1958 IRE WESCON Convention Record

STANFORD LIBRARY
NOV 29 1958
ENGINEERING
TK 7800. W4

PART 4

Sessions Sponsored by

IRE Professional Groups on

Automatic Control

Electronic Computers

Human Factors in Electronics

Information Theory

at

the Western Electronic Show and Convention

Los Angeles, Calif.

August 19-22, 1958

The Institute of Radio Engineers

Google
Exhibit 1027

1958 IRE WESCON CONVENTION RECORD

PART 4 - AUTOMATIC CONTROL; COMPUTERS; HUMAN FACTORS; INFORMATION THEORY

TABLE OF CONTENTS

Page

Computer Applications
(Session 1: sponsored by PGEC)

Data Preparation for Numerical Control of Machine Tools ..... H. D. Huskey and D. E. Trumbo 3
A Library of Blip Samples for Use in the Realistic Simulation and Evaluation of Automatic Radar Data Processing Systems ..... C. M. Walter and H. M. Willett 8
GCA by Automatic Voice Data Link ..... J. J. Fling and M. H. Nothman 28
A Computer Simulation Chain for Research on Picture Coding ..... R. E. Graham and J. L. Kelly, Jr. 41
Mapping Vacuum Tube Computers in Transistor Circuits (Abstract) ..... G. R. Monroe and H. G. Jones 47

Computer Devices
(Session 6: sponsored by PGEC)

Achieving Maximum Pulse Packing Densities and Transfer Rates ... B. W. Thompson and D. F. Eldridge 48
An Emitter-Follower-Coupled, High-Speed Binary Counter ..... I. Horn 54
Coincident Current Applications of Ferrite Apertured Plates ..... W. G. Rumble and C. S. Warren 62
Information Storage in Microspace (Abstract) ..... S. P. Newberry 66

Analog Computers
(Session 23: sponsored by PGEC)

Anticipatory Display Design Through the Use of an Analog Computer .... L. J. Fogel and M. Dwonczyk 67
A Transistorized, All-Electronic Cosine/Sine Function Generator ..... H. Schmid 89
An Analogue Memory ..... W. S. Kozak 108
Network Solution of the Right Triangle Problem ..... M. R. Winkler 123

Information Theory
(Session 4: sponsored by PGIT)

The Prediction of Derivatives of Polynomial Signals in Additive Stationary Noise ..... I. Kanter 131
Predictive Quantizing of Television Signals ..... R. E. Graham 147
Optimum Linear Estimation for Random Processes as the Limit of Estimates Based on Sampled Data ..... P. Swerling 158
Random Function Probability Distributions After a Nonlinear Filter ..... G. O. Young 164
Statistical Invariance of Noise in Sampled-Data Systems ..... S. A. Zadoff 173

Automatic Control
(Session 18: sponsored by PGAC)

Compensation of Multi-loop Control Systems ..... D. Lebell and M. Mandel 177
"Optimization" of Compensation for Cascaded Actuators in a Common Feedback Loop ..... G. S. Axelby and E. F. Osborne 182
Some Simplifying Additions to Basic Sampled-Data Theory ..... C. O. Carlson 197
Contributions to the Analysis of Nonlinear Feedback Control Systems ..... S. L. Mikhail 233
Enhanced Real-Time Data Accuracy for Instrumentation Radars by Use of Digital-Hydraulic Servos ..... R. P. Cheetham and W. A. Mulle 239

PREDICTIVE QUANTIZING OF TELEVISION SIGNALS

Robert E. Graham
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey

Abstract

A system is described for digital encoding of continuous information sources based on quantizing the difference between the original continuous signal and a predicted version thereof, as opposed to quantizing the original signal itself. The coding is tailored to the observer's perception by employing fine quantum steps for the small prediction errors, and coarse steps for the large errors where the predictor, and possibly the observer, are surprised. With this tapering of the steps in the quantizing staircase, the total number of levels needed in the quantized error signal for high-quality reproduction may well be so small that a simple nonstatistical coding of the error signal will yield a substantially lowered bit rate compared with conventional systems.

To extend the accuracy of digital representation obtained with this system, an additional operation is described in which the "idle times" - the blanking intervals in television - are commandeered to allow the introduction of extra samples in difficult regions of the signal. This requires "elastic" delay of a simple type in which the delay is varied step-by-step in one direction until reset to the starting point.

A series of photographs is included showing processed pictures obtained by computer simulation of the various coding methods.

General

The rapidly expanding interest in digital transmission for a variety of applications has stimulated research on the efficient coding of continuous sources such as speech and pictures into numerical data. This problem of source coding is essentially independent of channel considerations, involving only the statistics of the source and the perceptual characteristics of the human observer. The channel is here relegated to the drab if difficult task of providing error-free transmission of the discrete output of the source encoder.

It is well known that straightforward point-by-point quantization of picture brightness[1] causes a particularly objectionable kind of degradation, and that the approximate pictures obtained are satisfactory to the viewer only if a large number of discrete levels, 100 or so, are employed in the quantizing process. This results in the generally accepted requirement of 7 bits per picture point for PCM transmission of television signals. Various workers[2,3,4,5,6] have attempted to find more fortunate approximation means which would afford acceptable reproduction at a reduced information rate. Most of these attempts have been based on elementary perceptual properties; e.g., the viewer is very sensitive to discontinuities in brightness occurring within a picture, but is relatively insensitive to amplitude errors in reproducing such discontinuities. Some of the methods appear definitely superior to ordinary quantization, although the proven reductions in transmission rate for high-quality picture reproduction have so far been less than 2:1.

In principle it is possible to find efficient numerical approximations to the continuous pictures by elaborate testing of the human viewer to map his discriminability for all points of the picture space. (To be complete, this must be the space of all possible picture sequences.) Then the accuracy of approximation may be tailored to this perceptual map. It would be impractical to make an exhaustive map of this kind for any picture system having a nontrivial resolution level, but progressively improving theoretical hypotheses can help to reduce the testing required.

One method of assigning order in mapping the observer's fidelity requirement is to attempt coding schemes based on fragmentary knowledge, and to make subjective evaluations of the defects of the resulting pictures. Some elementary experimental observations which suggest the encoding approach to be described in this paper are as follows:

1) The viewer's ability to detect detailed amplitude distortions is particularly low in chaotic regions of the picture. (This is true for distortions of the type caused by "granulating" or quantizing, not for those caused by blurring.) Examples are regions dominated by random noise or complex texture.

2) Quantizing distortion or structure must be kept low in regions which the viewer can readily organize into simple patterns, subgroups, mnemonic structures - to which he can readily assign meaning. Examples are patches of uniform brightness, straight lines or edges, low-frequency periodic structure.

The above categories may be separated by the test of predictability. The "insensitive" random or complex regions of Item 1 represent regions in which accurate prediction from context is difficult or impossible. The sensitive but simply organized regions of Item 2 are practically, by definition, highly predictable from context. This suggests a quantizing technique having the following properties:

1) The variable to be quantized will be the instantaneous error between the original continuous signal and a predicted version thereof based on the past values of the quantized signal.

2) The discrete levels employed to approximate the original signal will be spaced close together for small prediction errors and far apart for large prediction errors.

Provided that the predictor is designed to be effective in simply organized regions of the picture, then these two properties will allow the numerical approximation to the original picture to be fine or coarse in accordance with the perceptual abilities of the viewer. This reduces the size of the numerical alphabet needed to encode each picture point and thereby reduces the information rate required to transmit pictures of satisfactory quality.

Before proceeding to a description of a specific system, we summarize the a priori case for predictive quantizing of television signals as follows: There is evidence from psychovisual observations, and from measurements on simple circuit predictors, that in those situations where the predictor makes sizable errors - is "surprised" - the perceptual discrimination of the human observer is particularly low, so that large quantizing distortions in encoding these large prediction errors will not be noticeable. The kind of signal behavior implied by "low-predictability" situations depends to a considerable extent upon the sophistication of the prediction process. In dealing with television signals very simple prediction such as that obtained by estimating the oncoming sample to be the same as its immediate predecessor - "previous-value" prediction - will yield large transient errors at vertical lines or edges in the picture. Correspondingly, observer discernement is fairly low in such regions. Better prediction, achieved by more detailed use of the signal past, may result in sizable errors only in highly chaotic regions of the picture or perhaps in situations where there is rapid object motion. Since it is in precisely such situations that viewer discrimination is very poor, it appears that the link between prediction difficulty and large tolerance in reproduction is a strong one. This points to a concept of predictive quantizing as a truly perceptual coding technique - in which the primary objective is not necessarily accurate prediction all or almost all of the time, which frequently is impossible, but only accurate prediction in those signal regions where the observer perception is high. This appears to be a more durable concept than that involved in so-called statistical coding systems - which tend to produce serious degradations whenever the running statistics of the signal depart appreciably from those postulated in the system design.

The use of a tapered staircase in quantizing the prediction errors is an important step in implementing the foregoing concept of perceptual coding, the primary intention of the modified quantization process being to reduce the size of the coding alphabet and not merely to affect the statistical properties of the transmitted signal.

Predictive Quantizing Systems

The basic predictive quantizing system is shown in Fig. 1. An original bandlimited continuous signal is sampled at an appropriate rate, compared with the predicted samples, and the difference supplied to a tapered quantizer. The output of the quantizer is a multi-level discrete error signal which is encoded for transmission over the digital channel, and also is fed back through a predictive accumulator network to the input comparator. (The straightforward coding and decoding operations which are necessary for transmission by binary PCM are not indicated in the figure.)

The accumulator network produces at point "A" a picture signal identical with that reconstructed by the receiver. Thus we see that what is quantized is the error between the original signal and the predicted signal, where the prediction is based, not on the past of the original signal, but on the past of the approximate signal as developed at the receiver output. It is essential that the transmitter prediction be made in this fashion so that the receiver may duplicate its action precisely - the approximate or quantized signal being the only one available at the receiver.

We may also describe the system operation by noting that each reconstructed receiver sample is derived by adding the corresponding predicted sample value to the quantized version of the prediction error. Thus, whenever the quantizing distortion is small the receiver output will be accurate even in the event of bad prediction.

Some likely types of predictor for use in this system are the so-called linear predictors[7] such as "previous-value", "slope", "planar", etc., as well as a nonlinear "variable mode" predictor to be described in this paper. An

interesting point about the predictor function in this system is that the predicted values conceivably need not be constrained to a discrete amplitude structure,* as was the case in the earlier predictive-subtractive system.[8] In other words the predictor may be allowed to generate a continuous signal, under the influence of the discrete output from the quantizer, as its estimate of the original continuous wave.

A suggested form of the quantizing characteristic is shown in Fig. 2. The particular staircase illustrated provides 8 levels in the quantized output, and thus may be coded into 3 bits per sample. The characteristic is made symmetrical about the origin since the error signal supplied to the quantizer may be of either polarity. As previously described, the output or "representative" levels are closely spaced for small error inputs and progressively more widely separated for larger error amplitudes. Typically, the innermost levels may be on the order of ±1 percent of the original video signal range, while the outermost levels are set at "saturation" values of perhaps ±20 to ±40 percent. This inner spacing is small enough to allow accurate reproduction of uniform brightness areas, while the saturation values are large enough to let the system make a reasonable stab at rendering large unpredicted transitions. There is considerable latitude in choosing the quantizing characteristic, although there are some limits imposed by stability requirements. These stability constraints depend to some extent upon the nature of the predictor. As an example, with simple "status quo" (previous-value) prediction each representative level must be less than twice the next lower decision level, or the system output will not converge for certain static inputs.

The simplest type of predictive quantizing system employs the aforementioned previous-value prediction. Fig. 3 illustrates this limiting case, the "predictor" consisting of a delay equal to the sample spacing.** Roughly, the effect of this process is that of quantizing point-to-point differences in the signal, hence the name <u>differential quantizing</u>.

Several variants of differential quantizing as well as a number of different picture coding schemes, are now being tested by computer simulation on an IBM-704 digital computer.[9,10] Pictures consisting of 100 x 100 elements are scanned at a 2-second rate, and the resulting signals transferred in digital form to magnetic tape. The data in this form is supplied to the computer, which is programmed to carry out the intended processing operations. The processed picture signals are ultimately reconverted to pictorial form for subjective evaluation.

Fig. 4 consists of six processed pictures obtained by this computer simulation and compares the performance of two different quantizing methods. The middle pictures are "originals", representing straight amplitude quantization to 512 brightness levels or 9 bits per sample. The left-hand pictures have been similarly quantized, but only to 8 brightness levels or 3 bits per sample. The right-hand pictures have been differentially quantized also to 8 (incremental) levels and 3 bits per sample.† Some defects are visible in the differentially quantized pictures at the vertical edges where the elementary predictor is surprised. However, the resulting picture quality appears considerably better than that obtained by conventional 3-bit quantization.

<u>Nonlinear Predictor</u>

In order to introduce a more effective prediction technique, a typical scanning raster is shown in Fig. 5 with crosses marking the spatial relation of successive sampling instants. The next sample to be predicted at a given instant is labelled 0,0, and a few of the neighboring past samples are designated correspondingly. For previous-value prediction the predictor takes just the past sample 1,0, as its estimate of the next sample. For linear prediction in general,[7] a constant-coefficient weighted sum of the past values is employed.

A nonlinear predictor to be described here employs a running selection from a number of simple prediction modes, the choice being made by logical tests on the past samples. In effect the predictor tries out various prediction modes on neighboring past regions of the picture, and then proceeds to use that mode affording the smallest trial error. A simple predictor of this type employs just two possible prediction modes, "horizontal" previous-value and "vertical" previous-value. The choice between the two modes is made by an elementary computer according to the

---

*That is, not in any simple sense.

**In this simple case, the operation reduces to a sort of multi-level delta modulation, in which an 8-level quantizing staircase is used instead of a 2-level one.

†The representative levels are 1, 3, 8, 20, and the decision levels are 0, 2, 5, 15, all in ± percent of the original signal range. This original signal is gamma-corrected, being proportional to the 0.4 power of the brightness of the subject scene.

following rule, letting S_{jk} stand for the sample value at j, k:

If $|S_{11} - S_{10}| \geq |S_{11} - S_{01}|$, choose the horizontal prediction, S_{10}.

If $|S_{11} - S_{10}| < |S_{11} - S_{01}|$, choose the vertical prediction, S_{01}.

In the first case, the two samples in a horizontal line, S_{11}, S_{01} are more nearly alike than those in a vertical line, S_{11}, S_{10}. In the second case, the opposite is true. The indicated prediction choices will be exact, for instance, whenever the brightness contours in the immediate vicinity are either horizontal or vertical. The largest errors tend to occur at "corners", along 45-degree lines, and at detail which is small in both the horizontal and the vertical direction.

Fig. 6 shows the system transmitter employing the two-mode predictor. For obvious reasons this operation has been called "alternate-mode differential quantizing." The indicated values of delay are for standard 525-line television, a full scanning-line delay being required to provide the vertical prediction. It is not unduly difficult to obtain such a video delay, but this component is clearly the most expensive element required in the transmitter and the receiver.

Fig. 7 is a series of photographs obtained by computer simulation which compare "originals" (center column) with the received pictures obtained by 3-bit versions of differential quantizing (left column) and alternate-mode differential quantizing (right column). Again, the "originals" represent 512-level conventionally quantized pictures. The representative and decision levels for all the 3-bit pictures are the same as those given for Fig. 4. The pictures obtained by AMD_{α} appear to be substantially better than those obtained by straight differential quantizing. It is not too surprising that for some types of pictures - particularly those with very complex detail - the 3-bit processed pictures occasionally look better than the originals. In such instances, the processed pictures appear to have been sharpened or "crispened."

The relative frequency of level occupancy for the pictures processed by AMD_{α} is shown in the following table:

TABLE I - Relative Level Frequency for Pictures Processed by Alternate-Mode Differential Quantizing

	Representative Levels			
Picture	±1	±3	±8	±20
Test Chart	0.77	0.12	.07	.04
Girl No. 1	0.64	0.24	0.10	.02
Girl No. 2	0.64	0.23	0.11	.02
Man	0.48	0.24	0.21	.07

As a matter of interest, the apparent source rates based on these monogram statistics were computed for the four pictures, yielding in turn, 2.1, 2.35, 2.35, and 2.64 bits per picture point. Thus for a picture as complex as that of the man, a Shannon-Fano encoding on a sample-by-sample basis would save no more than 0.36 bit per sample relative to the 3 bits per sample required with simple coding.

Reservoir Coding

In sending conventional television signals over digital transmission systems, we are free to collapse the idle (blanking) intervals at the end of the scanning lines and fields and use this time to better advantage, eventually restoring the idle intervals at the receiving terminal. One way to use this surplus time is to insert extra samples during the signal processing, not necessarily periodically, but only as required to ensure accurate portrayal of the original signal. The 10 microsecond horizontal blanking intervals in standard television afford a reservoir of some 80 Nyquist intervals per scanning line. This reservoir may be used to allow extra time in "difficult" regions of the signal. (The vertical blanking period constitutes a reserve of about 8,000 Nyquist intervals; however, it is simpler instrumentally to make use of only the horizontal intervals.)

This reserve of extra samples may profitably be used in a predictive quantizing system to increase the accuracy of numerical representation without requiring a higher transmission rate. This will be particularly helpful whenever the incidence of large prediction errors is fairly low - perhaps less than fifty occurring within each line scan. Such statistical data as is available on picture signals indicate that the number of significant errors will almost always be suitably low.

A method for combining reservoir sampling with predictive quantizing is to allow each sample occupying the extreme positive or negative quantizing levels to cue the introduction of an extra sample. A system which operates in this fashion is shown in Fig. 8. At the transmitter, the band-limited input signal is passed through a tapped delay line with a mobile output contact before reaching the sampler and quantizer. Assume that the quantizer representative levels are ±(1, 3, 8, 28) percent of the signal range. Then as long as only the interior levels ±1, ±3, ±8 are occupied, the system operation is the same as that of Fig. 1. Whenever the predictor makes an error large enough to occupy the ±28 levels, the corresponding sample is coded for transmission as usual, and the output connection of the delay line is stepped to the right by one sample period. This stepping action causes the next sample taken from the incoming signal to be identical with the preceding one. Momentarily the input becomes a "sitting duck." To take advantage of this situation, the predictor mode is switched to horizontal previous-value, so that the approximation process on the second trial will be much more accurate. At the end of each horizontal scan the delay-line connection is reset to the left end by the leading edge of the sync signal, and the stepping operation proceeds as before.

At the receiver, the string of samples is recovered by the decoder and supplied to a predictive accumulator as in the system of Fig. 1. The accumulator output is operated upon by a controlled delay line similar to that used at the transmitter, and then smoothed by a low-pass filter to obtain the received picture signal. The movable connection of the delay line remains stationary whenever the smaller sample values are received, and steps one sample to the right* whenever an extra sample is signalled by the occurrence of ±28. Whenever such a step occurs, the receiver blocks the cueing sample from reaching the delay line, since the next succeeding sample will itself be the cumulative result of the two samples allotted to a single ordinate of the original input signal.

The benefit derived from the injected extra samples is suggested by Table II which shows the alphabet of signal increments available with and without reservoir sampling.

TABLE II - QUANTIZING ALPHABETS

(In percent (±) of Original Video Range)

No Reservoir Sampling	With Reservoir Sampling	
	No Extra Sample	Extra Sample**
1	1	1
3	3	3
8	8	8
20		20
		25
		27
		29
		31
		36
		56

The extended alphabet range afforded by the extra samples tends to eliminate the visible defects of the AMDQ pictures of Fig. 7. The statistics presented in Table I indicate that for the four subject pictures in Fig. 7, extra samples will be called for 4, 2, 2, and 7 percent of the time respectively. These figures are well within the reservoir limits afforded by conventional horizontal blanking allowances.

For the simplest mode of operation, not allowing any carry over of reserve samples from one line to the next, the maximum number of serious prediction errors which can be suppressed during any given line scan equals the number of sample periods in the blanking interval. In the event that the reserve of samples is exhausted before the end of a line scan, the system will become locked in the normal or uniform sampling mode, and the receiver alphabet will be limited to ±(1, 3, 8, 28). The effect of this will be to slow down any large unpredicted transitions during the remainder of the particular line scan, but no quantizing distortion of the conventional sort will occur.

*Note that when the receiver delay connection steps to the right, the insertion delay is reduced. The opposite is true at the transmitter.

**It is assumed that only one extra sample can be grouped with each "normal" sample.

Effects of Transmission Errors

Throughout the discussion error-free transmission of the encoded signal has been assumed. It is certainly true that the picture coding schemes described require exceedingly reliable digital transmission for satisfactory performance. This is a familiar characteristic of predictive coding systems,[8] and tends to become more pronounced with more effective prediction methods. For example, an isolated transmission error in the case of alternate-mode differential quantizing tends to produce a constant brightness error over an extended rectangular area. This grievous situation can be alleviated to some degree by adjusting the positive feedback in the predictive accumulators to slightly less than unity. However, it appears that the required reliability of transmission will still be so high as to dictate the use of error-correcting codes with well designed digital transmission systems.

Bibliography

1. W. M. Goodall, Television by Pulse Code Modulation Bell System Technical Journal, January, 1951.

2. E. R. Kretzmer, Reduced Alphabet Representation of Television Signals, I.R.E. Convention Record, 1956, Part IV also, Versuche zur Guenstigen Codierung von Bildinformation Nachrichtentechnische Fachberichte, Vol. 6, 1957.

3. R. E. Graham, Communication Theory Applied to Television Coding, Acta Electronica, Vol. 2, 1957-1958.

4. W. A. Youngblood, Picture Processing pp 95-100, Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., January, 1958.

5. R. E. Graham, Subjective Experiments in Visual Communication, I.R.E. Convention Record, 1958, Information Theory.

6. W. F. Schreiber and C. F. Knapp, TV Bandwidth Reduction by Digital Coding, I.R.E. Convention Record, 1958, Information Theory.

7. C. W. Harrison, Experiments with linear Prediction in Television, Bell System Technical Journal, July 1952.

8. B. M. Oliver, Efficient Coding, Bell System Technical Journal, July 1952.

9. R. E. Graham and J. L. Kelly, Jr. A Computer Simulation Chain for Research On Picture Coding, Wescon, Aug. 1958, Computer Applications.

10. E. E. David, Jr., M. V. Mathews, and H. S. McDonald, Experiments with Speech Using Digital Computer Simulation, Wescon, Aug. 1958, Audio.

PREDICTIVE-QUANTIZING TRANSMISSION SYSTEM

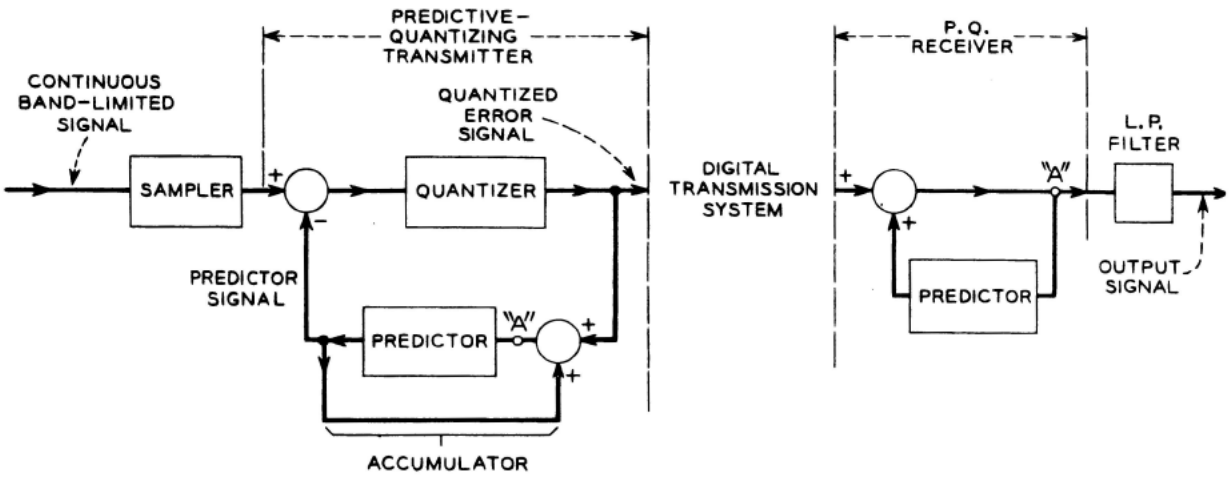


FIGURE 1

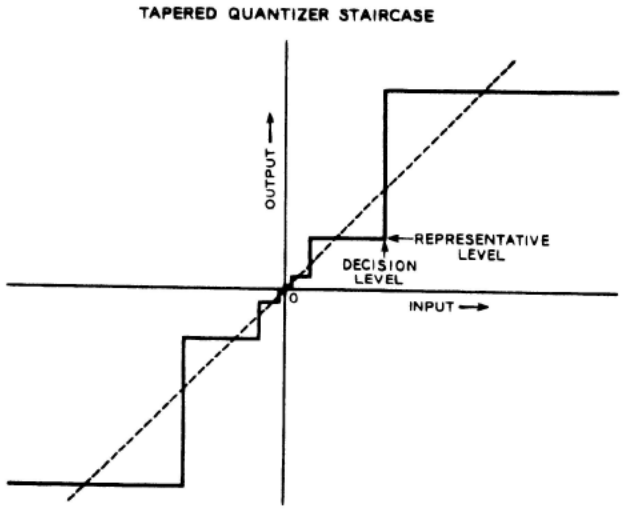


FIG. 2

DIFFERENTIAL QUANTIZED TRANSMITTER

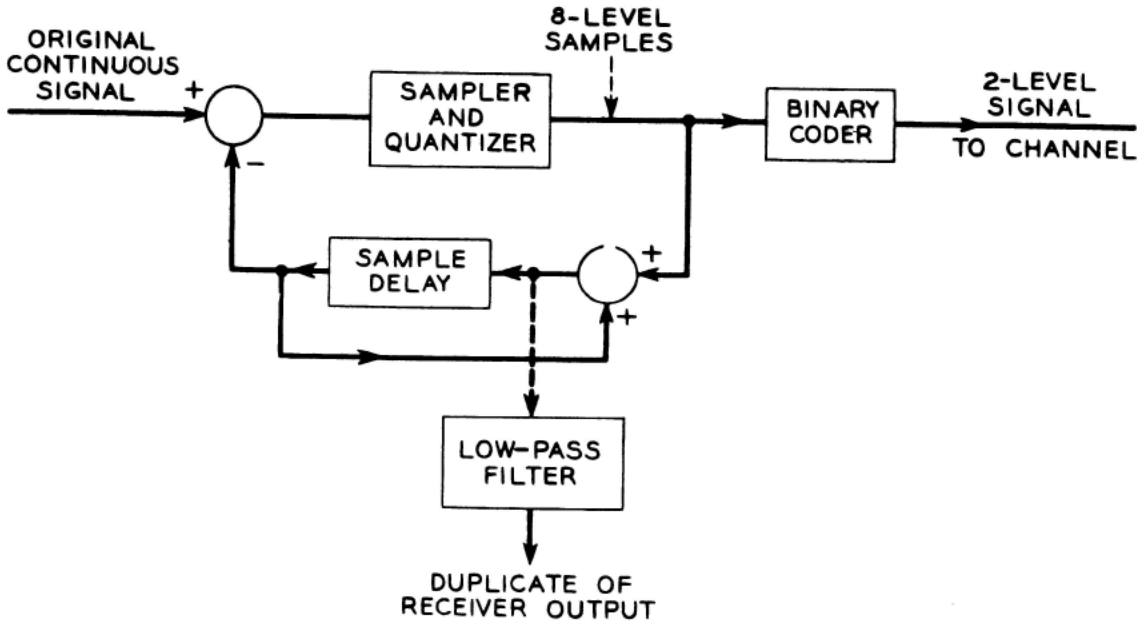


FIGURE 3

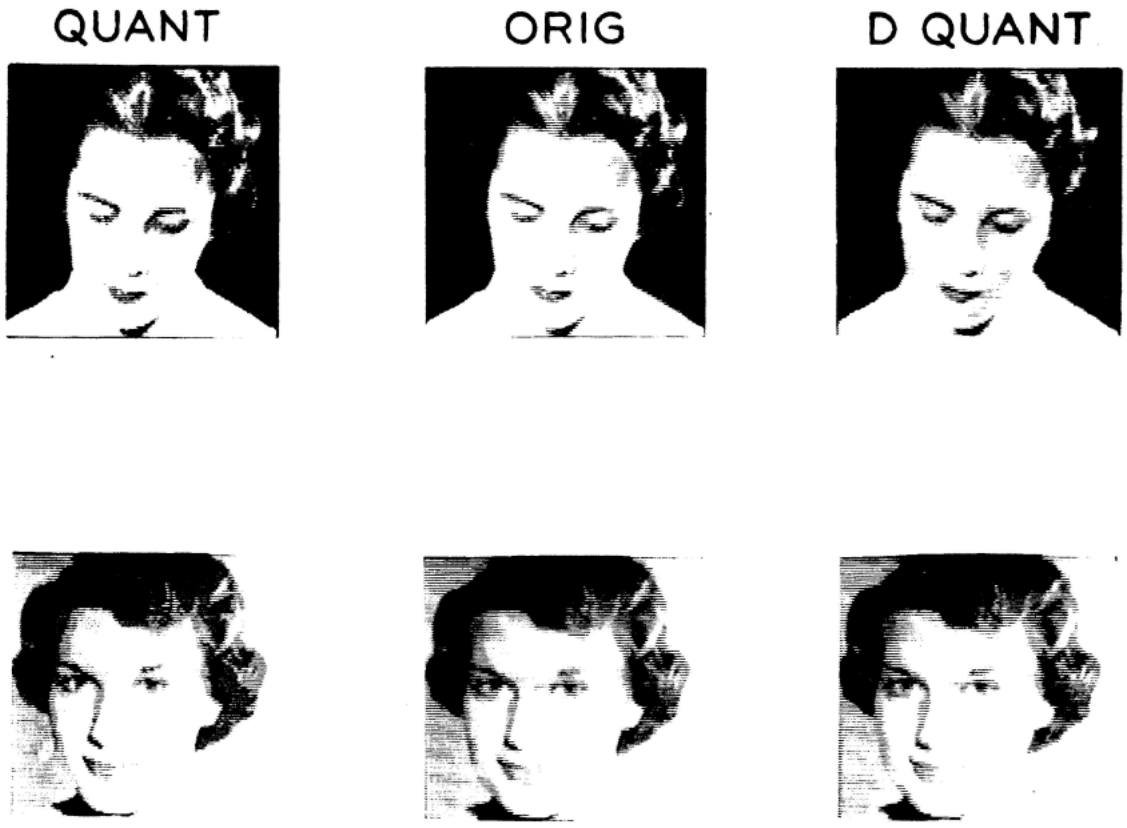


Fig. 4. Linear vs. differential quantizing.

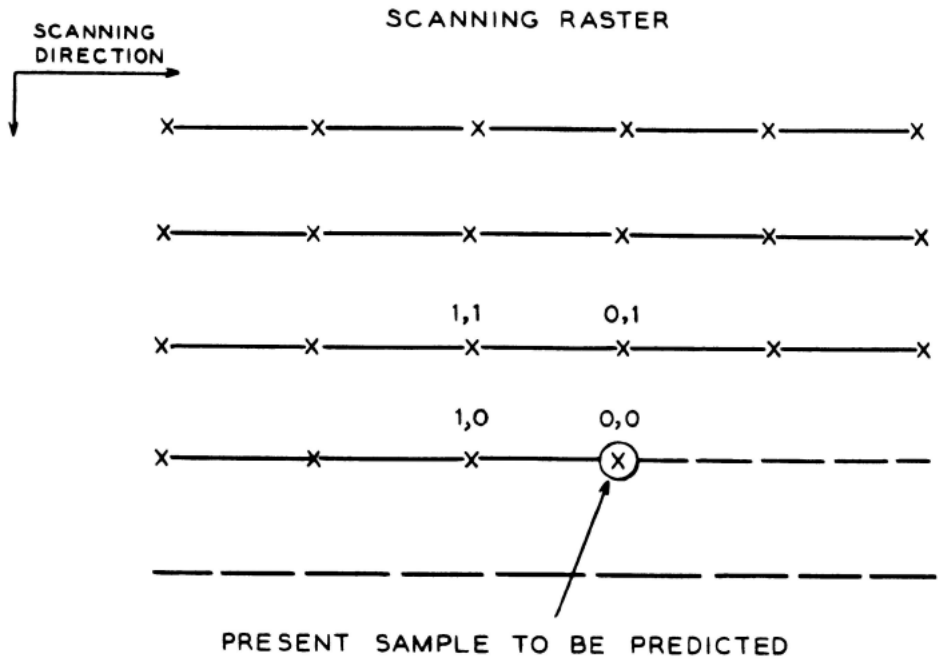


FIGURE 5

PREDICTIVE QUANTIZED TRANSMITTER
USING TWO-MODE PREDICTOR

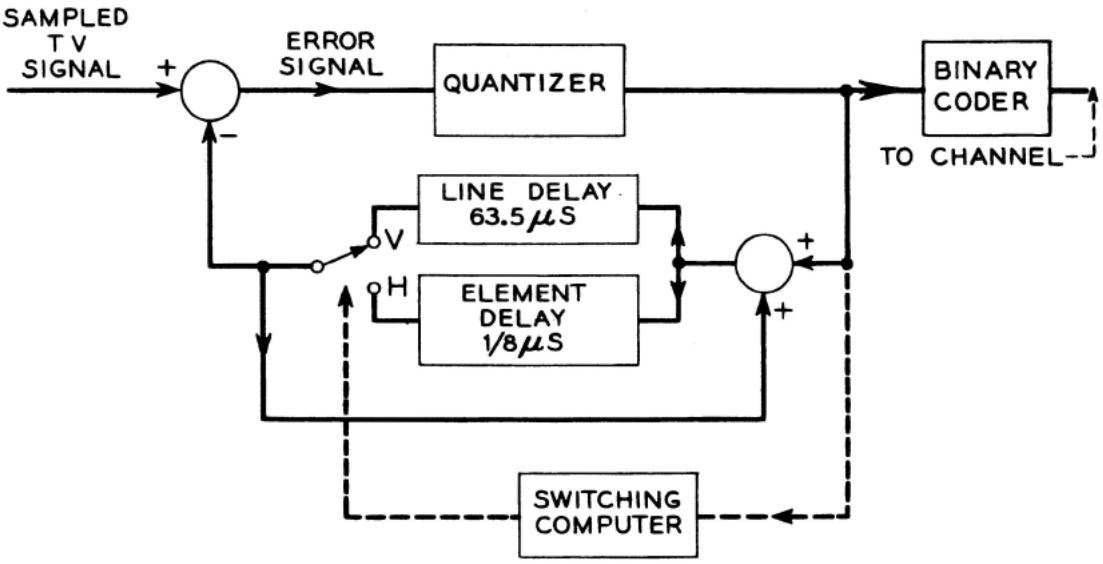


FIGURE 6



Fig. 7. Comparison of differential and alternate-mode differential quantizing.