best mode generator can also create and compare blocks which are averages of two or more of the best matched blocks which are received from the block matching means. These averaged modes can be based on any averaged combination of the best matched blocks. In certain applications, the most useful averaged modes have been found to be combinations of the past even and future odd blocks and of the past and future odd blocks from their respective enhanced fields of pixel data. The best mode generator then picks from among those modes the overall best matched block, also known as the best mode block.

After selecting the best mode block, the best mode generator generates three different outputs; the best mode block, a difference block and a signal to motion vector selector unit **62** and modulator unit **68** indicating which mode has been selected. Motion vector selector unit **62** then sends the motion vector information regarding the appropriate block or blocks (in the case of an averaged mode) to motion vector encoder **64**. Unit **64** encodes the motion

vector data and provides it to modulator **68**. The motion vector encoder uses variable length coding (VLC) which is based on a look-up table that stores the binary codes for all possible motion vectors. The look-up table is custom definable, however the present invention uses the same one which is used in the current MPEG proposal.

The difference block is the result of a pixel by pixel subtraction of the values of the overall best mode block from the block in  $E_i(t)$ . The difference block is then coded by block data encoder **41** and provided to modulator unit **68**. Data encoder **41** is illustrated in more detail in FIG. 4. Unit **48** converts the  $16 \times 16$  blocks received from the best mode generator to four  $8 \times 8$  blocks. A discrete cosine transform is applied to the difference block data by DCT unit **43**. The transform is performed on blocks of an  $8 \times 8$  size. The  $8 \times 8$  discrete cosine transform is defined as:

$$X(u,v) = (x)C(u)C(v) \sum_{i=0}^7 \sum_{j=0}^7 x(i,j) \cos \left( \frac{(2i+1)u\pi}{16} \right) \cos \left( \frac{(2j+1)v\pi}{16} \right)$$

where  $x(i,j)$ ,  $i,j=0, \dots, 7$ , is the pixel value,  $X(u,v)$ ,  $u,v=0, \dots, 7$ , is the transformed coefficient,

$$C(0) = \frac{1}{\sqrt{2}}$$

and  $C(u) = 1$ ,  $u,v=1, \dots, 7$ . DCT is well known in the art, and there are IC chips available for this purpose.

To achieve higher coding efficiency, the DCT coefficients are quantized by a uniform quantizer, shown in FIG. 5, with a fixed step  $S$ . The values of  $S$ , which are stored in a quantization table, typically vary from one coefficient to another. While FIG. 5 shows linear quantization, non-linear quantization is also possible. In the present instance the quantization table which is used is the current MPEG standard. Other quantization tables, however, are useable. After quantization, the DCT blocks contain a large amount of zero coefficients. Known techniques of zig-zag scanning may be applied to the DCT blocks in order to maximize the runs of zero coefficients and thereby effectuate higher data compression. The zig-zag scanning is implemented by a look-up table, shown in FIG. 6, which maps coordinates of DCT coefficient blocks to values between 0 and 63. This represents the order of variable length coding. A known form of Huffman coding may then be applied to convert the quantized DCT coefficients to binary codes. In the present instance, the MPEG VLC table is used for these purposes although other tables are also useable.

The coded difference block data is also provided to block data decoder **58** shown in FIG. 7. The block data decoder performs the reverse operations in the reverse order of the encoder. First the coded data is Huffman decoded and next unzig-zag scanning is applied. The data is then unquantized and an inverse discrete cosine transform is applied using known techniques. The decoder uses the same tables as the encoder. The output of block data decoder **58** is provided to block adder **56**. Block adder **56** also receives the best mode block from the best mode generator. It adds the difference block to the best mode block to create the same even field which will be recreated by the decoder. That even field is then provided to memory bank **50** where it will be used as the cosited past even field by cosited block matching unit **44** during the next iteration of the system.

Modulator unit **68** then combines the four sets of data it has received (odd field data, coded motion vector data, coded difference block data and best mode signal data) and provides an appropriate signal to terminal **70**. From there the data can be sent to an appropriate decoder.

FIG. **8** illustrates a suitable embodiment of the best mode generator **60**. The best mode generator includes four error generators shown as forward error generator (FEG) **92**, average error generator (FCEG) **94**, average error generator (BFEG) **96** and cosited error generator (CEG) **98**. The error generators receive as input a block from  $E_i(t)$  and the appropriate best matched blocks.

The forward error generator FEG compares the appropriate block in  $E_i(t)$  to the best matched forward block. The cosited error generator CEG compares the appropriate block in  $E_i(t)$  to the best matched cosited block.

The average error generators receive two or more best matched blocks which they average together to produce an average block. This average block is then compared to the appropriate block in  $E_i(t)$ . Thus average error generator BFEG creates a block which is the average of the best matched backwards block and the best matched forward block. Similarly the average error generator FCEG creates a block which is the average of the best matched forward block and the best matched cosited block. Averaging can be done by adding pixel values from the two blocks on a pixel by pixel basis and reducing each resulting pixel value by a factor of two (i.e. dividing each value in half).

From these inputs the error generators produce three outputs; a prediction block, a difference block and an absolute error.

The prediction block is the block which the error generator compares to the appropriate block in  $E_i(t)$ . Thus in the case of FEG or CEG, the prediction block is just the best matched block received from the block matching units. In the case of the average error generators, the prediction block is the average of two or more best matched blocks. The prediction blocks are outputted to the prediction block selector **93**.

The difference block is calculated by subtracting the value of a pixel in one block from the value of the corresponding pixel in the other block on a pixel by pixel basis. This value of this difference is then assigned to a corresponding pixel in the difference block. The sum of the absolute value of all of these pixels in the difference block is the absolute error.

The difference blocks are provided to the difference block selector unit **95**. The absolute errors are outputted to comparator unit **97**. Based on the absolute errors the comparator chooses the best mode. Typically this is the mode having the least absolute error, however, other selections are possible. This is referred to as the best mode. The comparator then supplies a signal indicating the best mode to the difference block selector unit **95**, modulator unit **68**, motion vector selector unit **62** and to the prediction block selector **93**. Upon receipt of the signal the difference block selector sends the appropriate difference block to block data encoder **41**, and the prediction block selector sends the appropriate prediction block (the best mode block) to block adder **56**.

Referring to FIG. **9**, there is illustrated an embodiment of the suitable error generator circuit for either the forward error generator FEG or the cosited error generator CEG, in FIG. **9** buffer block unit **67** and buffer block unit **69** receive a block from  $E_i(t)$  and the best matched block from either  $O_{ci}(t)$  or  $E_{ci}(t-1)$ . Subtraction unit **51** calculates the difference in value of each set of corresponding pixels in the two blocks and assigns that value to a corresponding pixel value in block buffer **55**. This is known as the difference block.

Absolute value generator **53** converts the value of the difference for each set of pixels to an absolute value and provides that information to the adder unit **57**. The adder unit **57** sums all of the absolute values for the differences of the two blocks being compared to create an absolute error value.

Referring to FIG. **10**, an embodiment of a suitable average error generator circuit is shown. Block buffer **78** receives a block in  $E_i(t)$ . Block buffers **79** and **83** receive the best matched blocks from the fields being averaged to create a block. In the case of error generator BFEG, the best matched blocks from  $O_{ci}(t-1)$  and  $O_{ci}(t)$  are used. In the case of average error generator FCEG, the best matched blocks from  $O_{ci}(t)$  and  $E_{ci}(t-1)$  are used. The values of each of the corresponding pixels in each of the best matched blocks is added and divided by two to create an average block. This is accomplished by unit **81**. This average block is then subtracted from the corresponding block in  $E_i(t)$  by subtraction unit **77**. In the same fashion as the other error generators, both a difference block and an absolute error value is created.

Referring to FIG. **11**, a suitable embodiment of the comparator unit **97** is shown. Minimum decision unit **74** picks the least value of the four absolute error inputs and outputs an appropriate best mode signal. While the current embodiment picks the mode with the least possible absolute error, other decision criterion are also available.

Referring to FIG. **12**, a suitable embodiment of a difference block selector is shown. Multiplexer unit **73** receives the four difference blocks as input. Responsive to the best mode signal, unit **73** outputs the appropriate difference block.

### Decoder Description

Because the implemented coding scheme is very unsymmetrical, the decoder is simpler than the encoder. This is due largely to the fact that the decoder does not have to perform block matching or make a best mode determination.

In FIG. **13**, the decoder includes input means, shown as terminal **80**, for receiving encoded data. Demodulating means, shown as demodulator unit **82** separates the encoded data into four bit streams: location signals in the form of a motion vector bit stream, a best mode signal bit stream, pixel error signals in the form of a difference block bit stream and an odd field data signal bit stream.

The first bit stream, containing the motion vector data, is decoded by a motion vector decoder **84** which uses the same VLC table as used in the encoder. The motion vector decoder **84** segments the bit stream into portions which represent one or two different motion vectors. Using the VLC table, the decoder provides the corresponding motion vectors. The motion vectors represent the displacement of the best matched blocks from the original blocks in  $E_i(t)$ . The motion vector decoder supplies the motion vectors to address generator unit **88**. The address generator also receives the best mode signal from demodulator unit **82**. The address generator uses the decoded motion vectors and the best mode signal to generate memory addresses of one or more of the best matched future odd, past odd and past even blocks, depending on the specific motion vector signals and the best mode signal. These blocks are sometimes referred to as the best matched forward, backward and cosited blocks, respectively.

In an alternative arrangement, only three bit streams need to be sent. In this arrangement the best mode signal and the motion vector would be combined in to an address bit stream

which would describe where in the receiver's memory the appropriate best matched blocks could be found.

Block coupling means, shown as prediction block generator unit **85**, receives the best matched forward, backward and cosited blocks from storage means shown as memory bank **86**. It also receives the best mode signal from demodulator **82**. Unit **85** then generates the same mode data block which was identified in the encoder. The mode data block is then provided to block adder unit **87**. Referring more specifically to FIG. **14**, a suitable embodiment of block generator **85** is shown. The best matched block or blocks representing the best mode data block are received from memory bank **86** into the appropriate block buffers. In this embodiment the two average modes are created by units **102** and **103**. The two other modes which merely use best matched blocks, are already available as received in the appropriate buffers. In operation, only the best matched block or blocks needed to provide the desired best mode block are supplied to block generator unit **85**. Thus, if either the future odd block or past even block represents the best mode block, only the respective desired block is received by unit **85** and it is coupled by unit **85** to block adder unit **87**. If, however, the best mode block is the block of data representing an average of the past even block and the future odd block, those blocks are provided from memory to buffers **100** & **101**, respectively, for averaging in unit **103** and coupling to block adder unit **87**. Operation is similar via buffers **99** and **100** and unit **102**, when the best mode block represents the average of the past and future odd field best matched blocks. As illustrated, unit **85** is responsive to the best mode signal in implementing the averaging function however, in other applications unit **85** need only be arranged to simply pass through any single input block and, in response to the input of two blocks simultaneously, to provide an averaged output to unit **87** whenever two blocks are received. In operation of unit **85** as illustrated, the appropriate mode is then loaded into MUX unit **106**, which outputs the appropriate prediction block to block adder unit **87**.

Block decoder unit **89** decodes the difference blocks and then provides the difference block to the block adder unit **87** where it is added to the single best mode data block from unit **85**. Referring more specifically to FIG. **7** there is an illustration of the decoder **89**. This decoder is of the same design as the decoder unit **58** in the FIG. **1** encoder. Units **59**, **61**, **63**, and **65** respectively perform the following functions in sequence: Huffman decode, unzig-zag scan, unquantize and inverse discrete cosine transform, upon the incoming coded difference block data. Unit **66** reassembles the four  $8 \times 8$  blocks into one  $16 \times 16$  block.

The combination by block adder unit **87** of the best mode block and the difference block creates the coded field  $Eci(t)$ . This field is then provided to memory bank **86** where it can be used to recreate the next even field. It is also provided to combiner means shown as unit **90**.

The fourth bit stream outputted by demodulator unit **82** is the coded odd field data. This data is provided to decoder unit **91**, which may provide MPEG type coding compatible with prior encoding. The decoded odd field data is provided to linear interpolator **107** which operates in the same fashion as the linear interpolator units in the encoder. Thus enhanced field of data  $Oci(t)$  is created and sent to combiner unit **90** and memory bank **86**. Memory bank **86** uses  $Oci(t)$  and  $Oci(t-1)$  pixel field data which was created in the system's previous iteration, to generate the appropriate blocks for block coupling means **85**. As previously mentioned,  $Eci(t)$  and hence  $Eci(t-1)$  are available also from storage in memory bank **86**.

Combiner unit **90** drops half the lines out of both the even

and odd enhanced fields of data it receives.  $Eci(t)$  and  $Oci(t)$  and sequentially combines them to provide reconstruction of the interlaced sequence of data that was originally inputted into terminal **20** of the encoder. As shown in FIG. **13**, the interlaced video data is supplied to delay unit **72** to permit viewing of the video sequence.

The term "best mode" as used herein is used to identify a selected mode. Normally the mode selection is made to minimize pixel error signals to be transmitted to a decoder, however, the term is used to include reference to any available mode selected for use in a particular application.

Combinations of modes, other than those described above are also available. FIG. **15(a)** shows an arrangement of a best mode generator which uses a different set of modes. The FIG. **15(a)** best mode generator compares the appropriate block in  $Ei(t)$  to the best matched future odd block, the best matched past odd block, the best matched past even block and to a block which is the average of the best matched future odd block and the best matched past even block. Error generator **110-113** carry out the appropriate comparisons. The other operations of the FIG. **15(a)** best mode generator block are similar to that of the FIG. **8** best mode generator block.

FIG. **15(b)** shows a suitable embodiment of a prediction block generator corresponding to the FIG. **15(a)** best mode generator. Unit **125** generates the average of the future odd and past even best matched blocks while units **121-123** couple as appropriate the best matched past odd, future odd and past even blocks to unit **127**. Unit **127** outputs the appropriate block responsive to the best mode signal.

Other arrangements are also possible. Original odd field data can be used for block matching purposes even if the odd field is being coded.

In another arrangement, the best mode generator could make comparisons based on only the past even field and the future odd field. Thus the best mode generator would require only 3 inputs.

In another alternative arrangement, the data received at terminal **20** can be interlaced data which has been compressed in to full frames of data. In arrangements of this type, field delay unit **19** is not necessary.

In summary, methods and systems according to the invention contain various modes of operation. The following four modes were found to be most useful, but it is possible to have more, at the expense of increased complexity, including intrafield, backward, or even three-way averaging.

1. A "recursive", predictive, mode in which the past cosited even field is used for prediction. A motion vector must be sent, which often has zero values for stationary objects.

2. A "forward" mode, in which the future odd field is used for prediction. A motion vector must be sent.

3. An "averaged" mode, in which both past and future odd fields are used, by averaging the pixel values of the two optimum blocks. In that case, two motion vectors must be sent.

4. A "recursive averaged" mode, in which the previous even cosited field is combined as above, with the future odd field.

Methods and systems according to the invention, when combined with appropriate coding of the progressive sequence resulting from dropping the even fields of interlaced video, yields high quality compression with reasonable encoder complexity. This technique can be used for about 5 Mbits/s coding of standard-quality video coding, or

for high-compression distribution quality digital HDTV coding. Coding the quantized DCT coefficients must be optimized depending on their statistical nature, which, in turn, depends on the desired quality of the final reconstructed signal. If horizontal downsampling is avoided, then the resulting asymmetry between the horizontal and vertical frequencies must be considered when coding the DCT blocks, for optimum results. We have used 16×16 blocks for motion estimation and 8×8 blocks for DCT coding, but other configurations may be optimum, depending on the application, including, e.g., a quadtree-based segmented block matching approach using both 16×16 and 8×8 blocks. In our simulations, we have found that the even fields are coded with about 60% of the bit rate of the odd fields, with the same quality. The same concept can be used for HDTV coding at low bit rates (e.g. below 20 Mbits/s). There are various proposals for HDTV coding, using at least 70 Mbits/s. We also found that nonlinear edge preserving noise smoothing preprocessing greatly enhances coding performance, particularly in the case of coding noisy HDTV video signals.

While there have been described what are believed to be the preferred embodiments of the invention, those skilled in the art will recognize that other and further modifications may be made thereto without departing from the of the invention, and it is intended to claim all such embodiments as fall within the true scope of the invention.

We claim:

1. A system, for multi-mode predictive interpolative coding of fields of video, comprising:
  - input means for coupling current and later fields of interlaced data, such fields including even fields having pixel data for line positions at which pixel data is omitted in prior and later odd fields;
  - separator means, coupled to said input means, for separating said even fields of data from said odd fields of data;
  - delayed coupling means, coupled to said separation means to receive odd fields of data, for providing past odd field data;
  - storage means for storing data and for providing past even field data from storage;
  - interpolation means, coupled to said separation means and delayed coupling means to receive current even, future odd and past odd fields of data, for deriving and coupling to said storage means enhanced fields of data corresponding to each of said fields of data and having estimated pixel data at omitted line positions;
  - block matching means, coupled to said interpolation means and storage means, for comparing said current even enhanced field data with each of said future odd and past odd enhanced fields and said past even field data to develop motion vector signals indicative of location of best matched blocks of future odd, past odd and past even data, and for coupling said motion-vector signals to said storage means;
  - comparator means, coupled to said storage means, for utilizing blocks of pixel data retrieved from said storage means in response to said motion vector signals for performing a plurality of mode comparisons of a block of current even pixel data with different ones of said best matched blocks alone or on an averaged basis for deriving a best mode signal representative of a single best mode block having the least error and deriving pixel error signals representing pixel by pixel errors in said best mode block; and

output means, coupled to said comparator means and separator means, for providing said pixel error signals, best matched block location signals based on motion vector signals corresponding to said best mode signal, and odd field pixel data signals for transmission for use by a decoder.

2. An encoding and decoding system, comprising:

(a) a system in accordance with claim 1, for coding fields of interlaced video to provide output signals; and

(b) a system, for decoding said output signals, comprising:

input means for coupling said output signals;

storage means, coupled to said input means, for storing fields of pixel data, including a future odd field and past odd and even fields;

address generator means, responsive to said location signals, for providing address signals to said storage means for retrieving one or more blocks of pixel data from said stored future odd and past odd and even fields;

block coupling means, responsive to blocks of data retrieved from said storage means, for providing a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved, and including means for averaging simultaneously retrieved blocks of pixel data;

block adder means, coupled to said input means and block coupling means, for combining said pixel error signals with said single best mode data block to provide a block of current even field pixel data; and combiner means, responsive to blocks of said current even field data and to said odd fields of pixel data, for providing video signals including alternating odd and even fields of data.

3. A coding system in accordance with claim 1, wherein said output means also provides said best mode signals for transmission for use by a decoder.

4. A coding system in accordance with claim 1, wherein said comparator means includes means for averaging blocks of pixel data from a past even field and a future odd field in deriving said best mode signal.

5. A system in accordance with claim 1, wherein said comparator means includes means for averaging blocks of pixel data from a past even field and a future odd field and averaging blocks of such data from past and future odd fields in deriving said best mode signal.

6. A coding system in accordance with claim 1, 4 or 5 wherein said comparator means includes means for averaging blocks of pixel data by adding two blocks of data on a pixel by pixel basis and reducing each resulting pixel value by a factor of two.

7. A coding system in accordance with claim 1, wherein said comparator means comprises:

first error generator means for deriving pixel error signals based on comparison of a block of current even field data with an average data block obtained by averaging a block of past even field data and a block of future odd field data.

8. A coding system in accordance with claim 7, wherein said comparator means additionally comprises:

second error generator means for deriving pixel error signals based on comparison of a block of current even field data with a block of past even field data.

9. A coding system in accordance with either of claims 7 or 8, wherein said comparator means additionally comprises:



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third error generator means for denying pixel error signals based on comparison of a block of current even field data with an average data block obtained by averaging a block of past odd field data and a block of future odd field data.

10. A coding system in accordance with either of claims 7 or 8, wherein said comparator means additionally comprises:

fourth error generator means for deriving pixel error signals based on a comparison of a block of current field data with a block of future odd field data; and means for comparing the overall error represented by each of said pixel error signals to derive a best mode signal indicative of the pixel error signal representing the least overall error.

11. A system, for multi-mode predictive interpolative coding of fields of video, comprising:

input means for coupling current and later fields of interlaced data, such fields including current even fields having pixel data for line positions at which pixel data is omitted in past and future odd fields;

separator means, coupled to said input means, for separating said even fields of data from said odd fields of data;

delayed coupling means, coupled to said separation means to receive odd fields of data, for providing past odd field data;

storage means for storing data and for providing past even field data from storage;

block matching means, coupled to said separation means, delayed coupling means and storage means, for comparing current even field data with each of said future odd and past odd and even field data to develop motion vector signals indicative of locations of best matched blocks of future odd, past odd and past even data, and for coupling said motion-vector signals to said storage means;

comparator means, coupled to said storage means, for utilizing blocks of pixel data retrieved from said storage means in response to said motion vector signals for performing a plurality of mode comparisons of a block of current even pixel data with different ones of said best matched blocks alone or on an averaged basis for deriving a best mode signal representative of a single best mode block having the least error and deriving pixel error signals representing pixel by pixel errors in said best mode block; and

output means, coupled to said comparator means and separator means, for providing said pixel error signals, best matched block location signals based on motion vector signals corresponding to said best mode signal, and odd field pixel data signals for transmission for use by a decoder.

12. A coding system in accordance with claim 11, wherein said comparator means includes means for averaging blocks of pixel data from a past even field and a future odd field in deriving said best mode signal.

13. A system, for decoding coded fields of video, comprising:

input means for coupling location signals providing location data for best matched blocks, pixel error signals representative of pixel value errors in a best mode block relative to a current even field of pixel data, and odd field pixel data signals;

storage means, coupled to said input means, for storing

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fields of pixel data, including a future odd field and past odd and even fields;

address generator means, responsive to said location signals, for providing address signals to said storage means for retrieving one or more blocks of pixel data from said stored future odd and past odd and even fields;

block coupling means, responsive to blocks of data retrieved from said storage means, for providing a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved, and including means for averaging simultaneously retrieved blocks of pixel data;

block adder means, coupled to said input means and block coupling means, for combining said pixel error signals with said single best mode data block to provide a block of current even field pixel data; and

combiner means, responsive to blocks of said current even field data and to said odd fields of pixel data, for providing video signals including alternating odd and even fields of data.

14. A decoding system in accordance with claim 13, additionally comprising interpolation means, responsive to said odd fields of pixel data, for deriving and coupling to said storage means enhanced fields of data corresponding to said odd fields of data and having estimated pixel data inserted at omitted line positions.

15. A receiver, for decoding and displaying fields of video, comprising:

a decoder in accordance with claim 13; and

display means for displaying said video signals.

16. A decoding system in accordance with claim 13, wherein signals coupled by said input means also include best mode signals indicative of a block of data representing the least overall error and wherein said best mode signals are coupled to said address generator means for use in deriving address signals and to said block coupling means for controlling operation of said averaging means.

17. A decoding system in accordance with claim 16 wherein said input means couples location signals comprising motion vector signals.

18. A decoding system in accordance with claim 13, wherein said block coupling means includes means for averaging blocks of pixel data from a past even field and a future odd field for deriving a best mode data block.

19. A decoding system in accordance with claim 13, wherein said block coupling means includes means for averaging blocks of pixel data from a past even field and a future odd field, and means for averaging blocks of pixel data from a past odd field and a future odd field, for deriving a best mode data block.

20. A decoding system in accordance with claim 13, wherein said block coupling means includes means for averaging blocks of pixel data when two blocks of such data are simultaneously retrieved, and for coupling to an output without modification singly retrieved blocks of such data.

21. A decoding system in accordance with claim 13, 18, 19 or 20 wherein said block coupling means includes means for averaging blocks of pixel data by adding two blocks of data on a pixel by pixel basis and reducing each resulting pixel value by a factor of two.

22. A method, for coding multi-mode predictive interpolative coded fields of video, comprising the steps of:

(a) providing a current field of interlaced pixel data, and past and future fields of such data;

(b) providing estimated pixel data at omitted line posi-

tions in said past and future fields of data to form enhanced fields of pixel data;

- (c) comparing a block of pixel data from said current field with corresponding blocks of data from said past and future fields to derive motion vector signals indicative of best matched blocks of data;
- (d) developing pixel error signals representing pixel by pixel errors based on utilization of said best matched blocks in different modes for comparison with said block of pixel data from said current field and developing best mode signals indicative of which of said modes represents the least overall error; and
- (e) providing said best mode signals, motion vector signals, pixel error signals, and said future field of data for transmission for use by a decoder.

**23.** A decoding method comprising:

- (a) receiving signals provided in accordance with claim **22**, including pixel error signals representative of pixel value errors in a best mode block relative to a current even field of data;
- (b) storing fields of pixel data which, relative to said current even field, include a future odd field and past odd and even fields;
- (c) deriving, with use of said location signals, address signals used in retrieving from storage one or more blocks of pixel data from said stored future odd and past odd and even fields;
- (d) providing an averaging function, responsive to blocks of pixel data retrieved in step (c), to provide a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved from storage;
- (e) combining said best mode data block with said pixel error signals to derive a block of current even field pixel data; and
- (f) assembling even fields of data for combination with said odd fields of data to provide video signals including alternating odd and even fields.

**24.** A method in accordance with claim **22**, wherein the fields of pixel data provided in step (a) include a current even field, a future odd field and past odd and even fields of data and step (d) includes a comparison mode in which said block of pixel data from said current even field is compared with a block of data representing an average of corresponding blocks of data from said future odd and past even fields of data.

**25.** A method in accordance with claim **22**, wherein the fields of pixel data provided in step (a) include a current even field, a future odd field and past odd and even fields of data and step (d) includes a comparison mode in which said block of pixel data from said current even field is compared with a block of data representing an average of corresponding blocks of data from said future odd and past even fields of data and an additional comparison mode in which said current even field block is compared with a block of data representing an average of corresponding blocks of data from said past and future odd fields of data.

**26.** A method in accordance with claim **22**, **24** or **25** additionally comprising the step of receiving an interlaced video signal and separating said signal into odd and even fields of interlaced pixel data.

**27.** A method in accordance with claim **22**, **24** or **25** additionally comprising the steps of storing and retrieving fields of pixel data and motion vector signals.

**28.** A method in accordance with claim **22**, **24** or **25** additionally comprising the steps of compression coding

odd fields of pixel data and combining best mode signals, motion vector signals, pixel error signals and said coded odd fields into a combined signal for transmission for use by a decoder.

**29.** A method, for coding multi-mode predictive interpolative coded fields of video, comprising the steps of:

- (a) providing a current field of interlaced pixel data, and past and future fields of such data;
- (b) comparing a block of pixel data from said current field with corresponding blocks of data from said past and future fields to derive motion vector signals indicative of best matched blocks of data;
- (c) developing pixel error signals representing pixel by pixel errors based on utilization of said best matched blocks in different modes for comparison with said block of pixel data from said current field and developing best mode signals indicative of which of said modes represents the least overall error; and
- (d) providing said best mode signals, motion vector signals, pixel error signals, and said future field of data for transmission for use by a decoder.

**30.** A method, for decoding coded fields of video, comprising the steps of:

- (a) receiving location signals providing location data for best matched blocks of data, pixel error signals representative of pixel value errors in a best mode block relative to a current even field of data, and odd field pixel data signals;
- (b) storing fields of pixel data which, relative to said current even field, include a future odd field and past odd and even fields;
- (c) deriving, with use of said location signals, address signals used in retrieving from storage one or more blocks of pixel data from said stored future odd and past odd and even fields;
- (d) providing an averaging function, responsive to blocks of pixel data retrieved in step (c), to provide a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved from storage;
- (e) combining said best mode data block with said pixel error signals to derive a block of current even field pixel data; and
- (f) assembling even fields of data for combination with said odd fields of data to provide video signals including alternating odd and even fields.

**31.** A decoding method in accordance with claim **30**, additionally comprising the step of decoding said odd fields of pixel data in a manner compatible with data compression coding provided prior to data transmission.

**32.** A decoding method in accordance with claim **30**, wherein said signals received in step (a) also include best mode signals indicative of a block of data representing the least overall error, and wherein said best mode signals are made available for use in deriving address signals in step (e) and for controlling said averaging function in step (d).

**33.** A decoding method in accordance with claim **32**, wherein step (d) includes averaging on a pixel by pixel basis corresponding blocks of data from said future odd and past odd blocks of data, when said two blocks of data are simultaneously retrieved in step (c).

**34.** A decoding method in accordance with claim **30**, wherein step (d) includes averaging on a pixel by pixel basis corresponding blocks of data from said future odd and past even blocks of data, when said two blocks of data are

simultaneously retrieved in step (c).

35. A decoding method in accordance with claim 30, 34 or 33 wherein said step (d) includes averaging blocks of data, when two blocks are simultaneously retrieved in step (c), by adding said two blocks on a pixel by pixel basis and reducing each resulting pixel value by a factor of two.

36. A system, for multi-mode predictive interpolative coding of fields of video, comprising:

input means for coupling current and later fields of interlaced data, such fields including current even fields having pixel data for line positions at which pixel data is omitted in past and future odd fields;

separator means, coupled to said input means, for separating said even fields of data from said odd fields of data;

storage means for storing data and for providing the nearest in time past even field data then available, relative to said current even field of data;

block matching means, coupled to said separation means and storage means, for comparing current even field data with said future odd and past even field data to develop motion vector signals indicative of locations of best matched blocks of future odd and past even data, and for coupling said motion-vector signals to said storage means;

comparator means, coupled to said storage means, for utilizing blocks of pixel data retrieved from said storage means in response to said motion vector signals for performing a plurality of mode comparisons of a block of current even pixel data with different ones of said best matched blocks alone or on an averaged basis for deriving a best mode signal representative of a single best mode block having the least error and deriving pixel error signals representing pixel by pixel errors in said best mode block; and

output means, coupled to said comparator means and separator means, for providing said pixel error signals, best matched block location signals based on motion vector signals corresponding to said best mode signal, and odd field pixel data signals for transmission for use by a decoder.

37. A system, for multi-mode predictive interpolative coding of fields of video, comprising:

input means for coupling current and later fields of interlaced data, such fields including current even fields having pixel data for line positions at which pixel data is omitted in past and future odd fields;

separator means, coupled to said input means, for separating said even fields of data from said odd fields of data;

delayed coupling means, coupled to said separation means to receive odd fields of data, for providing the nearest in time past odd field data then available, relative to said current even field of data;

storage means for storing data and for providing the nearest in time past odd field data then available, relative to said current even field of data;

block matching means, coupled to said separation means and storage means, for comparing current even field data with said future odd and even past field data to develop motion vector signals indicative of locations of best matched blocks of future odd and past even data, and for coupling said motion-vector signals to said storage means;

comparator means, coupled to said storage means, for

utilizing blocks of pixel data retrieved from said storage means in response to said motion vector signals for performing a plurality of mode comparisons of a block of current even pixel data with different ones of said best matched blocks alone or on an averaged basis for deriving a best mode signal representative of a single best mode block having the least error and deriving pixel error signals representing pixel by pixel errors in said best mode block; and

output means, coupled to said comparator means and separator means, for providing said pixel error signals, best matched block location signals based on motion vector signals corresponding to said best mode signal, and odd field pixel data signals for transmission for use by a decoder.

38. A coding system in accordance with claim 36 or 37, wherein said comparator means includes means for averaging blocks of pixel data from a past even field and a future odd field in denying said best mode signal.

39. A coding system in accordance with claim 36 or 37, additionally including interpolation means, coupled to said separation means, for deriving and coupling to said block matching means odd and even field data corresponding to odd and even fields of data having estimated pixel data at omitted line positions.

[40. A system, for decoding coded fields of video, comprising:

input means for coupling location signals providing location data for best matched blocks, pixel error signals representative of pixel value errors in a best mode block relative to a current even field of pixel data, and odd field pixel data signals;

storage means, coupled to said input means, for storing fields of pixel data, including a future odd field and a past even field;

address generator means, responsive to said location signals, for providing address signals to said storage means for retrieving one or more blocks of pixel data from said stored future odd and past even fields;

block coupling means, responsive to blocks of data retrieved from said storage means, for providing a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved, and including means for averaging simultaneously retrieved blocks of pixel data;

block adder means, coupled to said input means and block coupling means, for combining said pixel error signals with said single best mode data block to provide a block of current even field pixel data; and

combiner means, responsive to blocks of said current even field data and to said odd fields of pixel data, for providing video signals including alternating odd and even fields of data.]

[41. A decoding system in accordance with claim 40, wherein said block coupling means includes means for averaging blocks of pixel data from a past even field and a future odd field for deriving a best mode data block.]

[42. A decoding system in accordance with claim 40, wherein said block coupling means includes means for averaging blocks of pixel data when two blocks of such data are simultaneously retrieved, and for coupling to an output without modification singly retrieved blocks of such data.]

[43. A method, for decoding coded fields of video, comprising the steps of:

(a) receiving location signals providing location data for best matched blocks of data, pixel error signals repre-

sentative of pixel value errors in a best mode block relative to a current even field of data, and odd field pixel data signals;

- (b) storing fields of pixel data which, relative to said current even field, include a future odd field and past even fields;
- (c) deriving, with use of said location signals, address signals used in retrieving from storage one or more blocks of pixel data from said stored future odd and past even fields;
- (d) providing an averaging function, responsive to blocks of pixel data retrieved in step (c), to provide a single best mode data block regardless of the number of blocks of pixel data simultaneously retrieved from storage;
- (e) combining said best mode data block with said pixel error signals to derive a block of current even field pixel data; and
- (f) assembling even fields of data for combination with said odd fields of data to provide video signals including alternating odd and even fields.]

[44. A decoding method in accordance with claim 43, wherein said signals received in step (a) also include best mode signals indicative of a block of data representing the least overall error, and wherein said best mode signals are made available for use in deriving address signals in step (c) and for controlling said averaging function in step (d).]

[45. A decoding method in accordance with claim 43, wherein step (d) includes averaging on a pixel by pixel basis corresponding blocks of data from said future odd and past even blocks of data, when said two blocks of data are simultaneously retrieved in step (c).]

46. A method, for decoding coded fields of video data, wherein frames of video data consist of first and second fields of video data, comprising the steps of:

- (a) receiving location signals providing location data for best matched blocks of data, pixel error signals representative of pixel value errors in a best mode block relative to a first field of a current frame of data, and second field data signals;
- (b) selecting, with use of said location signals, one or more blocks of pixel data from a second field of said current frame and a first field of a past frame of data;
- (c) providing an averaging function, responsive to blocks of pixel data selected in step (b), to provide a single best mode data block regardless of the number of blocks of pixel data selected;
- (d) combining said single best mode data block with said pixel error signals to derive a block of first field of a current frame pixel data; and
- (e) assembling first fields of data for combination with said second fields of data to provide video signals including frames of first and second fields.

47. A decoding method in accordance with claim 46, further including the additional step of storing fields of pixel data which, relative to said first field of said current frame, include a second field of said current frame and a first field of a past frame of data, wherein said storing step is performed prior to step (b).

48. A decoding method in accordance with claim 47, wherein said blocks of pixel data selected from said second field of said current frame and said first field of said past frame of data are retrieved from storage.

49. A decoding method in accordance with claim 48, wherein step (b) includes using said location signals to

derive address signals which are used in said retrieval.

50. A decoding method in accordance with claim 46, wherein step (b) includes using said location signals to derive address signals which are used in said selection.

51. A decoding method in accordance with claim 50, wherein said signals received in step (a) also include best mode signals indicative of a block of data representing the least overall error, and wherein said best mode signals are made available for use in deriving said address signals in step (b) and for controlling said averaging function in step (c).

52. A decoding method in accordance with claim 46, wherein said first fields of video data are even fields and said second fields of video data are odd fields.

53. A decoding method in accordance with claim 46, wherein step (c) includes averaging on a pixel by pixel basis corresponding blocks of data, when two blocks of data are simultaneously selected.

54. A system, for decoding coded fields of video data, wherein frames of video data consist of first and second fields of video data, comprising:

- (a) input means for coupling location signals providing location data for best matched blocks of data, pixel error signals representative of pixel value errors in a best mode block relative to a first field of a current frame of data, and second field data signals;
- (b) selection means, responsive to said location signals, for selecting one or more blocks of pixel data from a second field of said current frame and a first field of a past frame of data;
- (c) block coupling means, responsive to blocks of data selected in step (b), for providing a single best mode data block regardless of the number of blocks of pixel data selected, and including means for averaging simultaneously selected blocks of pixel data;
- (d) block adder means, coupled to said input means and block coupling means, for combining said single best mode data block with said pixel error signals to derive a block of first field of a current frame pixel data; and
- (e) combiner means, responsive to said first fields of data and to said second fields of data, for providing video signals including frames of first and second fields.

55. A decoding system in accordance with claim 54, further including storage means, coupled to said input means, for storing fields of pixel data which, relative to said first field of said current frame, include a second field of said current frame and a first field of a past frame of data.

56. A decoding system in accordance with claim 55, wherein said blocks of pixel data selected from said second field of said current frame and said first fields of said past frame of data are retrieved from said storage means.

57. A decoding system in accordance with claim 56, wherein said selection means include address generator means, responsive to said storage means, for providing address signals for said retrieval to said storage means.

58. A decoding system in accordance with claim 57, wherein said signals received by said input means also include best mode signals indicative of a block of data representing the least overall error, and wherein said best mode signals are made available for use in deriving said address signals by said address generator means and for controlling said averaging means.

59. A decoding system in accordance with claim 54, wherein said first fields of video data are even fields and said second fields of video data are odd fields.

60. A decoding system in accordance with claim 54,

wherein said block coupling means includes means for averaging on a pixel by pixel basis corresponding blocks of data, when two blocks of data are simultaneously selected by said selection means.

61. A method, for coding multi-mode predictive interpo- 5  
lative coded fields of video, wherein frames of video data consist of first and second fields of video data, comprising the steps of:

- (a) providing a first and a second field of a current frame 10  
of interlaced pixel data, and fields of past frames of such data;
- (b) comparing a block of pixel data from said first field of 15  
said current frame with corresponding blocks of data from said second field of said current frame and fields from past frames to derive motion vector signals indicative of best matched blocks of data;
- (c) developing pixel error signals representing pixel by 20  
pixel errors based on utilization of said best matched blocks in different modes for comparison with said block of pixel data from said first field of said current frame and developing best mode signals indicative of which of said modes represents the least overall error; and
- (d) providing said best mode signals, motion vector 25  
signals, pixel error signals, and said second field of said current frame of data for transmission for use by a decoder.

62. A system, for coding multi-mode predictive interpo-  
lative coded fields of video, wherein frames of video data consist of first and second fields of video data, comprising:

- (a) input means for coupling a first and a second field of 5  
a current frame of interlaced pixel data, and fields of past frames of such data;
- (b) storage means, coupled to said input means, for 10  
storing data and for providing data;
- (c) block matching means, coupled to said storage means, 15  
for comparing a block of pixel data from said first field of said current frame with corresponding blocks of data from said second field of said current frame and fields from past frames to develop motion vector signals indicative of best matched blocks of data, and for 20  
coupling said motion vector signals to said storage means;
- (d) comparator means, coupled to said storage means, for 25  
utilizing blocks of pixel data retrieved from said storage means in response to said motion vector signals for performing a plurality of mode comparisons of a block of pixel data from said first field of said current frame with different ones of said best matched blocks alone or on an averaged basis for deriving a best mode block having the least error and deriving pixel error signals representing pixel by pixel errors in said best mode block; and
- (e) output means, coupled to said comparator means, for 30  
providing said best mode signals, motion vector signals, pixel error signals, and said second field of said current frame of data for transmission for use by a decoder.

\* \* \* \* \*

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**CERTIFICATE OF CORRECTION**

PATENT NO. : RE. 35,093 Page 1 of 3  
DATED : November 21, 1995  
INVENTOR(S) : Feng M. Wang et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:  
Title page, item [56]: OTHER PUBLICATIONS

Puri, A. et al. Video Coding with Motion-Compensated Interpolation for CD-ROM Applications, Image Communication, vol. 2, No. 2 pp. 127-144 Aug. 1990.

Burt, P. J. et al., The Laplacian Pyramid as a Compact Image Code, IEEE Transactions on Communications, vol. COM-31, No. 4 Apr. 1983.

Uz, K. M. et al., A Multiresolution Approach to Motion Estimation and Interpolation with Application to Coding of Digital HDTV, Proceedings, 1990 International Symposium on Circuits and Systems, p. 1298.

Barbero, M. et al., A System for the Transmission of HDTV Signals Based on the Discrete Cosine Transform, Proceedings, 1990 IEEE International Symposium on Circuits and Systems, pp. 1887-1890.

Yashima, Y. et al. HDTV/Standard-TV Compatible Coding Based on DCT, Proceedings, 1990 International Symposium on Circuits and Systems, pp. 1894-1898.

Fleischler, P.E. et al., Coding of Advanced TV for BISDN Using Multiple Subbands, Proceedings, 1990 International Symposium on Circuits and Systems, pp. 1314-1317.

Anastassiou, Dimitris et al., Gray-Scale Image Coding for Freeze-Frame Videoconferencing, IEEE Transactions on Communications, vol. 34, No. 4 Apr. 1986.

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International Organization for Standardization Simulation Model Editorial Group, MPEG Video Simulation Mode Three, Jul. 25, 1990.

Anastassiou, D., Generalized Three-Dimensional Pyramid Coding for HDTV Using Nonlinear Interpolation, Columbia University.

Anastassiou, D., Generalized Pyramid Coding Using Nonlinear Interpolation for HDTV Coding, Proceedings, 1990 Picture Coding Symposium.

Wang, F. and Anastassiou, D., Time Recursive Deinterlacing for HDTV and Pyramid Coding, Image Communication, Vol. 2, No. 3, Oct. 1990.

Netravali, A. N. and Haskell, B.G. "Digital Pictures: Representation and Compression", Plenum Press, 1988.

Col. 4, line 64, "OC(t-1)" should read --Oc(t-1).

Col. 6, line 22, at the beginning of the equation, "(x)" should read --1/4--.

Col. 7, line 28, "half." should read --half).--.

Col. 7, line 61, "CEG, in" should read --CEG. In--.

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DATED : November 21, 1995  
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Page 3 of 3

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Col. 12, line 48, "cooing" should read --coding--.  
Col. 16, line 57, "step (e)" should read --step (c)--.  
Col. 18, line 19, "denying" should read --deriving--.  
Col. 20, line 51, "first fields" should read --first  
field--.

Signed and Sealed this  
Twenty-ninth Day of October 1996

Attest:



BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks



UNITED STATES PATENT AND TRADEMARK OFFICE  
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Title page,

Item [56], before "Preliminary Examiner" insert

-- OTHER PUBLICATIONS

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Netravali, A.N. and Haskell, B.G. Digital Pictures: Representation and  
Compression, Plenum Press, 1988. --

Signed and Sealed this

Twelfth Day of February, 2002

*Attest:*



*Attesting Officer*

JAMES E. ROGAN  
*Director of the United States Patent and Trademark Office*