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# STUDY AND SIMULATION OF SPATIAL VIDEO COMPRESSION FOR REMOTELY PILOTED VEHICLES

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# STUDY AND SIMULATION OF SPATIAL VIDEO COMPRESSION FOR REMOTELY PILOTED VEHICLES

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## INTRODUCTION

Remotely piloted vehicles (RPVs) have limited power for the transmission of data and often work in electronically noisy environments that require channel coding to trade bandwidth for a better bit-error rate or signal-to-noise ratio. Both factors make bandwidth compression highly desirable for video transmission from RPVs.

Two approaches to the bandwidth reduction problem were considered in this study and simulation. One was to reduce the data rate by simply reducing the frame rate. The other was to reduce the number of bits required to transmit each frame by using digital video compression techniques, specifically, Hadamard transforms.

## FRAME REDUCTION

Films taken from a light plane were sped up to approximate an RPV's view of the terrain. They were then processed by Aeronutronic Ford to produce videotaped segments in the standard 30 frames per second format, with a limited number of frame changes per second. A rate of n frames per second was produced simply by repeating each frame 30/n times, and the n sample frames were taken from the film every 1/n s. There were four frame rates prepared: 6 frames per second (fps), 3 fps, 1 fps, and 0.5 fps. Ten scenes, each 40 to 50 s long, were processed at each of these frame rates, for a total of 40 sequences. This tape from Aeronutronic Ford was the source material for the work at Ames. Tape listings of both source and output tapes are given in the appendix.

## DIGITAL VIDEO COMPRESSION

### TV Format and Digitization

Standard video format consists of 30 frames of video per second, each frame containing 525 lines. Each frame is divided into two interlaced fields, $1/60^{th}$ s apart in time. The Ames Video Processor (ref. 1) digitizes the video by taking 512 samples per line (8 megasamples per second) and quantizing each sample to a 6-bit twos complement binary number. The range of brightness of each sample is thus divided into 64 discrete values from −32 (black) through 0 (grey) to +31 (bright white). The frame is viewed as a 512 × 525 matrix;

the fields are re-interlaced and the $1/60^{th}$-s time difference is ignored. The frame is divided into subpictures eight pels wide by eight lines high. Half of the lines in each subpicture (lines 1, 3, 5, 7) come from field 1, the other half from field 2 (lines 2, 4, 6, 8); this is shown in figure 1.

## The Hadamard Transform

The 64 pels in each subpicture are transformed into 64 Hadamard coefficients by digital hardware that implements the Hadamard transform, which is done by a series of additions and subtractions. Each of the 64 coefficients represents the degree to which a certain vector pattern is present in the subpicture. Figure 2 shows the 64 patterns. The subscripts below the patterns indicate the number of black/white or white/black transitions in each pattern in the vertical and horizontal directions, respectively. The number of transitions in each direction is called the vertical or horizontal sequency of the vector. Harmuth (ref. 2) gives a detailed treatment of the mathematics and applications of Hadamard and Walsh transforms.

Figure 3 shows typical probability distributions for vector coefficients; probability of occurrence is graphed against the value of the coefficient. Note that as horizontal or vertical sequency increases, the probability of occurrence of magnitudes not near zero drops quickly. This allows many coefficients to be replaced by zero and others to be quantized to code them as 2- to 5-bit numbers. The advantage of the Hadamard vector representation, unlike the pel representation, is that the vector coefficients do not have the same probability distributions and do not carry equal amounts of picture information.

## Basic Technique of Quantization

It requires six stages of addition and subtraction to compute a 64-point Hadamard transform; thus the Hadamard coefficients derived from 6-bit pel brightnesses could be 12 bits long. In the video processor the coefficients are truncated after the first two stages of arithmetic so that the coefficients are 8-bit numbers. Quantization is used to represent the 8-bit coefficients by 5, 4, 3, or 2 bits. The vector coefficient can assume 256 discrete values; *cutpoints* divide this range symmetrically about zero into 32, 16, 8, or 4 subranges. A 5-, 4-, 3-, or 2-bit code is transmitted to indicate the subrange into which the vector coefficient falls. The transform decoder has *representative values* (also symmetrical about zero) that represent the coefficient falling in each subrange. Quantization error is the difference between the value of the vector coefficient and the value of its "representative value" after quantization.

The work reported in this paper involved (1) selecting the number of bits (from 0 to 7) required for the transmission of each of the 64 coefficients (a quantization to 0 bits implies that the coefficient is not encoded and is replaced by zero at the decoder), and (2) determining the cutpoints and representative values for each quantization. In addition, some work was done on adaptive coding based on the magnitudes of coarse edges in each direction. These paramters were based on previous work done at Ames on 8 × 8 and 4 × 4 subpictures, and were determined subjectively.

## RESULTS

### Specific Quantization Parameters

The quantizations in table I were used in the video compression algorithms used to make the videotapes. Each set of cutpoints and representative values given in the table are coded by two numbers, n and m: n represents the number of bits to which the set of cutpoints and representative values will quantize the vector; m is a scale factor to adjust the quantization to the range of vector coefficient values determined experimentally. The m is missing for the 5-bit quantization as there is only one; the 7-bit quantization is the 8-bit vector truncated 1 bit; a and b are used to differentiate the two 2-bit quantizations; 4-1.3 LS and 3-Linear are special quantizations for adaptive modes that will be described later.

| | | | | | | |
|---|---|---|---|---|---|---|
| Example: | 3-1.0 | ± Cutpoints | 1 | 3 | 8 | |
| | | ± Rep. Val. | 0 | 2 | 5 | 12 |

In the example, vector values 0, 1 are quantized to zero; 2, 3 are quantized to 2; 4, 5, 6, 7, and 8 are mapped into 5; 9 and above are quantized to 12. The preceding sentence remains valid if each number is written with a minus sign in front of it; this is the significance of "±" cutpoints and "±" representative values. Generally, if a representative value r lies between cutpoints p and q, vector coefficients with absolute magnitudes from p + 1 through and including q will be quantized to +r if the coefficient is positive, or -r if it is negative. The leftmost representative value, always zero in practical quantizations, is assigned to coefficients with magnitudes from zero through and including the value of the leftmost cutpoint; the rightmost representative value is assigned, with the proper sign, to coefficients whose absolute magnitude exceeds that of the rightmost cutpoint.

The example shown is a 3-bit quantization with a scale factor of 1.0; 3-1.3 has larger cutpoints and representative values but is a coarser quantization than 3-1.0; conversely, 3-0.8 has a smaller range but is a finer quantization than 3-1.0.

### Nonadaptive Algorithms

Tables II, III, and IV give specific bit distributions for the 2-, 1.5-, and 1-bit-per-pel (bpp) nonadaptive algorithms. The vectors are denoted by their vertical and horizontal sequency numbers, which are also the subscripts in figure 2. The distributions were developed by fitting the ranges of the possible quantizations to the experimentally observed ranges of vector coefficient values for typical pictures; they were refined by observations of the transformed picture.

### Adaptive Algorithms

Some preliminary work on real-time adaptive algorithms was done as part of this investigation. The first algorithm used two different "options"--sets of cutpoints and representative values assigned to each vector. An overhead of 1 bit per subpicture is added to determine the option selected.

One option was used to code subpictures that were selected as having high contrast. This option was selected if either the absolute magnitudes of the coefficients of $A_{01}$ or $A_{10}$ exceeded 6 or if the absolute magnitude of the coefficient of $A_{11}$ exceeded 4. The full range of the coefficient magnitudes is 0 to 127; however, the largest coefficient values observed for $A_{01}$ and $A_{10}$ were only about 50 or 60. If none of the thresholds were exceeded, the low-contrast option was chosen.

Quantizations for the high-contrast option are coarser, and more bits are spent on the vectors representing simple edges (lower sequency vectors, especially those with zero sequency in one direction) at the expense of complex edges. Results of this experiment seemed inconclusive. Apparently, not enough correlation exists between the conditions $\left(|A_{01}| \geq 6 \wedge |A_{10}| \geq 6 \wedge |A_{11}| \geq 4\right)$ and the amplitudes of the remaining vector coefficients to make this particular scheme very useful. Table V lists the quantizations used in this algorithm.

A four-option adaptive scheme was investigated next. $A_{01}$ was thresholded at 3 $\left(|A_{01}| \geq 3\right)$ as a test of contrast in the horizontal direction (vertical edges are equivalent to horizontal transitions or contrasts) and $A_{10}$ was thresholded at 3 as a test of vertical contrast. The options were selected as follows:

Low-contrast option was selected if $|A_{01}| < 3$ and $|A_{10}| < 3$

Horizontal-contrast option was selected if $|A_{01}| \geq 3$ and $|A_{10}| < 3$

Vertical-contrast option was selected if $|A_{01}| < 3$ and $|A_{10}| \geq 3$

High-contrast option was selected if $|A_{01}| \geq 3$ and $|A_{10}| \geq 3$

An overhead of 2 bits per subpicture is required to code the choice of option. The threshold of 3 was determined by experiment. The condition $|A_{01}| \geq 3$ is well correlated with increased range in the magnitudes of $A_{03}$, $A_{02}$, $A_{04}$, $A_{05}$, $A_{06}$, $A_{07}$, $A_{11}$, and $A_{21}$. Likewise, $|A_{10}| \geq 3$ corresponds to higher ranges for $A_{30}$, $A_{20}$, $A_{40}$, $A_{50}$, $A_{60}$, $A_{70}$, $A_{11}$, and $A_{12}$. While orthogonal transforms tend to produce uncorrelated coefficients, the expected values of the magnitudes of the coefficients averaged over time may be correlated. Although the value of the $A_{01}$ coefficient cannot be used to predict the exact value of the $A_{03}$ coefficient, it can be used to predict the range of the $A_{03}$ coefficient. Thus the condition $|A_{01}| \geq 3$ can be used to determine the quantization ranges for several vector coefficients, as can the condition $|A_{10}| \geq 3$.

Table VI gives quantizations used to implement a 1.22-bit/pel algorithm. Table VII gives quantizations used in a 1.1-bit/pel algorithm. Table VIII gives an estimate of the high (rightmost) cutpoint in a quantization required to code each vector in each option. This information, determined experimentally, was used to set the quantizations in tables VI and VII.

Due to the fact that thresholds on $A_{01}$ and $A_{10}$ were used to choose the four options, no option needs to include full-range quantizations for the coefficients of $A_{01}$ and $A_{10}$. A special linear quantization 3-Linear was used to handle ranges of $A_{01}$ or $A_{10}$ from 0 to 2, and 4-1.3 LS (late start), which is used for the range above 2, begins at 3 to allow a finer quantization of the rest of its range.

More flexible and sophisticated spatial adaptive schemes have since been developed at Ames for 4 × 4 and 8 × 8 subpictures using the computer and its two-way interface to the video processor (ref. 3). These have not yet been implemented in real-time hardware and are still being optimized in software. The better ones use three to four options and thresholds on several vectors to choose options for "grey wall" (constant or very low contrast scenes), medium, or high-contrast scenes.

## SUMMARY AND CONCLUSIONS

Both frame rate reduction and spatial video compression techniques can be used to reduce the bandwidth of RPV video transmission. Minimum acceptable levels of frame rate and bits spent per pel for both flight and observation must be determined by tests with RPV pilots and ground observers. A higher frame rate with more spatial compression (and detail degradation) may be more useful for piloting the RPV, while a slow frame rate (which may make identification easier by holding the picture still) with more spatial detail might be more useful to the observer. Adaptive schemes for spatial video compression are more efficient than fixed schemes; however, more research must be done to determine optimal adaptive schemes. Work in this area is in progress using the computer interfaced to the video processor in the facility at Ames Research Center.

## APPENDIX

## TAPE LISTINGS FOR SOURCE AND PROCESSED OUTPUT VIDEOTAPES

The 1-in. tapes were played and recorded on IVC 870-C videotape recorders. The following is a tape listing of source tape provided by Wright-Patterson via Aeronutronic Ford.

| Scene number | Scene letter designation (if used) | Frame rate 6 fps | 3 fps | 1 fps | 0.5 fps |
|---|---|---|---|---|---|
| 1 | B | 2:10-2:45 | 15:10-15:45 | 28:10-28:45 | 41:10-41:45 |
| 2 | | 3:02-3:40 | 16:02-16:40 | 29:07-29:47 | 42:10-42:47 |
| 3 | | 4:05-4:50 | 17:02-17:50 | 30:07-30:55 | 43:10-44:00 |
| 4 | F | 5:10-5:55 | 18:05-18:53 | 31:10-32:00 | 44:12-45:00 |
| 5 | | 6:10-6:55 | 19:05-19:50 | 32:15-33:05 | 45:10-46:00 |
| 6 | D | 7:10-7:50 | 20:15-20:55 | 33:10-34:00 | 46:15-47:00 |
| 7 | E | 8:10-8:55 | 21:05-21:53 | 34:12-35:00 | 47:15-48:00 |
| 8 | | 9:20-10:05 | 22:07-23:05 | 35:15-36:10 | 48:15-49:10 |
| 9 | C | 10:20-11:10 | 23:15-24:07 | 36:25-37:15 | 49:25-50:15 |
| 10 | A | 11:20-12:12 | 24:20-25:07 | 37:27-38:15 | 50:30-51:17 |

Scene letter designation refers to scenes selected for digital video compression. The numbers refer to tape counter readings corresponding to minutes: seconds.

Brief scene descriptions:

B, 1. Sweep over highway bridge
2. Load with sharp switchback
3. Wooded valley with road
F, 4. Croplands with road, then mountains
5. Shallow valley with tiny stream or trail
D, 6. Sweep over suburb to river
E, 7. Mountains, then dam
8. SAM site
C, 9. SAM site followed by canyon
A, 10. Sweep over water, city, hills

The tape listings for compressed videotapes 1 and 2 are given on the next page; 000 is referenced to the title beginning both tapes, "Ames Research Center RPV Data 12/29/75 Video Compression."

Tape 1

*000 - "Ames Research Center" Title

| Scene | fps | Uncomp. | 2 bpp | 1.5 bpp | 0.5 bpp |
|---|---|---|---|---|---|
| A | 6 | 0:30 | 1:27 | 2:30 | 3:30 |
| | 3 | 4:30 | 5:30 | 6:30 | 7:30 |
| | 1 | 8:30 | 9:30 | 10:30 | 11:30 |
| | 0.5 | 12:30 | 13:30 | 14:30 | 15:30 |
| B | 6 | 6:30 | 17:20 | 18:20 | 19:10 |
| | 3 | 20:00 | 20:50 | 21:40 | 22:30 |
| | 1 | 23:20 | 24:10 | 25:05 | 26:00 |
| | 0.5 | 26:50 | 27:40 | 28:25 | 29:15 |
| C | 6 | 30:05 | 31:15 | 32:15 | 33:15 |
| | 3 | 34:15 | 35:15 | 36:15 | 37:15 |
| | 1 | 38:15 | 39:15 | 40:15 | 41:15 |
| | 0.5 | 42:15 | 43:15 | 44:20 | 45:20 |
| D | 6 | 46:17 | 47:10 | 48:05 | 49:00 |
| | 3 | 49:55 | 50:50 | 51:45 | 52:40 |
| | 1 | 53:35 | 54:30 | 55:25 | 56:20 |
| | 0.5 | 57:15 | 58:10 | 59:05 | 60:00 |

*60:55 - "End of Tape" Title

Tape 2

*000 - "Ames Research Center" Title

| Scene | fps | Uncomp. | 2 bpp | 1.5 bpp | 0.5 bpp |
|---|---|---|---|---|---|
| E | 6 | 0:30 | 1:30 | 2:30 | 3:30 |
| | 3 | 4:30 | 5:30 | 6:30 | 7:30 |
| | 1 | 8:30 | 9:30 | 10:33 | 11:33 |
| | 0.5 | 12:30 | 13:30 | 14:30 | 15:30 |
| F | 6 | 16:30 | 17:30 | 18:30 | 19:30 |
| | 3 | 20:30 | 21:30 | 22:30 | 23:30 |
| | 1 | 24:30 | 25:30 | 26:30 | 27:30 |
| | 0.5 | 28:30 | 29:30 | 30:30 | 31:30 |

*32:45 - "Adaptive Processing" Title

| Scene | fps | Uncomp. | 2 bpp Non-Adapt. | 1.5 bpp Opt. Adapt. | 0.5 bpp Non-Adapt. |
|---|---|---|---|---|---|
| A | 6 | 33:15 | 34:15 | 35:15 | 36:15 |
| | 0.5 | 37:15 | 38:15 | 39:15 | 40:15 |
| B | 6 | 41:15 | | 42:05 | |
| | 0.5 | | | 42:55 | |
| C | 6 | 44:05 | | 45:00 | |
| | 0.5 | | | 46.05 | |

| Scene | fps | Uncomp. | 1.22 bpp 4 Opt. Adapt. | 1.1 bpp 4 Opt. Adapt. |
|---|---|---|---|---|
| A | 6 | 47:15 | 48:20 | |
| | 0.5 | 44:20 | 50:20 | |
| B | 6 | | 51:20 | |
| | 0.5 | | 52:10 | |
| C | 6 | | 53:05 | |
| | 0.5 | | 54:10 | |
| A | 6 | 55:15 | 56:20 | 57:15 |
| | 0.5 | | | 58:10 |
| B | 6 | | | 59:10 |
| C | 6 | | | 59:55 |

*Title, End Tape 2

TABLE I.- QUANTIZATIONS: CUTPOINTS AND REPRESENTATIVE VALUES

| | | | | |
|---|---|---|---|---|
| **5 Bits** | | | | |
| | 0 1 2 3 5 7 9 11 13 16 20 26 32 41 52 | | | ± Cutpoints |
| | 0 1 2 3 4 6 8 10 12 15 18 23 29 36 47 58 | | | ± Rep. Value |
| **4 Bits** | | | | |
| 4-1.5 | 1 3 6 12 20 30 41 | | | ± Cutpoints |
| | 0 1 4 9 15 23 33 45 | | | ± Rep. Value |
| 4-1.3 LS[a] (Late Start) | 3 5 8 12 18 25 34 | | | |
| | 0 4 6 10 15 22 29 40 | | | |
| 4-1.3 | 1 2 5 10 17 26 34 | | | |
| | 0 2 4 8 13 21 29 39 | | | |
| 4-1.0 | 1 2 4 7 11 17 24 | | | |
| | 0 2 3 6 9 14 21 28 | | | |
| 4-0.8 | 0 1 2 5 8 13 18 | | | |
| | 0 1 2 4 7 11 16 22 | | | |
| 4-0.5 | 0 1 2 4 6 9 13 | | | |
| | 0 1 2 3 5 8 11 15 | | | |
| 3-1.3 | 2 5 12 | 3-1.0 | 1 3 8 | ± Cutpoints |
| | 0 3 8 15 | | 0 2 5 12 | ± Rep. Value |
| 3-0.8 | 0 2 6 | 3-Linear[a] | 0 1 2 | |
| | 0 1 4 9 | | 0 1 2 3 | |
| 2a | 3 | 2b | 2 | |
| | 0 6 | | 0 4 | |

[a]Quantization for adaptive mode only.

TABLE II.- BIT DISTRIBUTION AND QUANTIZATION FOR A 2-BIT/PEL NONADAPTIVE ALGORITHM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 5 | 4-0.8 | 4-0.8 | 4-0.8 | 4-0.5 | 4-0.5 | 4-0.5 |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 5 | 4-0.8 | 4-0.5 | 4-0.5 | 4-0.5 | 4-0.5 | 4-0.5 | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 4-0.5 | 4-0.5 | 4-0.5 | 3-0.8 | 3-0.8 | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | 4-0.5 | 4-0.5 | 3-0.8 | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 4-0.5 | 4-0.5 | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 4-0.5 | 4-0.5 | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 4-0.5 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 4-0.5 | | | | | | | |

TABLE III.- BIT DISTRIBUTION AND QUANTIZATION FOR A 1.5-BIT/PEL NONADAPTIVE ALGORITHM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 5 | 4-0.8 | 4-0.8 | 4-0.8 | 4-0.5 | 4-0.5 | 3-1.0 |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 5 | 4-0.8 | 4-0.5 | 4-0.5 | 2a | 2a | 2a | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 4-0.5 | 3-1.0 | 2a | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | 3-1.0 | 2a | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | 2a | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | 2a | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 3-1.0 | | | | | | | |

TABLE IV.- BIT DISTRIBUTION AND QUANTIZATION FOR A 1-BIT/PEL NONADAPTIVE ALGORITHM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 4-1.5 | 4-0.8 | 4-0.8 | 3-1.0 | 2a | 2a | 2a |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-1.5 | 4-0.8 | 3-1.0 | | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 3-1.0 | 3-1.0 | | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | | | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2a | | | | | | | |

TABLE V.- HIGH AND LOW-CONTRAST OPTIONS IN A TWO-OPTION, 1.1-BIT/PEL ADAPTIVE ALGORITHM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| High-contrast option | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 4-1.3 | 4-1.0 | 4-1.0 | 2a | 2a | 2a | 2a |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-1.3 | 4-1.0 | 3-1.0 | 3-1.0 | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-1.0 | 3-1.0 | 3-1.0 | | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-1.0 | 3-1.0 | | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2a | | | | | | | |
| Low-contrast option | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 4-0.5 | 3-1.0 | 3-0.8 | 2b | 2b | 2b | 2b |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-0.5 | 3-1.0 | 3-0.8 | 2b | 2b | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.5 | 3-0.8 | 2b | 2b | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 3-0.8 | 2b | 2b | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-0.8 | 2b | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-0.8 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 2b | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2b | | | | | | | |

**TABLE VI.- BIT DISTRIBUTION AND QUANTIZATION FOR A 1.22-BIT/PEL FOUR-OPTION ADAPTIVE ALGORITHM**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Low-contrast option | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 3-Lin | 3-1.0 | 3-1.0 | 3-0.8 | 2a | 2a | 2b |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 3-Lin | 3-1.0 | 3-1.0 | 2a | 2b | 2b | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 3-1.0 | 2b | 2b | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 3-1.0 | 3-1.0 | 2b | 2b | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | 2b | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | 2b | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2b | | | | | | | |
| Horizontal-contrast option | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Qunatization → | 7 | 4-1.3 LS | 4-0.8 | 4-0.8 | 3-1.0 | 3-1.0 | 3-1.0 | 3-0.8 |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 3-Lin | 3-1.3 | 3-1.0 | 2a | 2b | 2b | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 3-1.0 | 2b | 2a | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 3-1.0 | 3-1.0 | 2a | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2a | | | | | | | |

TABLE VI.- Concluded

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Vertical-contrast option** | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 3-Lin | 4-0.8 | 3-1.0 | 3-0.8 | 3-0.8 | 3-0.8 | 2b |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-1.3 LS | 3-1.3 | 3-1.0 | 2a | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-1.0 | 3-1.0 | 2a | 2b | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | 3-1.0 | 2a | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | 2a | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | 2a | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 3-0.8 | | | | | | | |
| **High-contrast option** | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 4-1.3 LS | 3-1.3 | 3-1.3 | 3-1.0 | 3-1.0 | 2a | 2a |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-1.3 LS | 4-0.8 | 3-1.0 | 3-1.0 | 2b | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-1.0 | 3-1.0 | 3-1.0 | 2b | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | 3-1.0 | 2b | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | 2b | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 2a | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2a | | | | | | | |

TABLE VII.- BIT DISTRIBUTION AND QUANTIZATION FOR A 1.1-BIT/PEL FOUR-OPTION ADAPTIVE ALGORITHM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Low-contrast option | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 3-Lin | 3-1.0 | 3-1.0 | 3-0.8 | 2a | 2a | 2b |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 3-Lin | 3-1.0 | 3-1.0 | 2a | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 3-1.0 | 2b | 2b | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 3-1.0 | 3-1.0 | 2b | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | 2a | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2b | | | | | | | |
| Horizontal-contrast option | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 4-1.3 LS | 4-0.8 | 4-0.8 | 3-1.0 | 3-1.0 | 3-1.0 | 3-0.8 |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 3-Lin | 3-1.3 | 3-1.0 | 2a | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-0.8 | 3-1.0 | 2a | | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 3-1.0 | 3-1.0 | | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2a | | | | | | | |

TABLE VII.- Concluded

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Vertical-contrast option** | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 3-Lin | 4-0.8 | 3-1.0 | 3-0.8 | 2a | 2a | 2b |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-1.3 LS | 3-1.3 | 3-1.0 | 2a | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-1.0 | 3-1.0 | 2a | | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | 3-1.0 | 2a | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quanization → | 3-1.0 | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 3-0.8 | | | | | | | |
| **High-contrast option** | | | | | | | | |
| Vector → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Quantization → | 7 | 4-1.3 LS | 3-1.3 | 3-1.3 | 3-1.0 | 3-1.0 | 2a | 2a |
| Vector → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Quantization → | 4-1.3 LS | 4-0.8 | 3-1.0 | 3-1.0 | | | | |
| Vector → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Quantization → | 4-1.0 | 3-1.0 | 3-1.0 | | | | | |
| Vector → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Quantization → | 4-0.8 | 3-1.0 | | | | | | |
| Vector → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Quantization → | 3-1.0 | | | | | | | |
| Vector → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Quantization → | 2a | | | | | | | |
| Vector → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Quantization → | 2a | | | | | | | |

TABLE VIII.- VECTOR RANGES AS FUNCTION OF OPTION IN A FOUR-OPTION ADAPTIVE ALGORITHM

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vector | → | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| Low/horiz. | → | / | / | 7/10 | 5/9 | 3/4 | 4/4 | 3/5 | 2/3 |
| Vert./high | → | / | / | 9/11 | 6/10 | 4/5 | 3/6 | 4/5 | 2/4 |
| Vector | → | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Low/horiz. | → | / | 9/10 | 5/5 | 4/4 | 2/3 | 2/3 | / | / |
| Vert./high | → | / | 10/13 | 6/8 | 4/5 | 3/3 | 2/4 | / | / |
| Vector | → | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| Low/horiz. | → | 14/14 | 5/6 | 3/4 | 3/3 | / | / | / | / |
| Vert./high | → | 16/16 | 7/8 | 4/5 | 3/3 | / | / | / | / |
| Vector | → | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Low/horiz. | → | 8/8 | 4/4 | 2/3 | 2/2 | / | / | / | / |
| Vert./high | → | 14/14 | 5/5 | 3/3 | 2/3 | / | / | / | / |
| Vector | → | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Low/horiz. | → | 4/3 | 3/2 | / | / | / | / | / | / |
| Vert./high | → | 5/5 | 3/3 | / | / | / | / | / | / |
| Vector | → | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| Low/horiz. | → | 4/5 | 2/2 | / | / | / | / | / | / |
| Vert./high | → | 5/6 | 2/3 | / | / | / | / | / | / |
| Vector | → | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| Low/horiz. | → | 5/5 | / | / | / | / | / | / | / |
| Vert./high | → | 6/6 | / | / | / | / | / | / | / |
| Vector | → | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| Low/horiz. | → | 3/4 | / | / | / | / | / | / | / |
| Vert./high | → | 5/5 | / | / | / | / | / | / | / |

## REFERENCES

1. Noble, S. C.; Knauer, S. C.; and Giem, J. I.: A Real-Time Hadamard Transform System for Spatial and Temporal Redundancy Reduction in Television. Proceedings of the International Telemetering Conference, Washington, D. C., Oct. 1973.

2. Harmuth, H. F.: Transmission of Information by Orthogonal Functions. Springer-Verlag.

3. Jones, H. W.: A Real-Time Adaptive Hadamard Transform Video Compressor. To be published in the Proceedings of the 20th Annual Technical Symposium of the Society of Photo-Optical Instrumentation Engineers, San Diego, California, August 1976.

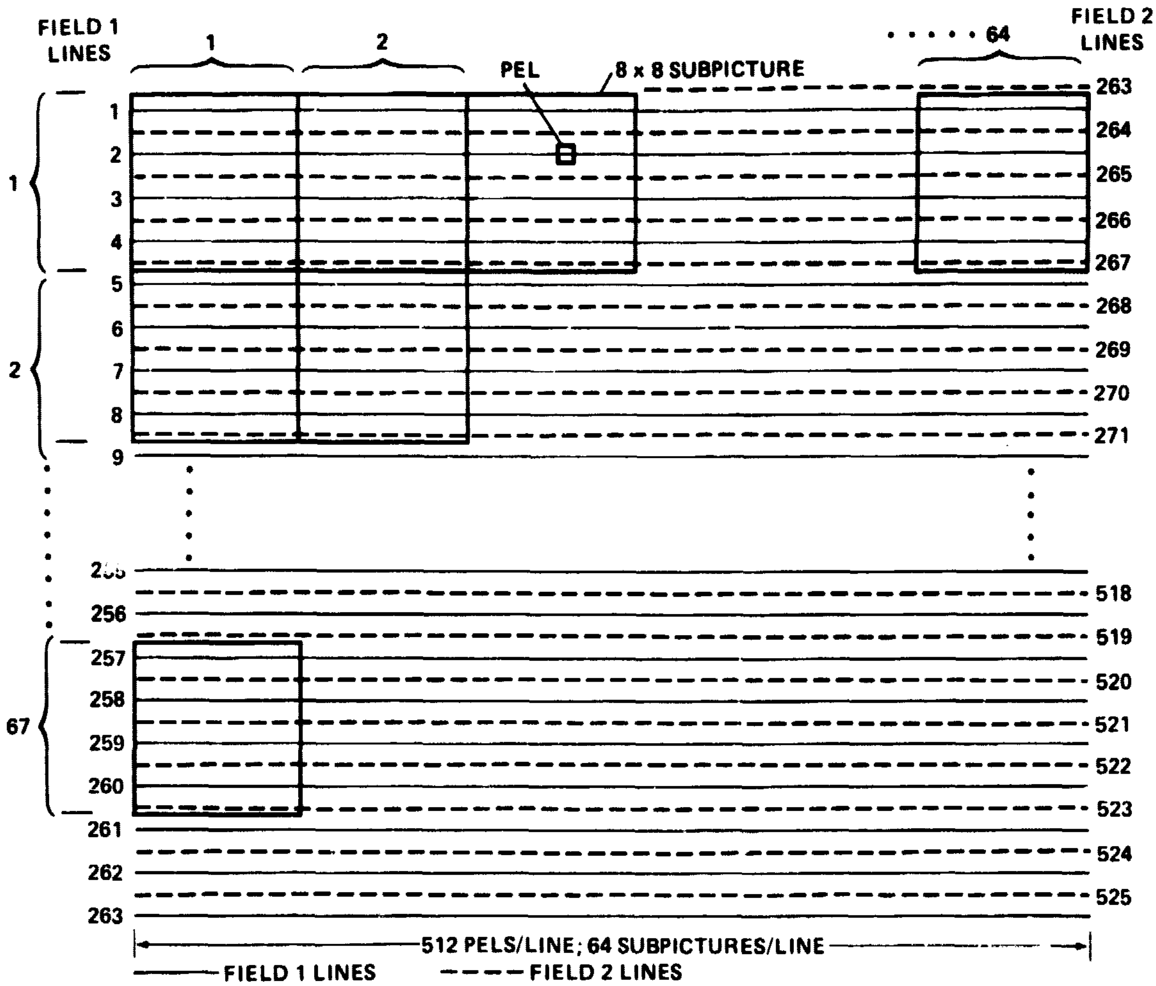


Figure 1.- One frame of interlaced video showing 8 pel × 8 line subpictures.

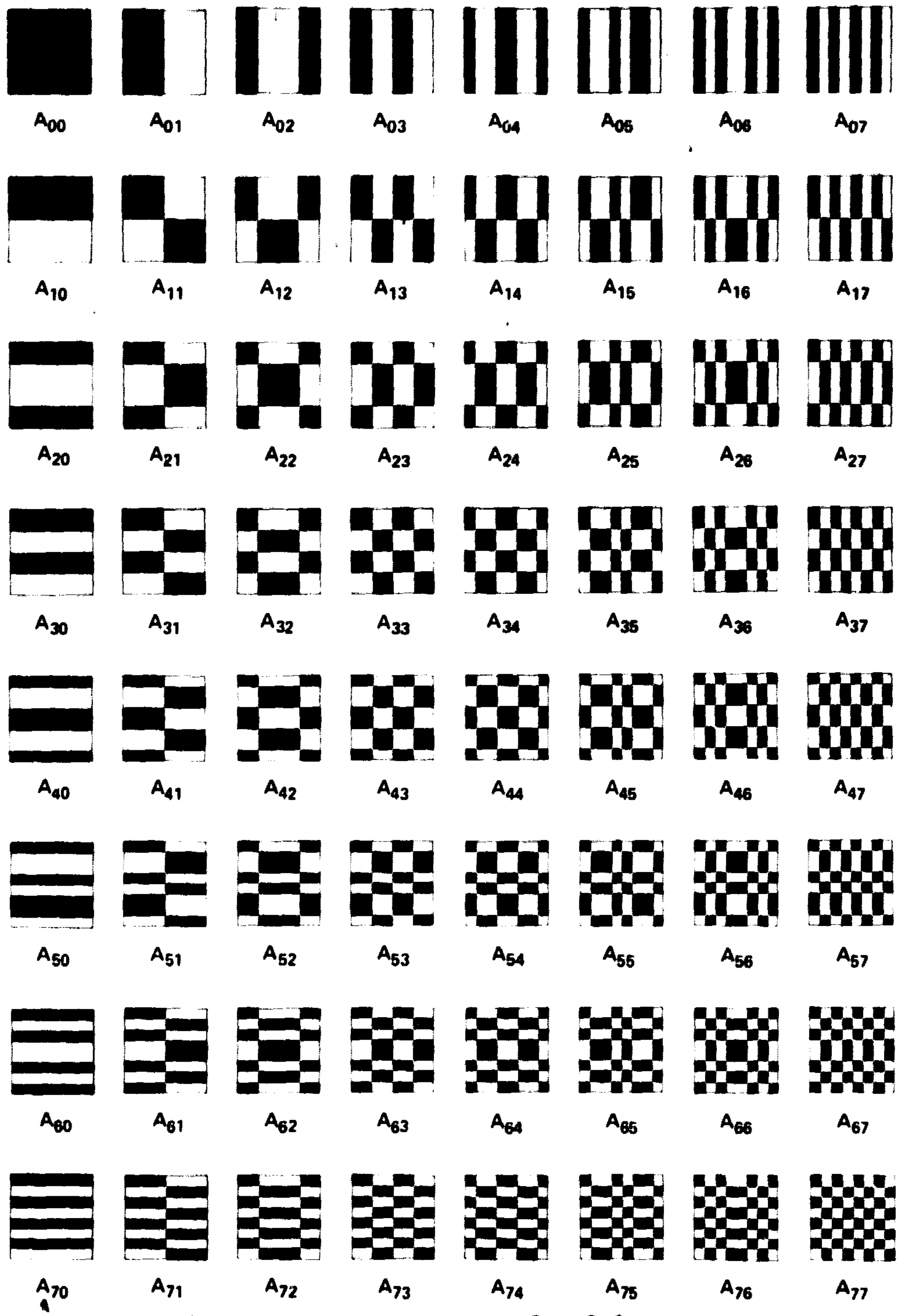


Figure 2.- Hadamard vector patterns for an 8 × 8 2-D transform. Subscripts indicate the number of edges in the vertical and horizontal directions respectively.

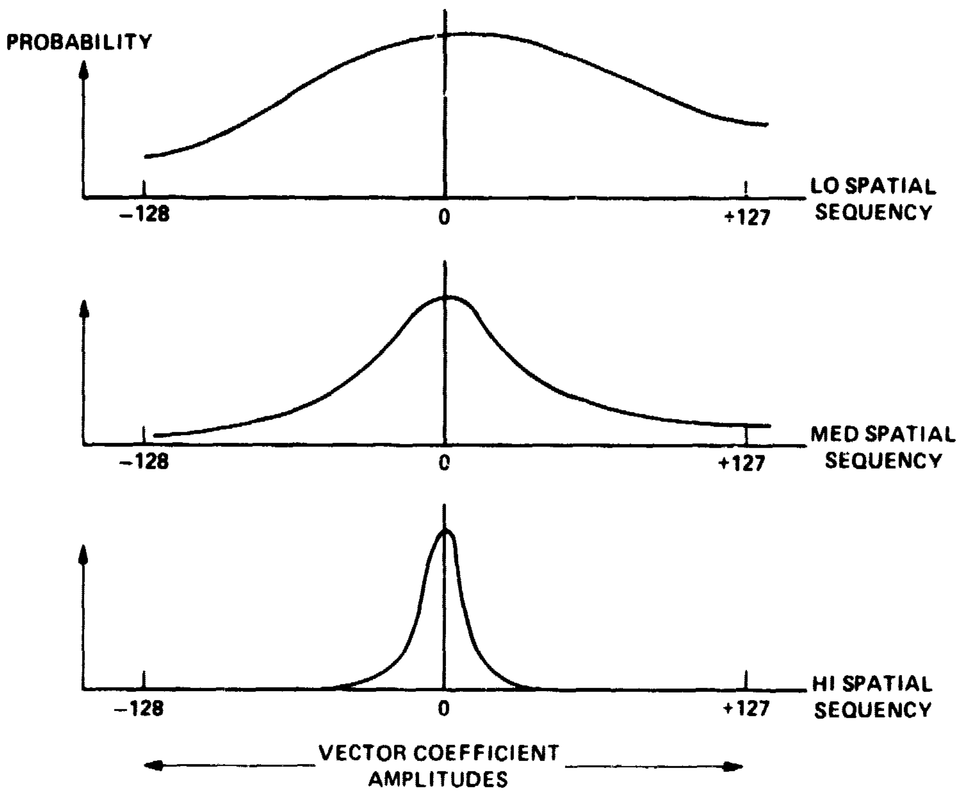


Figure 3.- Probability distribuıions of vector coefficient values as functions of horizontal or vertical sequency.