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COMMUNICATION SYSTEM ANALYSIS

FOR MANNED SPACE FLIGHT

April 17, 1976 - June 1, 1977

Johnson Space Center

Houston, Texas

under

NASA Contract: NAS9-13940

Donald L. Schilling
Professor of Electrical Engineering
Principal Investigator

COMMUNICATIONS SYSTEMS LABORATORY

DEPARTMENT OF ELECTRICAL ENGINEERING

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Introduction

This report summarizes the development of an adaptive delta modulator capable of digitizing a video signal. The delta modulator encoder accepts a 4MHz black and white composite video signal or NASA's field sequential color video signal and encodes it into a stream of binary digits at a rate which can be varied from 8 to 19 Mb/s. The output bit rate is determined by the user and alters the picture quality. The digital signal is decoded in the delta modulator decoder to reconstruct the picture.

The following doctoral students were partially supported by this grant: R. Lei and N. Scheinberg.

Following a long history of cooperation between NASA and Dr. Schilling, an ADM system has been constructed for JSC. A demonstration of the system took place at JSC in June 1977 and a final unit will be delivered to JSC in the Fall of 1977.

During the next year we shall turn our attention to the encoding of Color Video Signals.

An All Digital Adaptive Delta Modulator

I. Introduction

The development of an adaptive delta modulator capable of encoding a television picture has been completed. The delta modulator encoder accepts a 4MHz black and white composite television signal, or NASA's field sequential color television signal, and encodes it into a binary signal at a rate of up to 19 Mb/s. The output bit rate is determined by the user. Useable pictures can be obtained with bit rates between 8 and 19 Mb/s. The higher the rate the better the picture quality.

The digital signal is converted back into analog form by a delta modulator receiver. The receiver requires a bit synchronizer to provide "bit timing". "Word timing" as used in PCM is not necessary with the adaptive delta modulator.

No special circuits are required to provide for horizontal and vertical syncronization of the TV monitor at the receiver. The composite video signal that entered the delta modulator encoder will emerge from the delta modulator receiver with its horizontal and vertical sync pulses intact. Thus the TV monitor will obtain its syncronization from the composite video signal emerging from the delta modulator decoder.

II. Theory of Operation

The delta modulator used to digitize the television pictures is shown in block diagram form in Fig. 1. The folowing is an explanation of the delta modulator algorithm. First, the video signal, S(k), is compared to X_k. This yields the output of the encoder, E_k, where

$$E_{k+1} = \text{sgn}\,(S_k - X_k) \tag{1}$$

X_k, is the transmitter estimate, and is obtained using the recursive equation.

$$X_k = .98\, X_{k-1} + Y_k \tag{2}$$

Y_k, is the step size and is generated using the algorithm

$$Y_k = \begin{cases} |Y_{k-1}|\,(E_k + .5\, E_{k-1}); & |Y_{k-1}| \geq 2\, Y_{min} \\ 2\, Y_{min}\, E_k; & |Y_{k-1}| < 2\, Y_{min} \\ Y_{max}; & |Y_k| > Y_{max} \end{cases} \tag{3}$$

where Y_{min} is 1/128 of the peak-to-peak video signal and Y_{max} is 1/8 of the peak-to-peak video signal.

The delta modulator decoder is just the feedback loop of the encoder. The decoder reconstructs the estimate, X_k, from the E_k pulse train and converts X_k to an analog signal $\hat{S}(t)$. The quality of the received picture as compared to that of the transmitted picture depends upon how closely $\hat{S}(t)$ approximates the original signal, S(t).

III. Implementation of the Delta Modulator

The implementation block diagram is shown in Fig. 2. The two flip-flops on the top of the diagram store E_k and E_{k-1}. The upper adder/subtracter register, multiplexer and "OR" gates implement Eq. 3, the step size equation. The other adder/subtracters and registers are used to generate Eq. 2, and the D/A converter and comparator implement Eq. 1. The complete circuit schematic for the delta modulator is shown in Fig. 3. It was constructed employing ECL integrated circuits, one D/A converter and a high speed compartor. It was built on a single board 8" by 6" and consumes 7 watts of power.

VI. Instructions for Using the Delta Modulator

A typical test set-up using the delta modulator encoder and decoder is shown in Fig. 4.

The encoder has four BNC connectors on its front panel. The function and electrical characteristics of each connector is listed below:

(1) Digital Output

a. ECL compatible voltage levels

b. Designed to drive 50Ω tied to -1.3V.

(2) Clock Input

a. 8 to 19 MHz

b. ECL compatible voltage levels (-0.9V to -1.7V)

c. The input impedance is 50 Ω tied to -1.3V.

(3) Analog Video Input

a. 1 volt peak-to-peak composite video from TV camera

b. 75Ω input impedance tied to ground.

(4) Analog Video Output

a. 1 volt peak-to-peak composite video from the feedback loop of the encoder. It is used to monitor the operation of the encoder.

The decoder has three BNC connectors on its front panel. The function and electrical characteristics of each connector is listed below:

(1) Digital Input

a. ECL compatible voltage levels

b. The input impedance is 50Ω tied to -1.3V.

(2) Clock Input

a. 12 to 19 MHz - phase locked to incomming digital data

b. ECL compatible voltage levels (-.9V to -1.7V)

c. The input impedance is 50Ω tied to -1.3V.

(3) Analog Video Output

a. 1 volt peak-to-peak composite video signal

b. Bandlimited to 4MHz by a four pole Butterworth filter

c. Must be terminated to 75Ω to ground.

Adaptive Delta Modulation Systems for Video Encoding*

R. Lei N. Scheinberg D. L. Schilling

City College of New York

New York, N.Y. 10031

ABSTRACT

This paper describes several adaptive delta modulators designed to encode video signals.

One- and two-Dimensional ADM algorithms are discussed and compared. Results are shown for bit rates of 2 bits/pixel, 1 bit/pixel and 0.5 bits/pixel. Pictures showing the difference between the encoded-decoded pictures and the original pictures are presented.

Results are also presented to illustrate the effect of channel errors on the reconstructed picture.

A two-Dimensional ADM using interframe encoding is also presented. This system operates at the rate of 2 bits/pixel and produces excellent quality pictures when there is little motion. We also describe and illustrate the effect of large amounts of motion on the reconstructed picture.

* The research described in this paper has been partially supported by NASA under grants NSG-5013, and NSG 7144 and contract NAS 9-13940.

I. INTRODUCTION

It is often convenient to digitally encode a video signal prior to transmission. A standard PCM system employs an A/D converter which generates N bits for each sample taken. Typically, N=8 when the samples are taken at the Nyquist rate which would result in a very high transmission bit rate. As a result, PCM is not usually considered practical, and other techniques such as Transform Coding, Delta PCM (DPCM) or Delta Modulation (DM) are employed.

Hadamard transform coding has been studied extensively at Ames Research Center and by others, and such systems appear to be capable of encoding the video signal employing 0.5 - 1 bit per picture element (pixel). However, the hardware required to construct the system is quite complex, and the response of the system to errors caused by channel noise is not good [1].

Delta PCM [2-9] has also been studied extensively. These systems operate at sampling rates of 2-4 bits/pixel and have moderate complexity caused in part by the need to employ an A/D converter.

The Delta Modulator [10-18] is a 1-bit/sample predictive encoder. However, it usually samples the signal at rates which exceed the Nyquist (pixel) rate. The DM systems described in this paper operate at rates from 1 - 3 bits/pixel. Thus, the DM and the DPCM systems operate at comparable rates. However, the complexity of the DM system is less than the complexity of the DPCM system since DM does not employ an A/D converter.

In this paper we discuss several DM algorithms. The basic algorithm employed was first employed by Song [14].

The equations of the Song mode adaptive delta modulator are:

$$E_{k+1} = \operatorname{sgn}[S_{k+1} - X_k] \tag{1a}$$

$$Y_{k+1} = \begin{cases} |Y_k| \cdot [E_{k+1} + \tfrac{1}{2} E_k] & \text{if } |Y_k| \geq Y_{min} \\ Y_{min} E_{k+1} & \text{if } |Y_k| < Y_{min} \end{cases} \tag{1b}$$

$$X_{k+1} = X_k + Y_{k+1} \tag{1c}$$

where

E_{k+1} is the transmitted binary digit

S_{k+1} is the present sample of the input signal to the encoder

Y_{k+1} is the step-size of the delta modulator

Y_{min} is the minimum allowable step-size

X_{k+1} is the predicted value or the estimate of the input sample

Fig. 1 shows the relationship among the clock pulse, the output bit stream, the input signal and the estimate. Notice that the system responds to the rising edge of each clock pulse. Observe that when the estimate X(k+1) is less than the sample of the input signal S(k+1), the transmitted bit is a 1 and the step-size is increased by the factor 1.5. Thus, the estimate rises exponentially. When an overshoot occurs, the transmitted bit is a Ø and the step-size decreases by the factor 0.5.

II. GENERATION OF THE VIDEO SIGNAL

The video system employed to test the DM algorithms described below is shown in Fig. 2. The video signal is generated from a commercial quality television camera bandlimited to 3.75 MHz. The frame rate of the camera is 30 frames/sec. One complete frame is taken and stored in a scan converter which is employed to slow down the picture so that it can be processed in a noninterlaced mode by the PDP-8L computer used to simulate the DM algorithms. The computer output is stored in a second scan converter. The output of this scan converter is displayed on the TV monitor at normal video rates. In the system employed, we display 500 lines/frame so that the line rate is 15,000 lines/sec. In addition, each line is divided into 500 picture elements so that the pixel rate is 7.5 M pixels/sec. which is equal to the Nyquist sampling rate.

Figure 3 shows a picture which has been encoded using 10-bit PCM. The original picture was sampled at the rate of 500 samples/line. This picture represents the quality of our system which corresponds to 10 bits/pixel.

III. THE ONE DIMENSIONAL DELTA MODULATOR

Fig. 4a shows the same picture used in Fig. 3 but encoded using a 1 dimensional DM (1DDM). The signal was sampled at twice the Nyquist (or pixel) rate thereby generating 2 bits/pixel. The algorithm employed in the 1DDM is described by Eq. 1 with the following conditions: (1) the minimum step-size is equal to 1/64 of the maximum peak-to-peak input signal and (2) the maximum step-size is limited to 20 times the minimum step-size.

Figure 4b shows the difference between the pictures shown in Fig. 3 and Fig. 4a with an amplification factor of 2. The outline seen in the picture is due to the encoding error caused by the DM and is due mainly to the estimate overshooting the signal.

Figure 4c shows the picture encoded using the 1DDM operating at 1 bit/pixel. In this encoding process, the signal was sampled at the Nyquist (pixel) rate. Note edge busyness and ringing along edges of high contrast.

Figure 5 shows a "resolution chart" which has been encoded using 10-bit PCM. When the resolution chart is encoded using the 1DDM at 2 bits/pixel, the result is shown in Fig. 6a. Note the high quality of reproduction of the horizontal lines whereas vertical lines are degraded. Figure 6b shows the result of encoding at 1 bit/pixel. The degradation caused by halving the sampling rate is clearly seen.

IV. A TWO DIMENSIONAL DELTA MODULATOR

Since pictures are two dimensional in nature, the correlation of picture elements is a function of distance between pixels and is not a function of the direction of orientation. One should not emphasize the correlation in one direction and neglect that of another direction as is the case of the 1DDM algorithm. Thus, a delta modulator, when used to encode pictures, should have the ability that the coding path of the encoder is free to move in a two dimensional domain.

In a conventional scanning system, the picture element P at row m+1 and column k+1, as shown in Fig. 7, is surrounded by the up-to-date previous estimates α, β, Δ and γ. In expanding the one dimensional delta modulator to a two dimensional

We define,

$$
\left.\begin{aligned}
X_{ref.m+1,k+1} &= X_{m+1,k} \\
Y_{ref.m+1,k+1} &= Y_{m+1,k} \\
E_{ref.m+1,k+1} &= E_{m+1,k}
\end{aligned}\right\} \quad \text{if } D_{H,m+1,k+1} \leq D_{V,m+1,k+1}
$$

$$
\left.\begin{aligned}
X_{ref.m+1,k+1} &= X_{m,k+1} \\
Y_{ref.m+1,k+1} &= Y_{m,k+1} \\
E_{ref.m+1,k+1} &= E_{m,k+1}
\end{aligned}\right\} \quad \text{if } D_{H,m+1,k+1} > D_{V,m+1,k+1} \tag{2b}
$$

Then the algorithm becomes

$$
\begin{aligned}
E_{m+1,k+1} &= \mathrm{sgn}\left[S_{m+1,k+1} - X_{ref.m+1,k+1}\right] \\
Y_{m+1,k+1} &= \left|Y_{ref.m+1,k+1}\right|\left[E_{m+1,k+1} + \tfrac{1}{2} E_{ref.m+1,k+1}\right] \\
X_{m+1,k+1} &= X_{ref.m+1,k+1} + Y_{m+1,k+1}
\end{aligned} \tag{2c}
$$

In (2c) it is clear that the difference between a 1DDM and a 2DDM is in the previous references, $X_{ref.m+1,k+1}$, $Y_{ref.m+1,k+1}$ and $E_{ref.m+1,k+1}$. In a 1DDM system, the previous reference pixel is always the pixel to the left of the present pixel, i.e., pixel α in Fig. 9. In a 2DDM system, the extimates of pixel α and pixel β are compared against the input sample as shown in Fig. 10. The resultant difference D_H and D_V are then compared as described in (2b) to decide whether pixel α or pixel β will be used as the previous reference pixel. The algorithm is based on the assumption that by choosing that previous estimate which is closer to the input sample, a better estimate of the picture will be produced. Fig. 8b is the picture encoded by a normal 2 DDM at 1 bit/pixel. The most noticeable effect when comparing the 1DDM (Fig. 4c) and the 2DDM (Fig. 8b) is seen to be the significant reduction of edge busyness. This is because that at any edge the movement of the coding path of a delta modulator is adjusted in the direction of the edge. Therefore, the edge will appear to be smooth and free of wiggle.

The system described above is called the normal 2 DDM. In the next section, we discuss another algorithm called the Look-Ahead 2DDM.

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VI. 2DDM WITH LOOK-AHEAD

In the normal 2DDM system, we assumed that choosing the previous estimate which is closer to the input sample will result in a better estimated picture. This assumption is not always correct. In Fig. 11, for a normal 2DDM system, $X_{m,k+1}$ and $X_{m+1,k}$ are compared with $S_{m+1,k+1}$ and, therefore, $X_{m,k+1}$ would be chosen as $X_{ref.\,m+1,k+1}$ and the error signal would be "down" and consequently $X^{-}_{m,k+1}$ would be the estimate for the input sample $S_{m+1,k+1}$. However, in Fig. 11, it is clear that $X^{+}_{m+1,k}$ is a better estimate than $X^{-}_{m,k+1}$ for $S_{m+1,k+1}$. The delta modulator would have made a better estimate if it was allowed to "look" one clock period ahead, thereby delaying its decision by one clock pulse. In other words, the delta modulator should wait until all four new estimates have been generated and then make the decision based upon the new estimates instead of the previous estimates. This look-ahead scheme, if generalized, by employing the tree search technique for the entire picture will allow the best possible coding path to be picked. However, for the reason of cost effectiveness only the one bit look-ahead scheme was studied in detail. It is interesting to note that Cutler [17] pointed out that look-ahead (delayed decision) does not greatly improve the system S/N. It does, however, prevent the estimate from overshooting, thereby reducing the amount of edge busyness. Hence, the subjective improvement in the picture quality is significant.

Figure 12a shows a picture encoded using the Look-Ahead 2DDM at the rate of 2 bits/pixel. That is, the video signal was sampled at the Nyquist rate and two bits are generated at each sample. Figure 12b is the picture of the difference between Fig. 12a and the 10-bit/pixel PCM encoded picture of Fig. 3. If we compare Fig. 12b with Fig. 4b, we see that the total amount of noise obtained using the 2DDM is only slightly less than in the 1DDM; however, the noise is redistributed so that Fig. 12a is subjectively more pleasant to view than is Fig. 4a. (It was pointed out by O'Neal [19] that the SNR improvement using 2D-DPCM rather than 1D-DPCM is only about 3 dB).

Fig. 13a shows the picture obtained using the Look-Ahead 2DDM at the rate of 1 bit/pixel. In this case, we sampled the video signal so as to obtain 250 samples/line and display 500 lines/frame. Figure 13b is the same picture encoded using 250 samples/line and 250 lines. Such encoding corresponds to 1/2 bit/pixel. The missing lines were estimated by averaging the surrounding encoded lines. Comparing Figs. 12a, 13a and 13b, we see the increased picture degradation as sampling rate decreases. However, the associated bits have also decreased and for many systems, the degradation is tolerable and the low bit rate a necessity. (Note that Fig. 12a requires 15 Mb/s while Fig. 13a employs 7.5 Mb/s and Fig. 13b transmits at 3.75 Mb/s.)

Figure 13a should also be compared to Fig. 4c. Note that the picture encoded using the 2DDM is subjectively the better.

Fig. 14 shows the "resolution chart" encoded using the Look-Ahead 2DDM Fig. 14a was obtained by sampling the signal 500 samples/line with the $\alpha-\gamma$ pair as the reference pels. The horizontal lines and lines at 45° are encoded with little subjective error, but the vertical lines appear to be jagged. Fig. 14b is the same as Fig. 14a except that the $\alpha-\beta$ pair is employed. The vertical lines, horizontal lines and lines at 135° are now seen to be quite clear. However, the lines at 45° are wiggling because at that direction of scanning the encoder is incapable of making good predictions of input samples. Fig. 14c shows the resolution chart after encoding at 250 samples/line. The $\alpha-\beta$ pair is used here because of this extremely low sampling rate. Once again, the graceful degradation over the 1DDM encoder can be seen when comparing Fig. 14c with Fig. 6b.

VII. WEIGHTED-AVERAGE 2DDM

The 2DDM systems described above sent an additional bit of information at each sample to "tell" the receiver whether to use α or β. The Weighted-average 2DDM does not require this extra bit of information and, therefore, operates at one-half the bit rate of the other 2DDM systems although the sampling rates are the same.

In a Weighted-average 2DDM, a predicted value is formed based on the previous estimate of the horizontal and the vertical pixels. If the $\alpha-\beta$ pair is used, the predicted value, $\overline{P}$, is obtained as [5]:

$$\overline{P} = 0.75\,\overline{\alpha} + 0.75\,\overline{\beta} - 0.5\,\overline{\Delta} \qquad (3)$$

where $\overline{\alpha}$, $\overline{\beta}$, $\overline{\Delta}$ are the encoded estimate of pels α, β and Δ.

Because of the requirement of the previous step-size and the previous error sign of an adaptive DM, the value of $\overline{P}$ can not be utilized directly except to serve as a guide to help decide the coding path. $\overline{P}$ is compared with $\overline{\alpha}$ and $\overline{\beta}$, and whether pixel α or pixel β will be used to encode the input sample depends on whether $\overline{P}$ is closer to $\overline{\alpha}$ or $\overline{P}$ is closer to $\overline{\beta}$.

It can be shown that the process of forming $\overline{P}$ first and then comparing $\overline{P}$ with $\overline{\alpha}$ and $\overline{\beta}$ is not necessary. In Appendix I, it is shown that this procedure of comparison is equivalent to simply comparing $\overline{\Delta}$ with $\overline{\alpha}$ and $\overline{\beta}$. If $\overline{\Delta}$ is closer to $\overline{\alpha}$, use β to encode the input sample and if $\overline{\Delta}$ is closer to $\overline{\beta}$, pixel α will be used.

Fig. 15a and Fig. 15b are the Weighted-average 2DDM encoded pictures at 1000 samples/line (2 bits/pixel) and 500 samples/line (1 bit/pixel), respectively. Fig. 15c is the difference picture between Fig. 15a and Fig. 3 and magnified by a factor of 2. The jaggedness along the edges are clearly seen. This jaggedness results because the predicted value, P, does not always guide the encoder to encode along the best coding path. Fig. 16a and Fig. 16b show the Weighted-average 2DDM encoded "resolution chart" encoded at 2 bits/pixel and 1 bit/pixel, respectively. All pictures shown with Weighted-average 2DDM encoder employ the α-β pair as the reference pixels.

VIII. COMPARISON

Among the three DM algorithms discussed above, the Look-Ahead 2DDM performs the best. The capabilities and limitations of these three algorithms are best revealed at the encoding rate of 1 bit/pixel. At this low bit rate, 7.5Mb/s, all DM encoders degrade their performance. The Look-Ahead 2DDM degrades most gracefully and, thereby, produces the most subjectively acceptable pictures.

Interlacing

In an interlaced scanning system, the 2DDM encoded pictures show more degradations than pictures encoded by a noninterlaced scanning system due to the fact that less vertical correlation exists between picture elements in an interlaced scanning system. When the picture of the "girl" is encoded by the Look-Ahead 2DDM encoder with interlaced and noninterlaced scan, the difference is small. However, the Look-Ahead 2DDM encoded "resolution chart" shows tearing along 45° angle lines as shown in Fig. 17.

IX. EFFECTS OF CHANNEL ERRORS

Transmission errors cause a deviation between the received and transmitted binary digits, thus, they generate error patterns which are superimposed on the decoded pictures. The interdependencies between the picture elements generated by the delta modulation system caused the error to propagate.

The response of the delta modulator decoder to a transmission error is a permanent DC level shift. The result of a permanent DC shift is an erroneous brightness pattern in the reconstructed picture. In a one dimensional delta modulator, the error patterns propagate only horizontally [16]. However, in a two dimensional delta modulator the error pattern can spread out both in the horizontal and in the vertical directions. In a 2DDM decoder, each channel error, depending on the pixel position of the initiating error in a particular coding path, causes a different kind of shape in the error pattern.

Refer to a particular coding path as shown in Fig. 18. If an error occurs at pixel a, the error will not propagate because pixel a is isolated and will not be used for the estimation of other pixels. Thus, the error at pixel a is like a PCM error and, hence, a brightness deviation will be observed only at that point. Because of the small size of a pixel and the possibility that the deviation is small, this kind of error is not clearly visible. It can be readily shown that the probability of a pixel in a coding path being isolated is 1/4. It implies that one out of every four errors in the decoded picture will not propagate and, therefore, will not be visible.

If an error occurs at pixel b, the error will propagate along the coding path, and a horizontal streak of 4 pixels in length will appear on the decoded picture. The probability that an error will cause a horizontal or a vertical streak in length of n pixe can be shown to be $(1/2)^{+2n}$. In the example of pixel b, n is equal to 5. Therefore, the probability that the error will move only horizontally for 4 pixels is $(1/2)^{+10}=10^{-3}$ which is very small. Hence, generally, three out of four errors received will spread into a two dimensional area of various sizes and shapes such as would be the case if pixel c in Fig. 18 is in error. The entire area covered by the coding path following pixel c will be affected. The convergence and divergence property of the coding path after the erroneous pixel determines whether the error pattern is constrained or not. The worst case happens when there are multiples errors in a divergent coding path. The result is often the total destruction of part of the picture covered by the coding path following several erroneous pixels. Fig 19a is the decoded picture with a probability of error of 5×10^{-5}. The picture has been encoded using a 2DDM operating at 1 bit/pixel. Since there are 2.5×10^{5} pixels in a frame, there are, on the average, 12.5 errors/frame. The error patterns in Fig. 19a are not very clear because at this low error rate, errors are separated. Thus, no multiple error pattern occurs so that the propagation of errors are not very noticeable. Fig. 19b shows the effect of multiple errors in the diverging coding path. The probability of error shown here is 2×10^{-4}. The total number of errors is 50. The large error probability causes the errors to be closer and, therefore, the errors interfere with one another and cause the estimate to drift further from the correct value, consequently the total destruction of portion of the picture occurs.

However, channel errors occur randomly. All the registers of the delta modulator encoder and decoder are reset to zero prior to the beginning of each new frame. The errors in each frame appear at different places, and pictures seen on the TV screen are not as severely distorted by the error patterns as the pictures taken from a single frame.

The deviation between the transmitted picture and the decoded picture due to channel errors can be reduced by employing a leaky integrator into a delta modulator and also by restricting the maximum allowable step-size of a DM. There is a trade-off between picture quality and channel noise reduction. A larger maximum allowable step-size allows the DM to respond to an edge quickly whereas a smaller maximum step-size helps reduce the maximum discrepancy of the transmitted and the decoded picture. A larger leaky factor of the leaky integrator can correct the errors of a decoded picture in a shorter period of time, but the overall picture quality will be reduced due to the large amount of decay at each picture element.

X. TWO DIMENSIONAL DELTA MODULATION USING INTERFRAME ENCODING

The previous discussion gave the results of using the two dimensional delta modulator algorithm as an intraframe encoder. In this section, we will discuss the results that we obtained when we used the algorithm in a real time interframe encoder.

The interframe encoder differed from the intraframe encoder already described in only two ways. First, as an interframe encoder, it uses the estimate from the previous frame and the previous horizontal estimate to predict the next estimate. Secondly, it did not use the Look-Ahead scheme.

A simplified block diagram of the encoder is shown in Fig. 20. From this figure it is apparent that the encoder consists of two delta modulators. One encodes horizontally and the other, frame-to-frame. Decision circuitry compares the estimate from the horizontal encoder with the input signal and also compares the frame-to-frame estimate with the input signal. The decision circuitry then throws SW1 so as to save the E_k bit, step-size, and estimate from the delta modulator that produced the estimate that was closer to the input signal.

This encoder requires 2 bits to be transmitted each time the input signal is sampled and, therefore, operates at the rate of 2 bits/pixel. The first bit is E_k, and the other bit is used to signal the receiver whether to encode from the horizontal direction or the frame-to-frame direction. If the delta modulator is biased so that it switches to the horizontal direction only when the horizontal direction of encoding is significantly better than the frame-to-frame direction, then the delta modulator will choose the horizontal direction only on that part of the scene that changes from frame-to-frame. Since most pictures change little from frame-to-frame, it is possible to code the bits sent to the receiver to achieve an average bit rate somewhere between one and two bits per pixel.

Figure 21 illustrates the quality of the pictures obtained from the encoder. These pictures were taken from a standard TV monitor using a camera with a shutter speed of 1/30 sec. The sampling rate is 7.5 MHz, and the analog video signal is bandlimited to 3.75 MHz by a 4 pole butterworth filter. Because the sides of the picture are cut off, the viewer sees only 256 samples or about 2/3 of a visible frame in each picture. The video signal occupies about 85 quantization levels and the negative going sync pulse, about 30 levels. The minimum step-size is ±1 level, and the maximum step-size is ± 16 levels.

Figure 20a shows a stationary resolution chart. It shows the resolution of the encoder and also the fact that stationary pictures are undistorted. Figure 20b is also of a stationary scene. It shows good gray level rendering but also a slight amount of speckling noise as compared with Fig. 20c, the original analog picture. The speckling is due to the minimum step-size pattern. Figure 20d shows the camera "panning" across the scene. Notice the edge busyness in the picture. The edge busyness which is about 7 pixels wide appears because the encoder reduces to a one dimensional delta modulator when encoding moving objects, i.e., it tends to encode only horizontally. Picture 20e is an analog video signal with the camera panning at about the same rate as in Figure 20d. Although the edge busyness is noticeable, it does not appear to be subjectively annoying on facial scenes or on graphics.

XI. CONCLUSIONS

This paper has shown that video signals can be encoded using DM to obtain good quality pictures at a relatively low level of complexity and cost.

Intra-frame and inter-frame two dimensional encoding systems were discussed and compared. A comparison of the pictures shown here with those obtained by other investigators using DPCM or other techniques indicates that the picture quality depends on the number of bits/pixel required for encoding far more than the encoding technique employed,i.e., DPCM or DM. The major advantage of DM over the other encoding techniques is its low cost and small size due to its low level of complexity. For example, the cost of the components used in a DM is less than the cost of the A/D needed in DPCM.

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APPENDIX I

$$\bar{P} = 0.75\bar{\alpha} + 0.75\bar{\beta} - 0.5\bar{\Delta}$$

Pixel α will be chosen as the previous reference pixel if $\bar{P}$ is closer to $\bar{\alpha}$,

i.e. $\quad |\bar{\alpha} - \bar{P}| < |\bar{\beta} - \bar{P}|$

or $\quad (\bar{\alpha} - \bar{P})^2 < (\bar{\beta} - \bar{P})^2$

or $\quad \bar{\alpha}^2 - 2\bar{\alpha}P + \bar{P}^2 < \bar{\beta}^2 - 2\bar{\beta}P + \bar{P}^2$

or $\quad -0.5\bar{\alpha}^2 - 1.5\bar{\alpha}\bar{\beta} + \bar{\alpha}\bar{\Delta} < -0.5\bar{\beta}^2 - 1.5\bar{\alpha}\bar{\beta} + \bar{\beta}\bar{\Delta}$

or $\quad -0.5(\bar{\alpha}^2 - 2\bar{\alpha}\bar{\Delta} + \bar{\Delta}^2) < -0.5(\bar{\beta}^2 - 2\bar{\beta}\bar{\Delta} + \bar{\Delta})$

or $\quad (\bar{\alpha} - \bar{\Delta})^2 > (\bar{\beta} - \bar{\Delta})^2$

or $\quad |\bar{\alpha} - \bar{\Delta}| > |\bar{\beta} - \bar{\Delta}|$

The results indicate that pexil α will be chosen as the previous reference pexil if $\bar{\Delta}$ is closer to $\bar{\beta}$ than to $\bar{\alpha}$.

REFERENCES

[1] P.A. Wintz, "Transform picture coding", Proc. of IEEE, pp. 809-820, July, 1972.

[2] D.J. Connor, R.F.W. Pease and W.G. Scholes, "Television coding using two-dimensional spatial prediction", Bell Syst. Tech. J., Vol. 50, pp. 1049-1061, March 1971.

[3] D.J. Connor, R.C. Brainard and J.O. Limb, "Intraframe coding for picture transmission", Proc. IEEE, Vol. 60; pp. 779-791, July 1972.

[4] Hiroshi Inose and Mitsuru Ishizuka, "Adaptive coding using two dimensional prediction for image signals", Electronics &Communications in Japan, Vol. 57, pp. 50-58, July, 1974.

[5] R. Lippman, "DPCM - bilduberträgung mit geringer storempfindlichkeit" Interner Bericht, Institut fur Flugfuhrung, Deutsche Forschungs - und Versuchsanstalt fur Luft - und Raumfahrt E.V.

[6] F.W. Mounts, "A video encoding system using conditional picture element replenishment", Bell Syst. Tech. J., Vol. 48, pp. 2545-2554, Sept. 1969.

[7] J.C. Candy, M.A. Franke, B.G. Haskell and F.W. Mounts, "Transmitting televisions as clusters of frame to frame difference", Bell Syst. Tech. J., Vol. 50, pp. 1889-1917, July 1971.

[8] B.G. Haskell, F.W. Mounts and J.C. Candy, "Interframe coding of videotelephone pictures" Proc. of IEEE, pp. 792-799, July 1972.

[9] J.O. Limb, R.F.W. Pease and K.A. Walsh, "Combining intraframe and frame to frame coding for television", Bell Syst. Tech. J., Vol. 53, pp. 1137-1173, July 1974.

[10] J.E. Abate, "Linear and adaptive delta modulation", Proc. of IEEE, Vol. 55, pp. 298-308, March 1967.

[11] R.H. Bosworth and J.C. Candy, "A companded one bit coder for television transmission", Bell Syst. Tech. J., Vol. 48, pp. 1459-1480, May 1969.

[12] N.S. Jayant, "Adaptive delta modulation with one bit memory", Bell Syst. Tech. J., Vol. 49, pp. 321-342, March 1970.

[13] H.R. Schindler, "Delta modulation", IEEE Spectrum, Vol. 7, pp. 69-78, Oct. 1970.

[14] C. L. Song, J. Garodnick and D. L. Schilling, "A Variable-step-size robust delta modulator", IEEE Trans. Commun., Vol. COM-19, pp. 1033-1044, Dec. 1971.

[15] L. Weiss, I.M. Paz and D. L. Schilling, "Video encoding using an adaptive digital delta modulator with overshoot suppression", IEEE Trans. Commun., Vol. COM-23, pp. 905-920, Sept. 1975.

[16] N. Scheinberg and D. L. Schilling, "Techniques for correcting transmission errors in video adaptive delta modulation channels", IEEE Trans. Commun., Vol. COM-24, pp. 1064-1069, Sept. 1976.

[17] C.C. Cutler, "Delayed encoding: Stabilizer for adaptive coders", IEEE Trans. Commun., Vol COM- 19,pp. 898-906, Dec. 1971.

[18] J. Uddenfeldt and L.H. Zetterberg, "Algorithms for delayed encoding in delta modulation with speech-like signals", IEEE Trans. Commun., Vol. COM-24, pp. 652-658, June 1976.

[19] J.B. O'Neal, Jr., "Predictive quantizing system (differential pulse code modulation) for the transmission of television signals", Bell Syst. Tech. J., Vol. 45, pp. 689-721, May 1966.

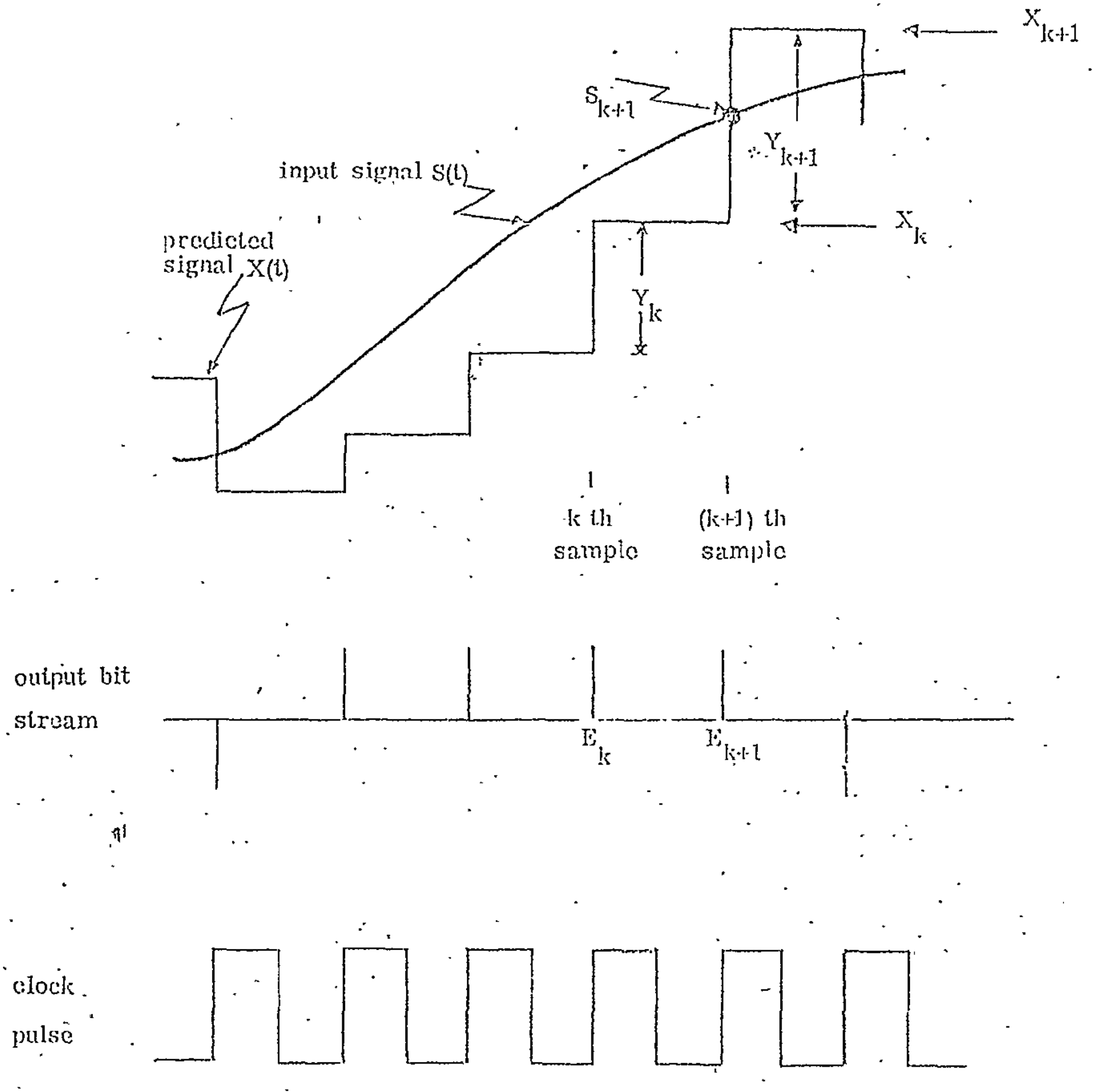

Fig. 1 The delta modulator

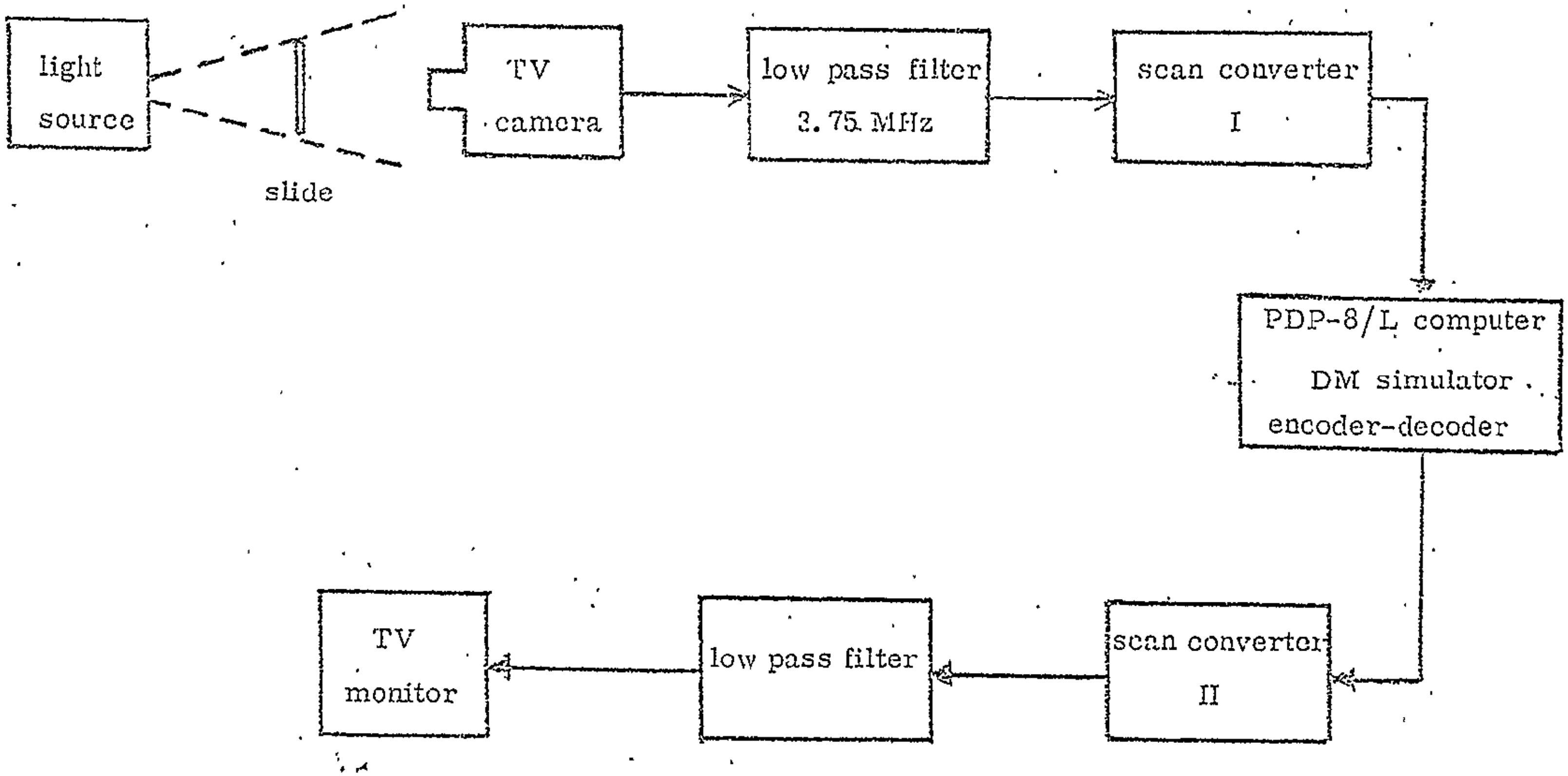

Fig. 2 . The video system employed to test DM algorithns

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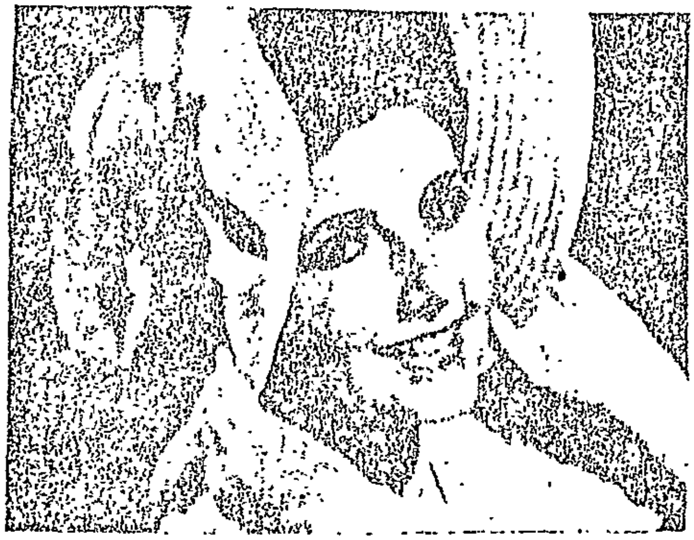

Fig. 3 10-bit PCM encoded "head and shoulder" picture

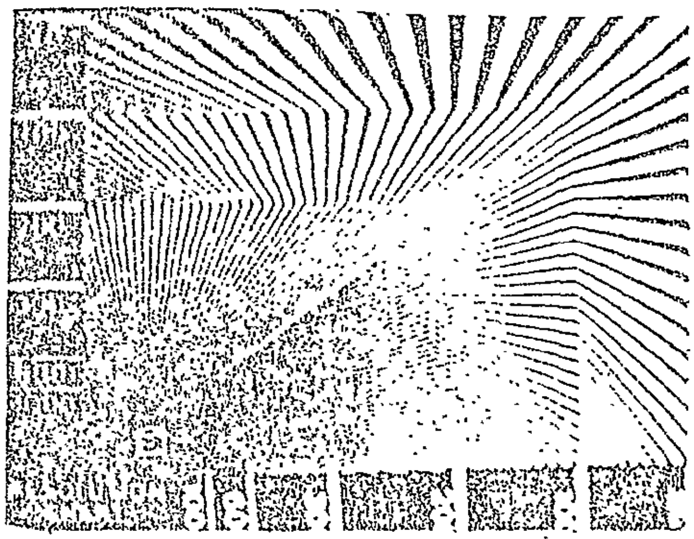

Fig. 5 10-bit PCM encoded "resolution chart"

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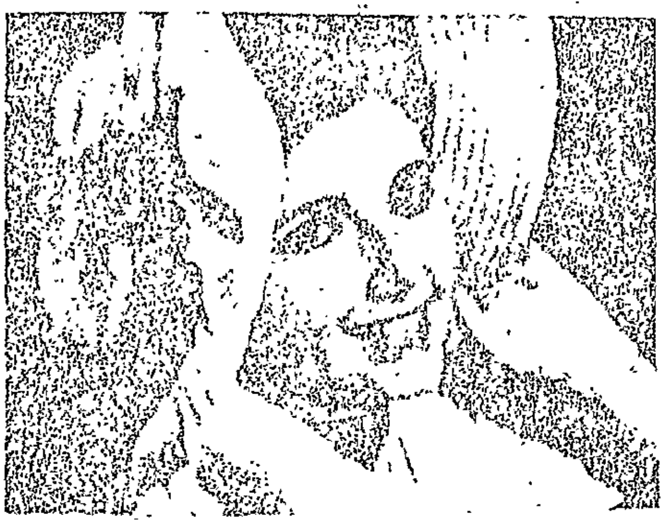


Fig. 4a) 1 DDM encoded picture at the rate of 2 bit/pixel

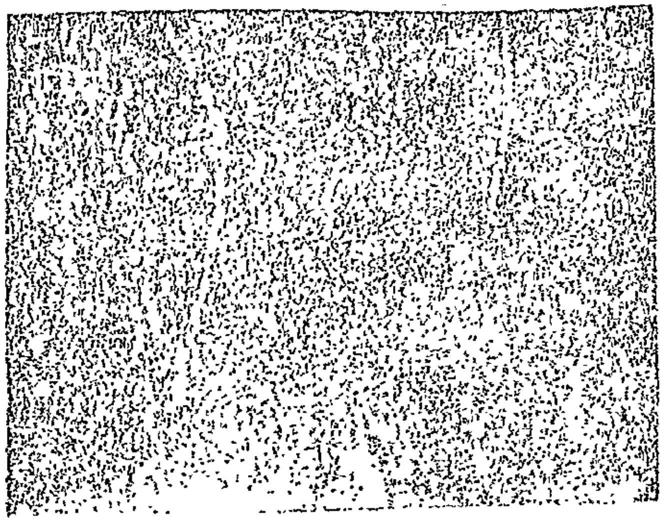


Fig. 4b) The difference picture of Fig. 4a) and Fig. 3

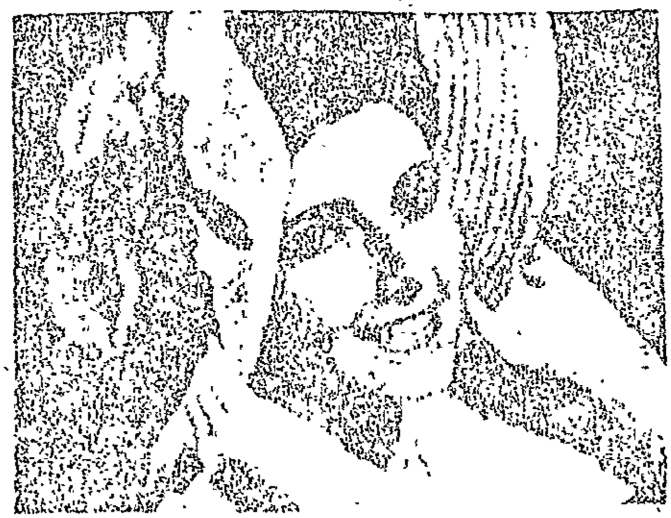
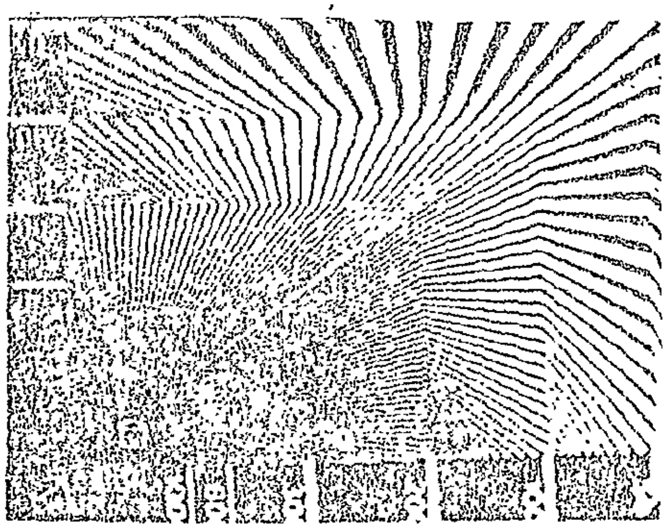


Fig. 4c) 1 DDM encoded picture at the rate of 1 bit/pixel



(a)

(b)

Fig. 6 Pictures encoded by a 1 DDM at the rate of a) 2 bit/pixel b) 1 bit/pixel

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		k	k+1	k+2	
m		Δ	β	γ	
m+1		α	ρ		

Fig. 7 The relative positions of the picture elements

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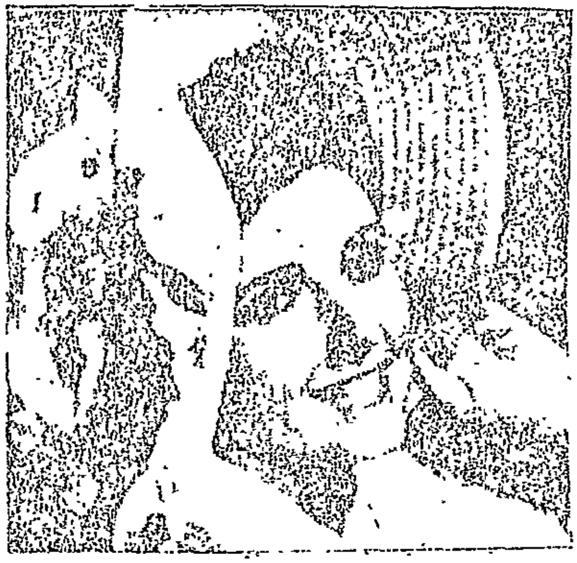

Fig. 8a Picture encoded by a normal 2DDM with α-γ pair as the reference pixels at the rate of 1 bit/pixel

Fig. 8b Picture encoded by a normal 2DDM with α-β pair as the reference pixels at the rate of 1 bit/pixel

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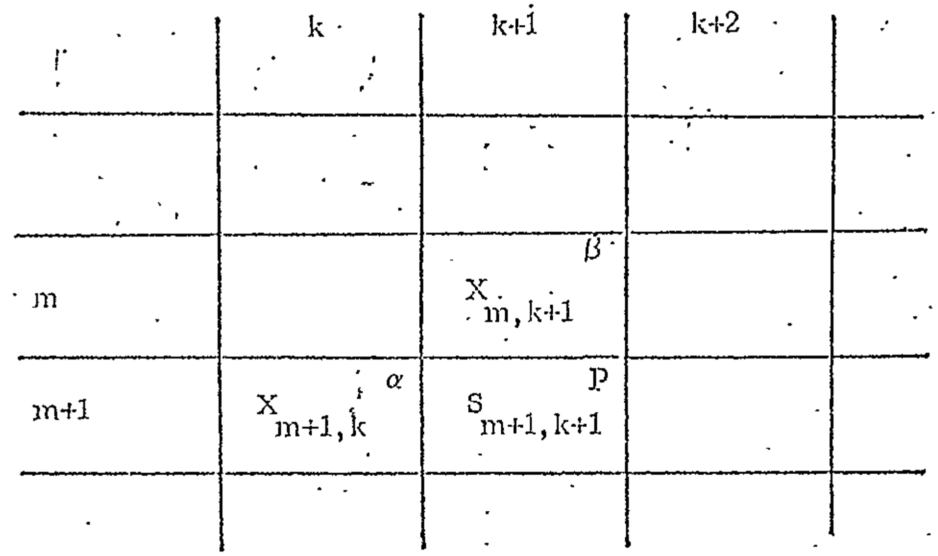


Fig. 9 The relative positions of the previous estimates of the input sample

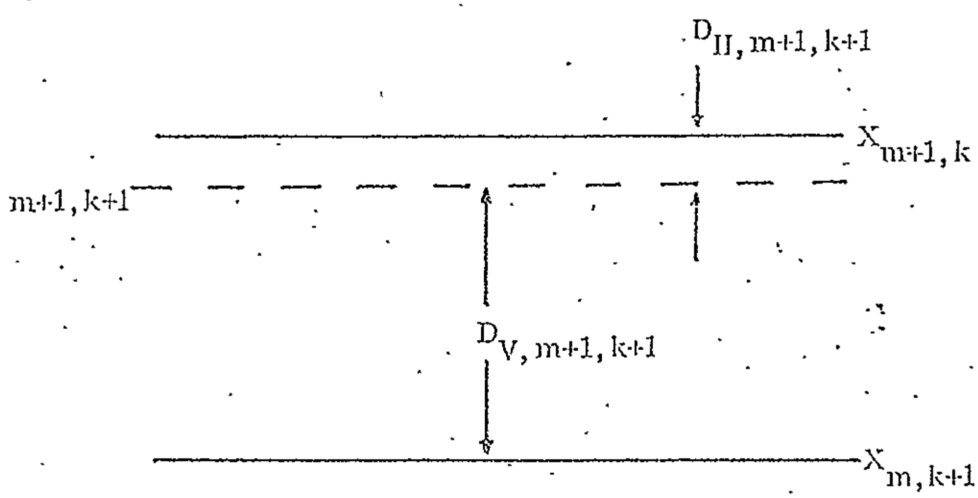


Fig. 10 The comparison of the two previous estimates to the present input sample

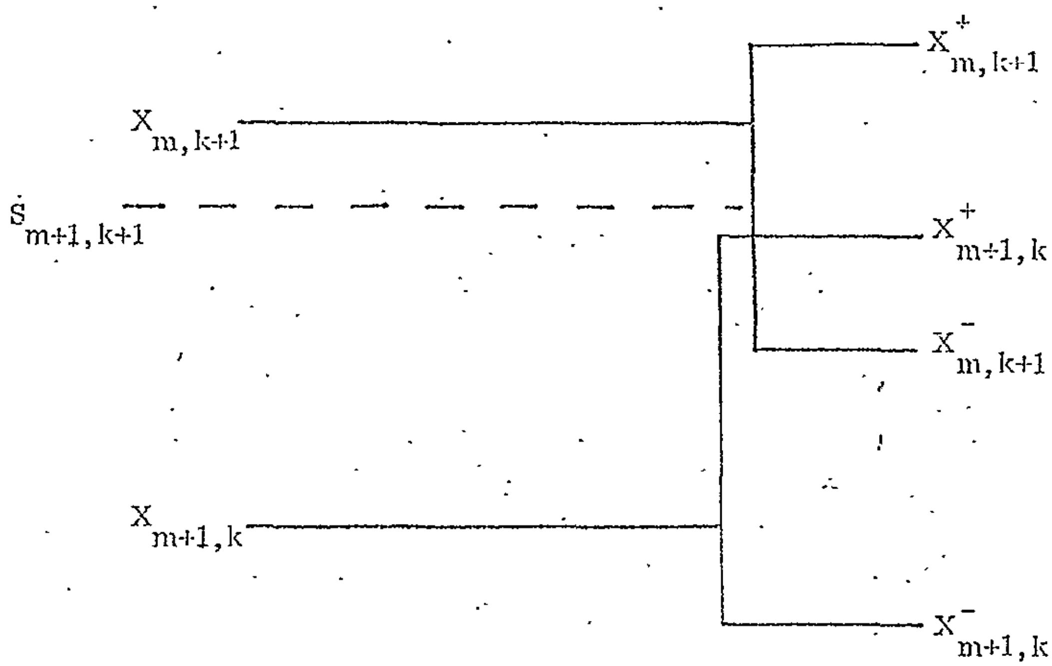
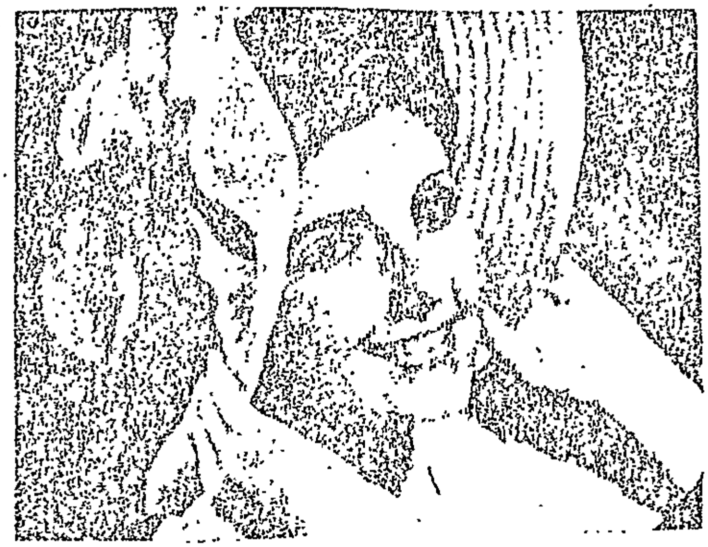
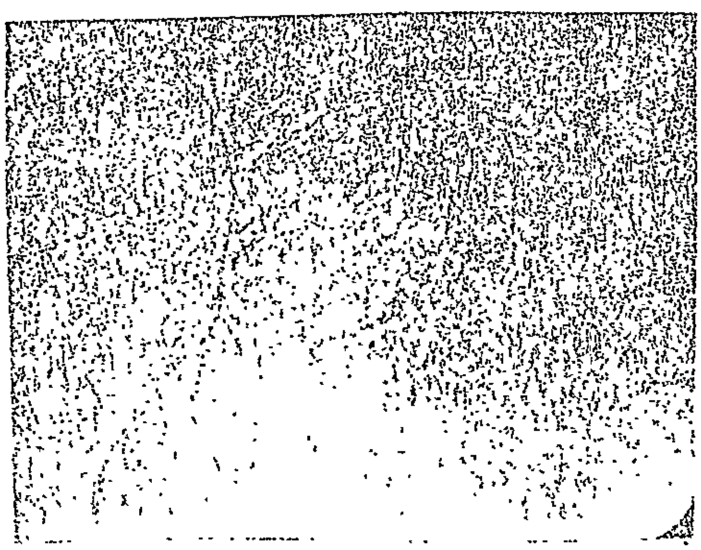


Fig.11 The input sample compares to the four new estimates instead of the two previous estimates in a look-ahead 2DDM system.



(a)



(b)

Fig. 12 a) The Look-Ahead 2DDM encoded picture using α-β pair at the rate of 2 bit/pixel b) The difference picture between Fig. 12a and Fig.3

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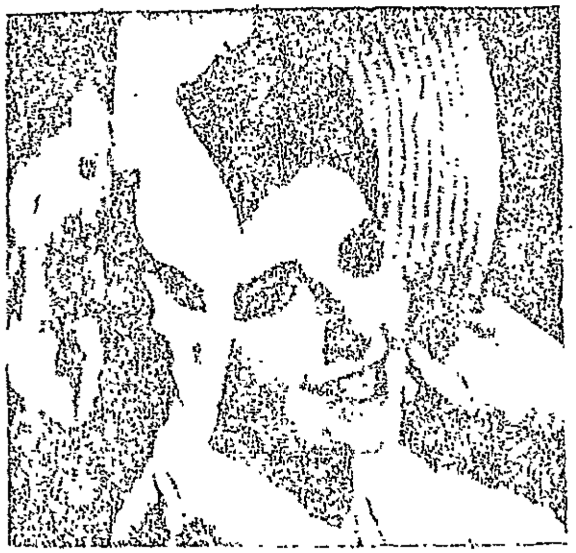
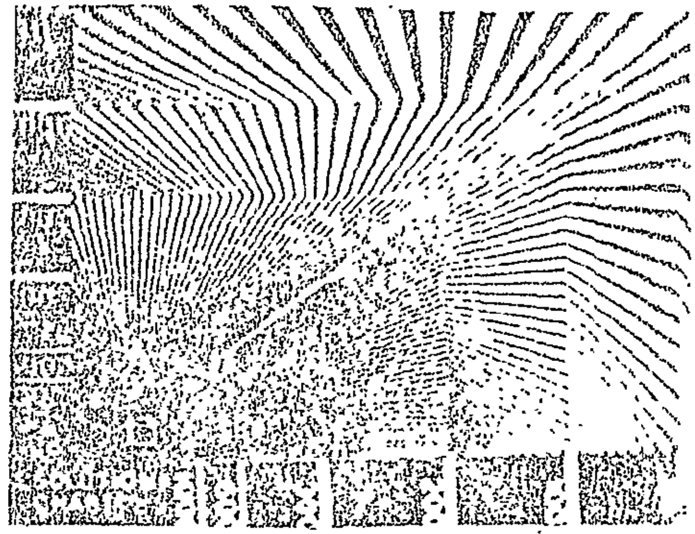
(a)



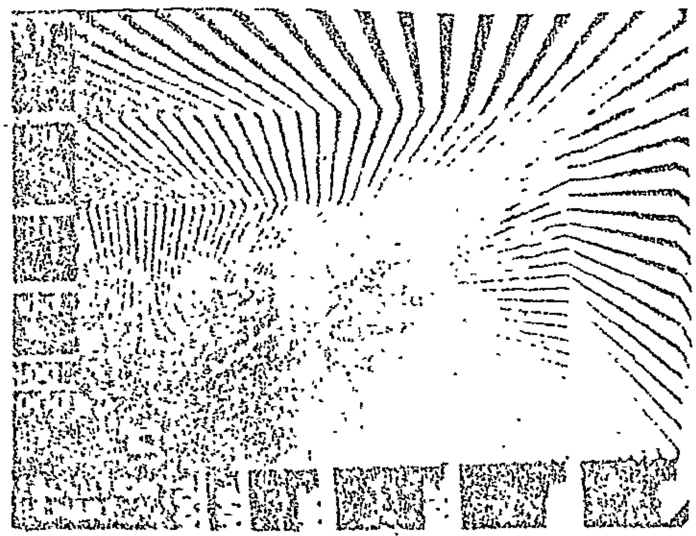
(b)

Fig. 13 The Look-Ahead 2DDM encoded pictures using α–β pair at the rate of a) 1 bit/pixel b) 0.5 bit/pixel

a) 2 bit/pixel using α–γ pair



b) 2 bit/pixel using α–β pair



c) 1 bit/pixel using α–β pair

Fig. 14 The Look-Ahead 2DDM encoded pictures

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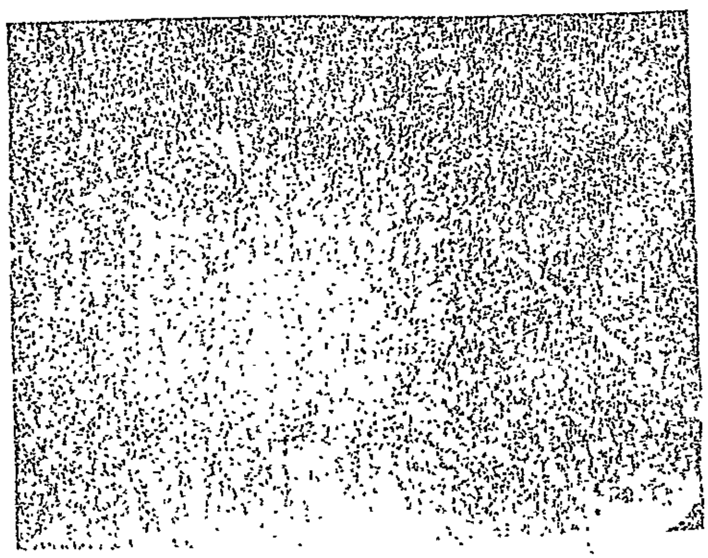
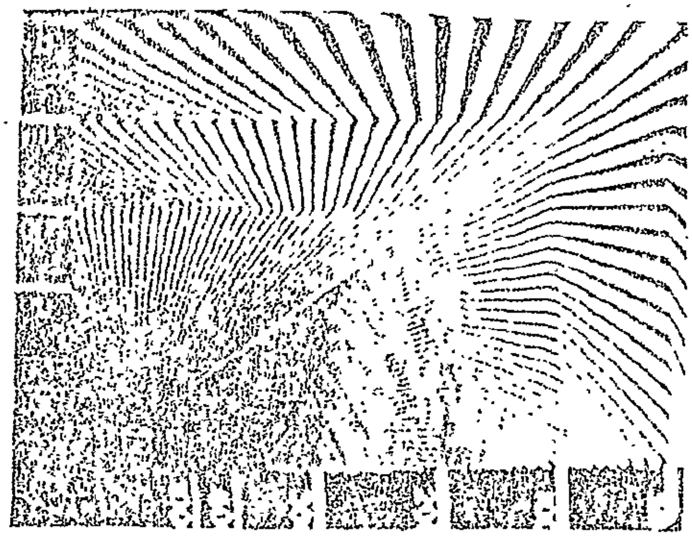
a) 2 bit/pixel

b) 1 bit/pixel

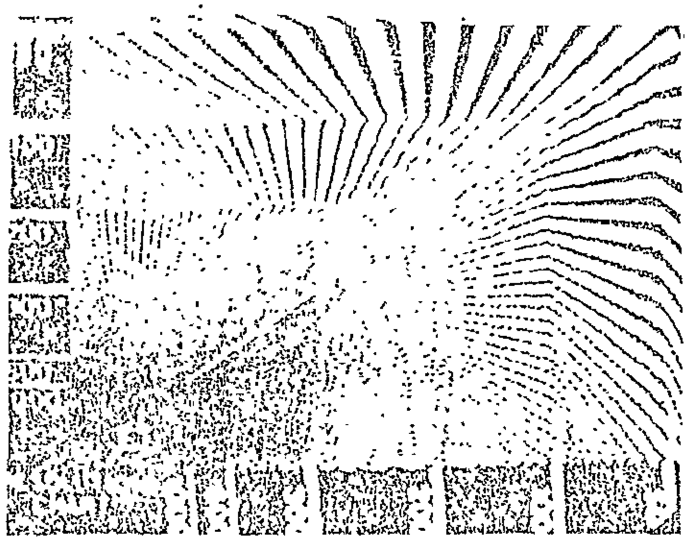


c) the difference picture between Fig. 15 a and Fig. 3

Fig. 15 The Weighted-average 2DDM encoded pictures



(a)



(b)

Fig. 16 Pictures encoded using Weighted-average 2DDM at the rate of (a) 2 bit/pixel (b) 1 bit/pixel

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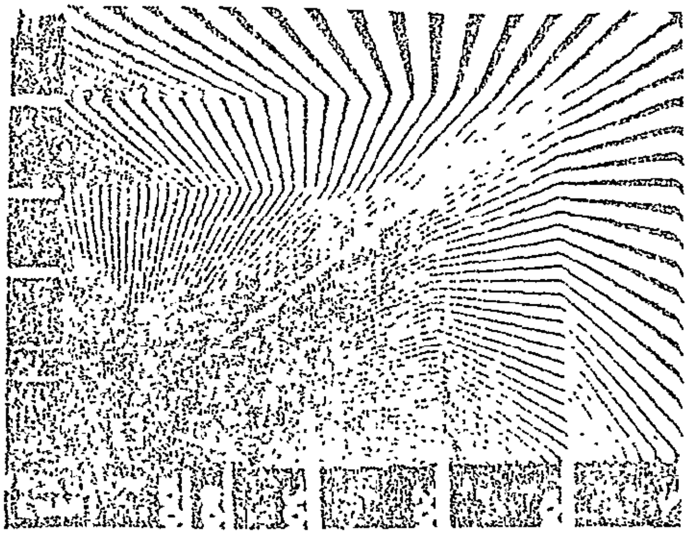


Fig. 17 The Look-Ahead 2DDM encoded picture at the rate of 2 bit/pixel using α–γ pair and interlaced scan

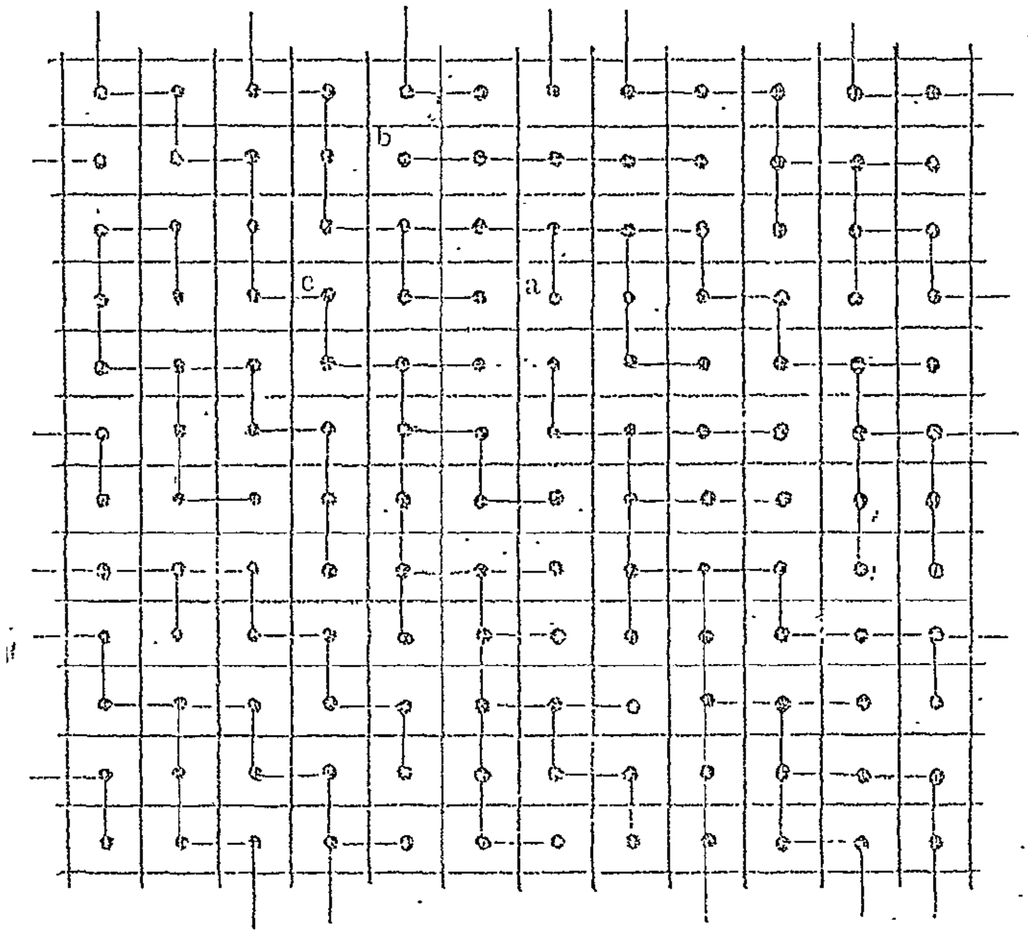
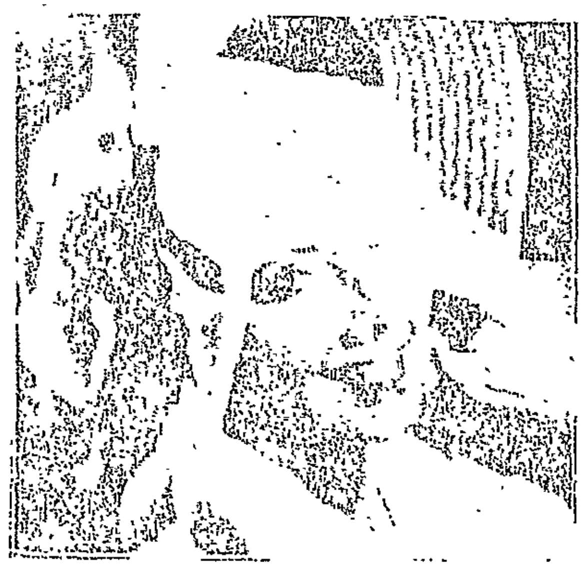


Fig. 18 Portion of a coding path

a) P(e) = 5x10^{-5}



b) P(e) = 2x10^{-4}

Fig. 19 . The Look-Ahead 2DDM decoded pictures with channel errors at the rate of 1 bit/pixel.

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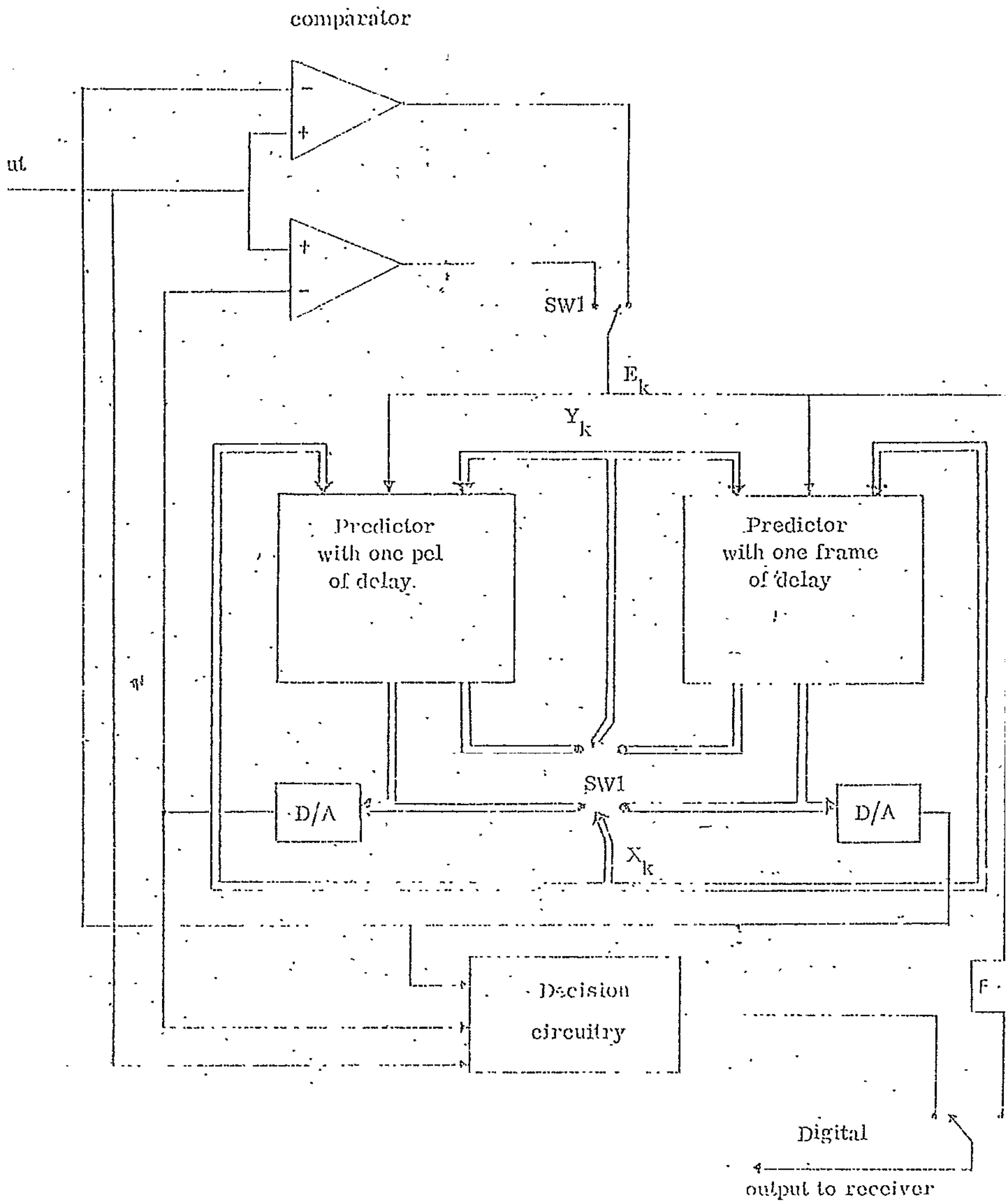
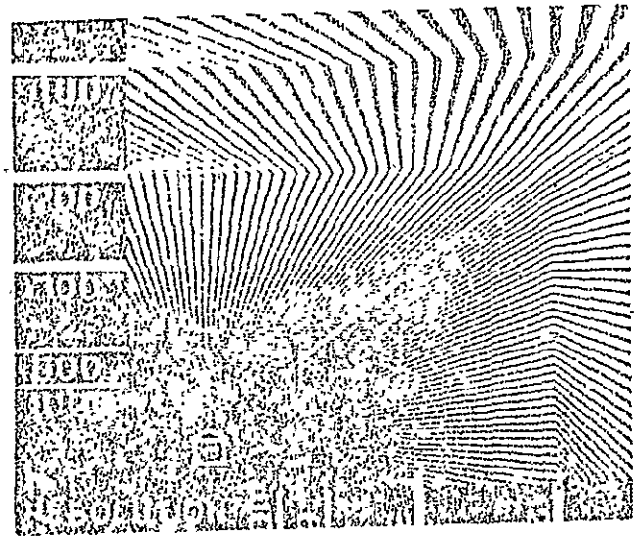
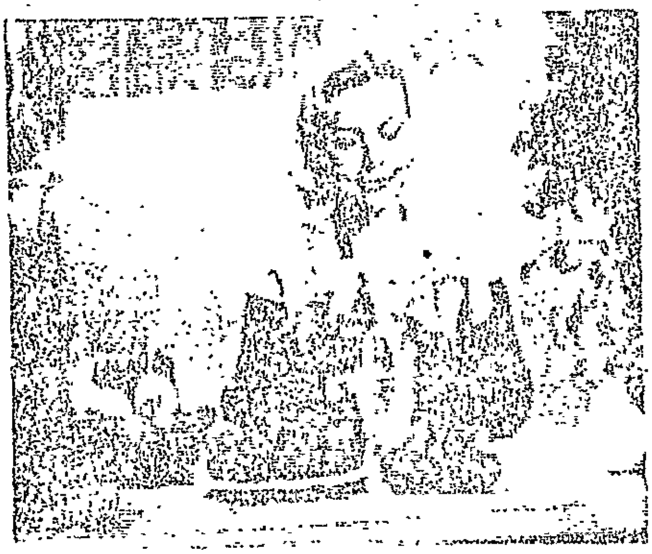


Fig. 20 Two dimensional interframe encoder

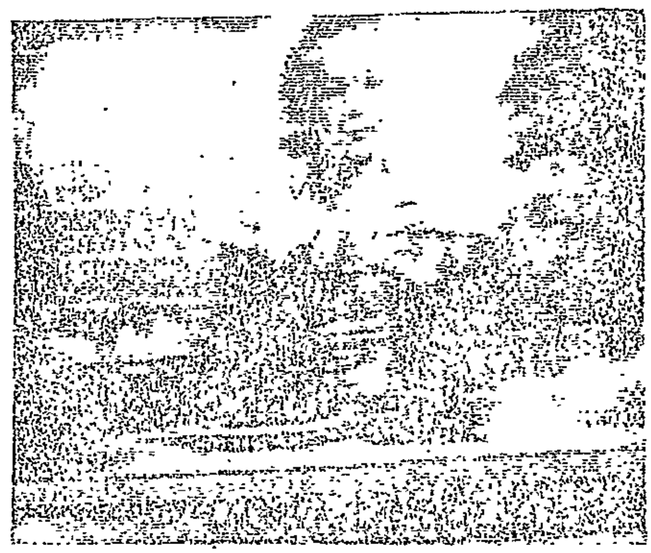


(a)

(b)



(c)



(d)

(e)

Fig. 21 Two Dimensional Interframe Encoder (a) Resolution Chart, no motion; (b) Girl, no motion; (c) Original analog video; (d) Effects of "panning" the scene (e) Analog video with "panning.

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V. Papers Published

Scheinberg, N. and D. L. Schilling, "Techniques for Correcting Transmission Errors in Video Adaptive Delta Modulation Channels", IEEE Trans. on Comm, September 1976, pp. 1064-1070.

Lei, R., Scheinberg, N. and D. L. Schilling, "Adaptive Delta Modulation Systems for Video Encoding", IEEE Trans. on Comm, November 1977.

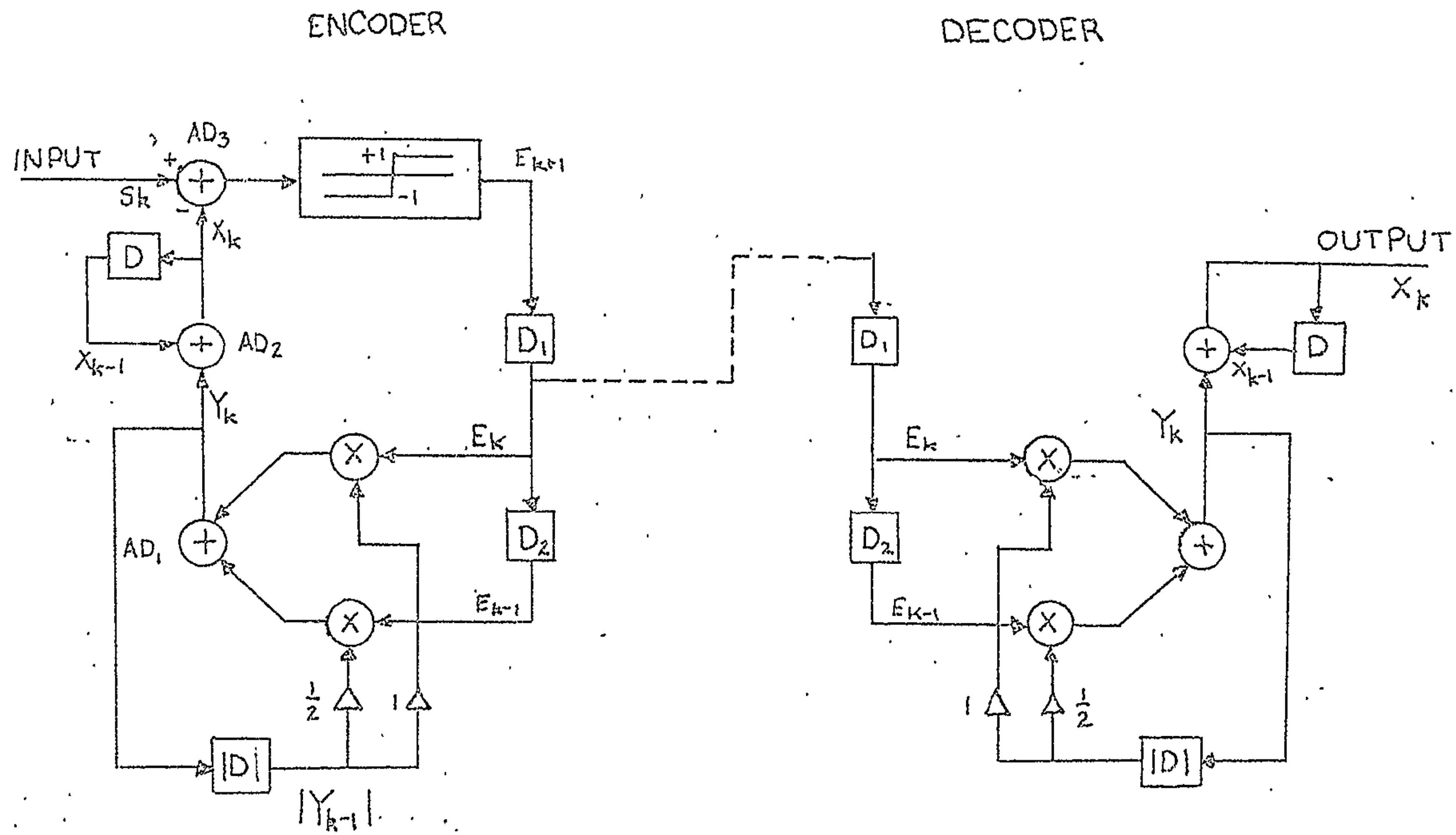


FIG. 1 DIGITAL ADAPTIVE DELTA MODULATOR

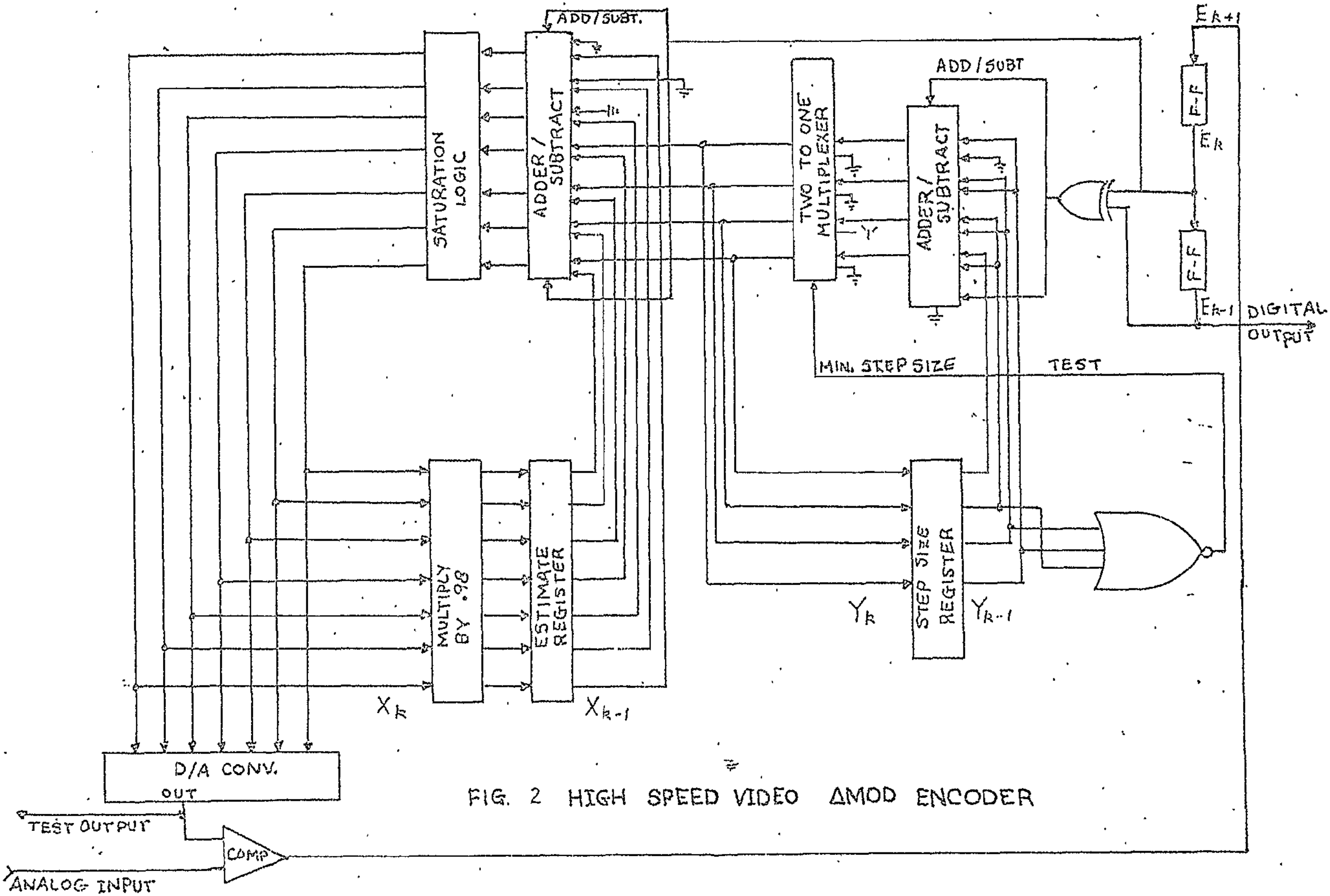


FIG. 2 HIGH SPEED VIDEO ΔMOD ENCODER

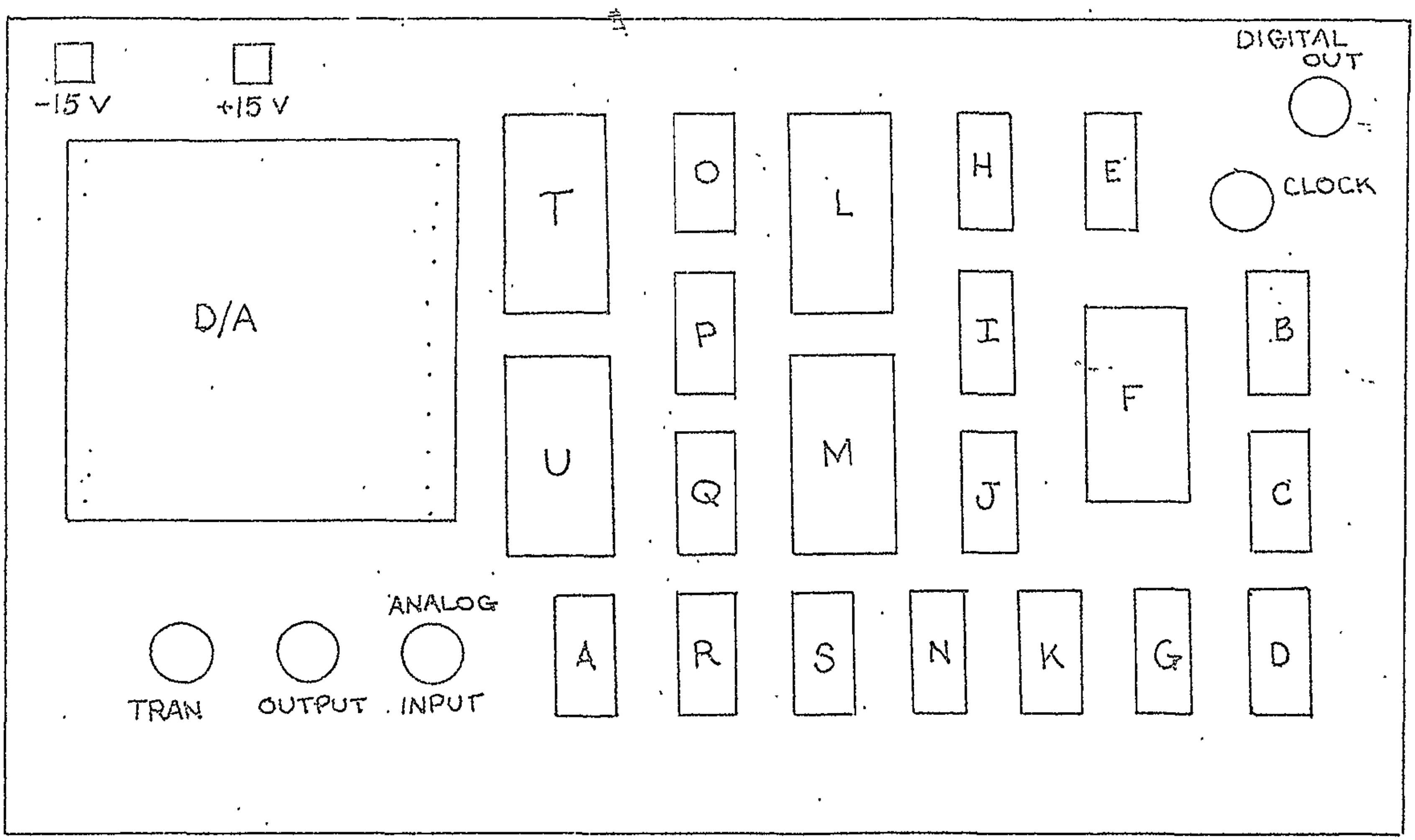
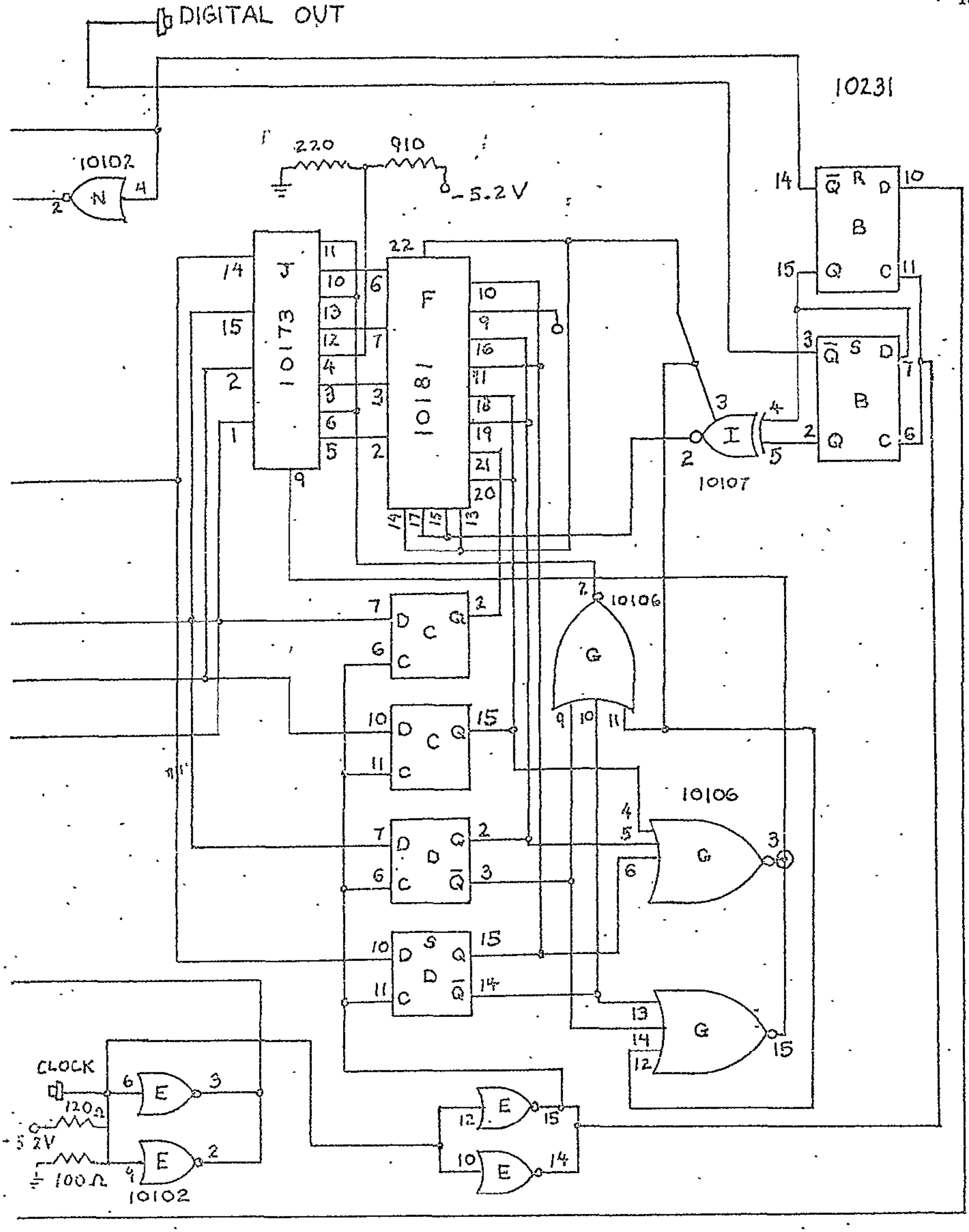
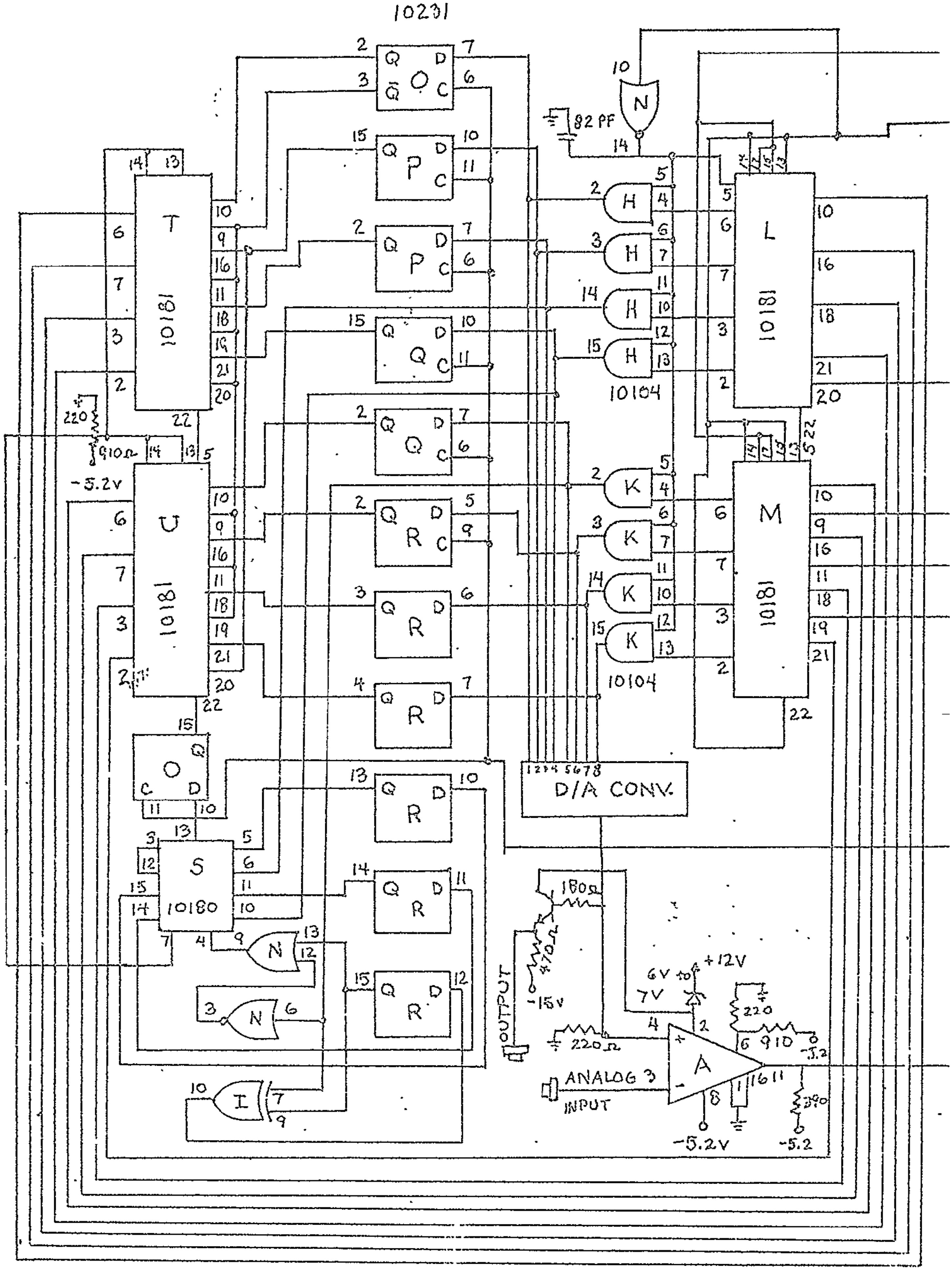


FIG 3 ONE DIMENSIONAL DELTA MOD TRANSMITTER



TRANSMITTER


10231
Q D O C
Q̄
Q P D C
Q Q D C
Q R D C
Q R D
T
10181
U
10181
L
10181
M
10181
H
K
10104
N
82 PF
220
910Ω
-5.2V
O
C D Q
S
10180
I
D/A CONV.
180Ω
470Ω
-15V
OUTPUT
220Ω
6V
7V
+12V
220
910
-5.2
A
ANALOG 3
INPUT
390
-5.2V
-5.2

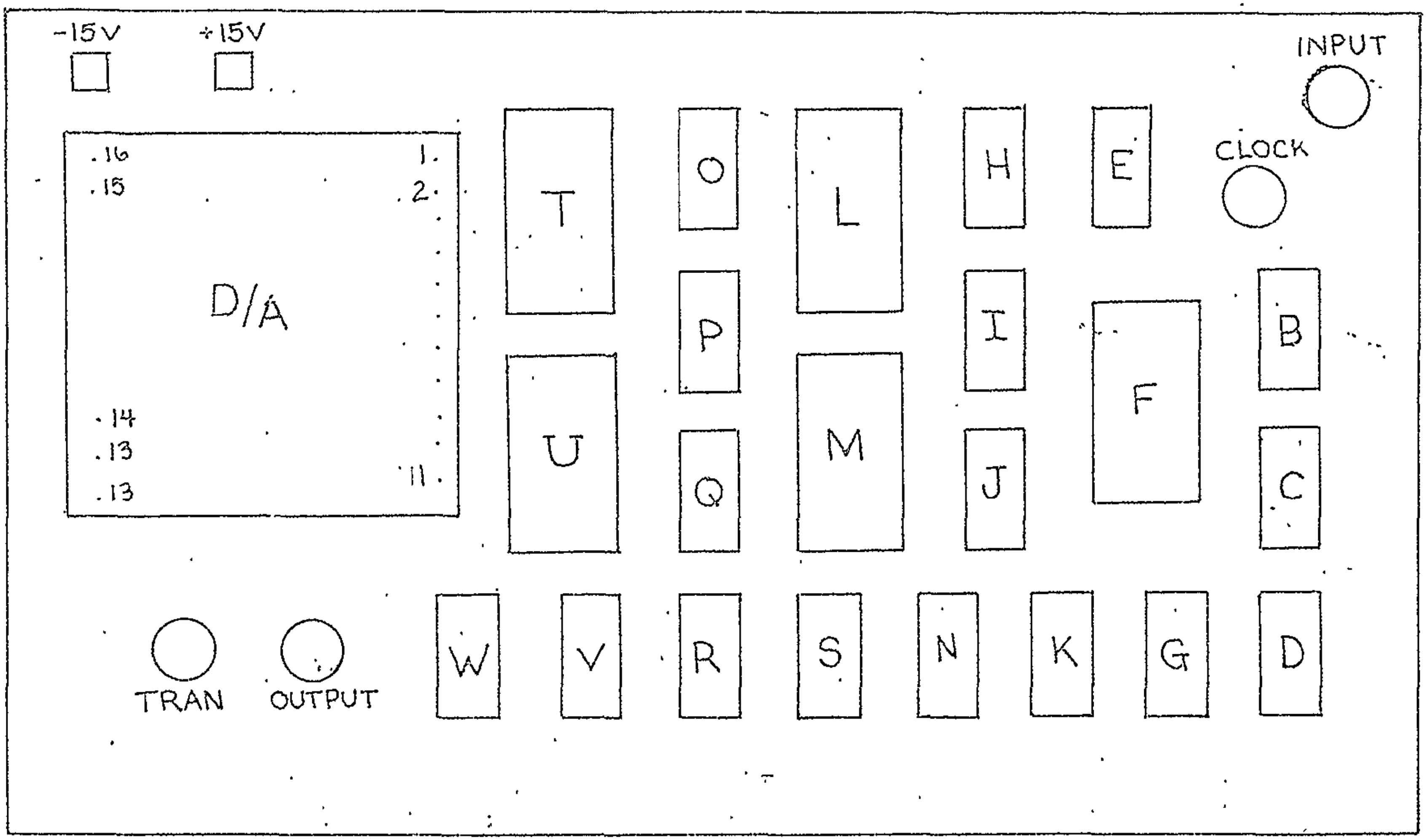
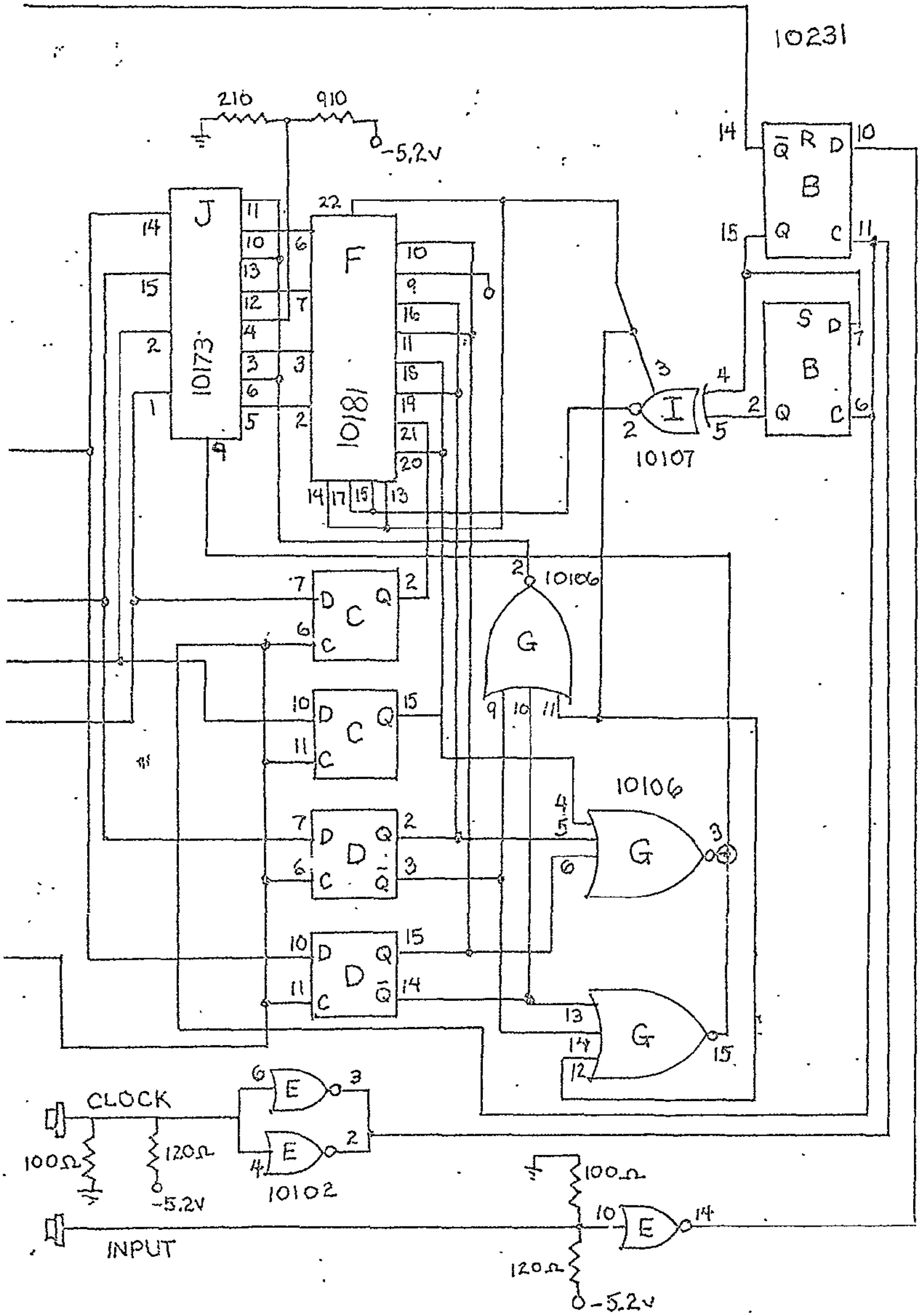
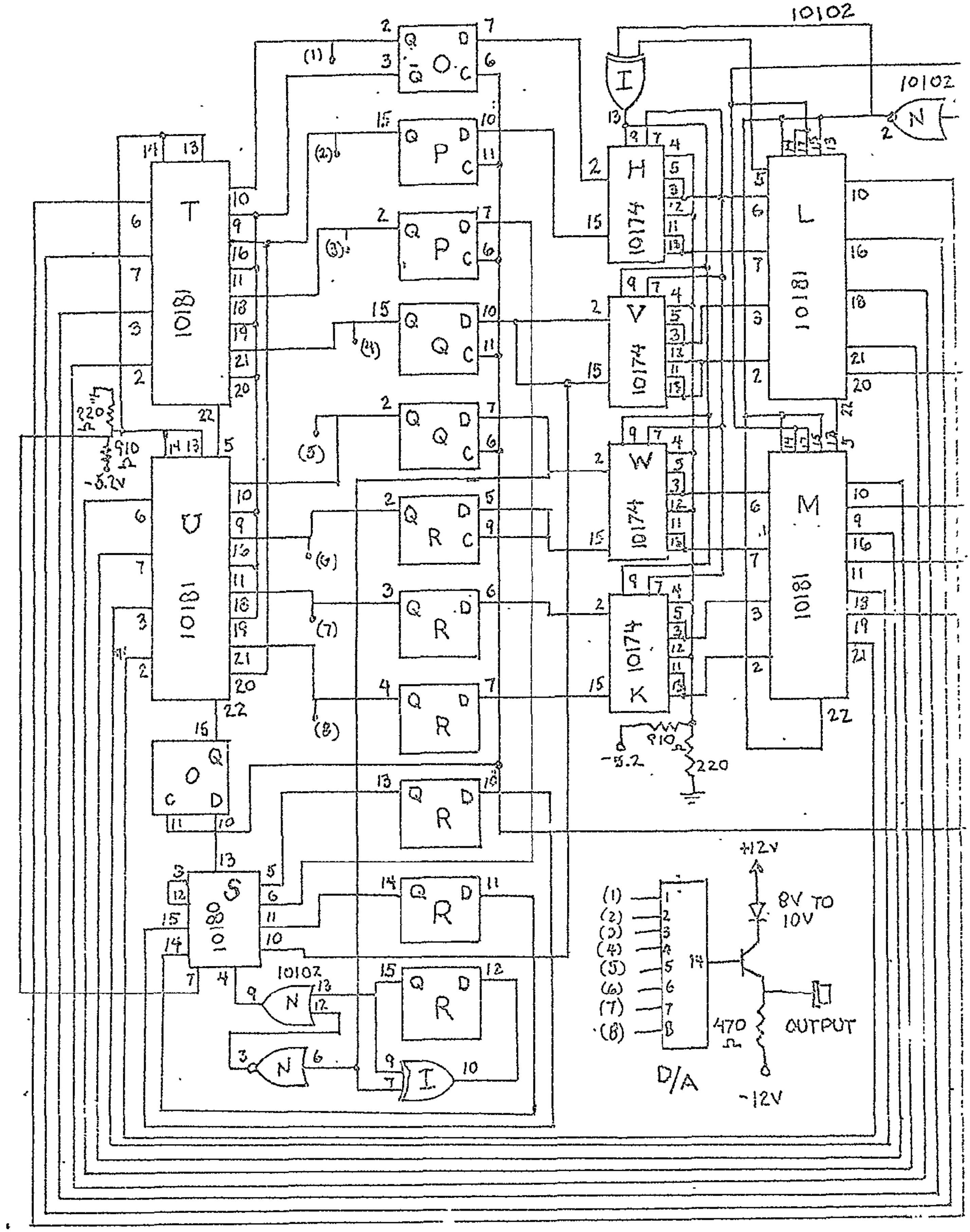


FIG 3 ONE DIMENSIONAL DELTA MOD RECEIVER


10231
210
910
-5.2V
J
10173
F
10181
B
I
10107
C
D
G
10106
E
10102
CLOCK
100Ω
120Ω
-5.2V
INPUT
100Ω
120Ω
-5.2V

RECEIVER


10102
10102
10181
10181
10174
10174
10174
10174
10181
10181
10180
10102
-5.2V
-5.2
910 Ω
220
+12V
8V TO 10V
470 Ω
OUTPUT
-12V
D/A

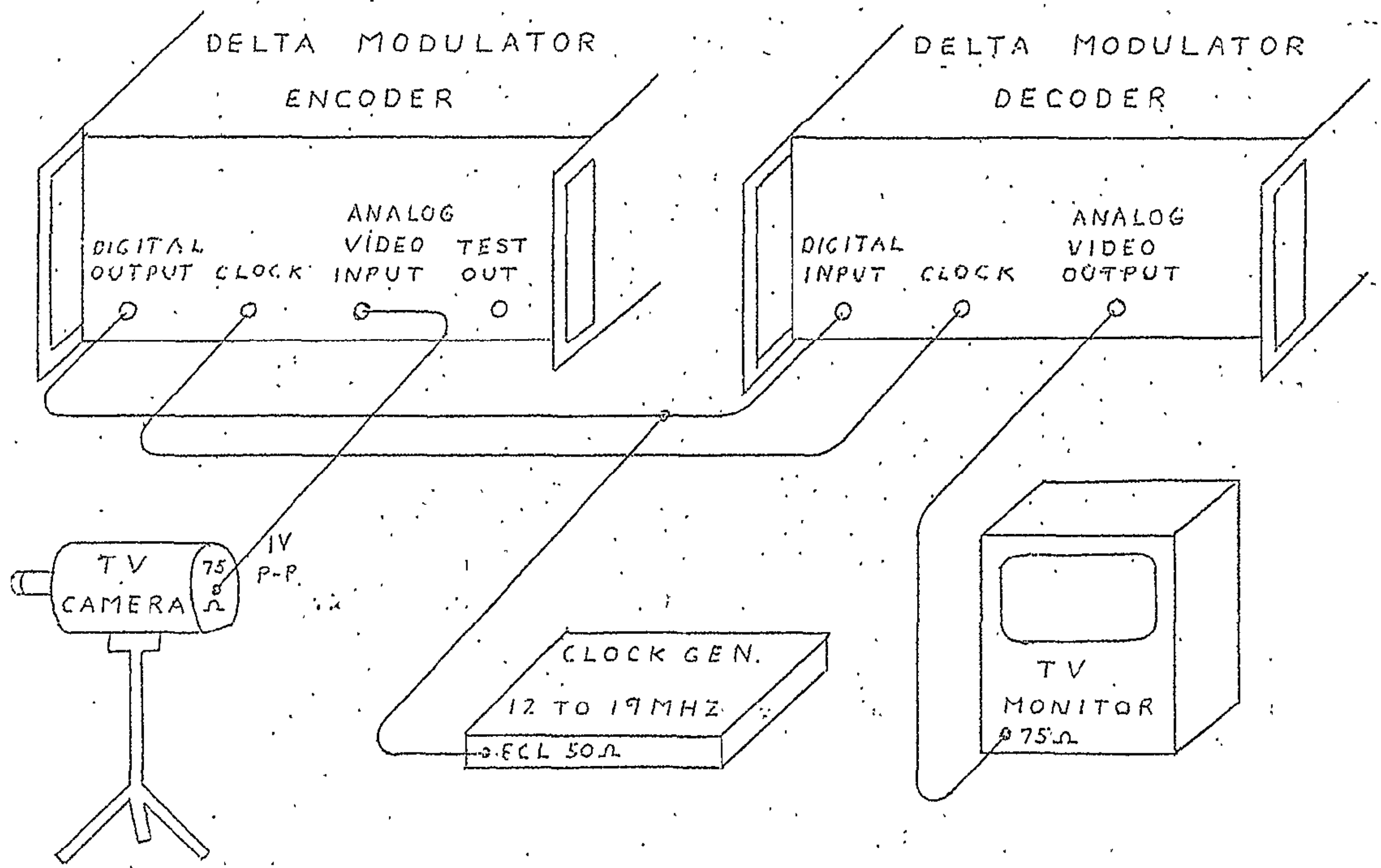


FIG 4 TEST SETUP FOR DELTAMODULATOR

THE CITY COLLEGE of THE CITY UNIVERSITY of NEW YORK

Convent Avenue at 138th Street, New York, New York 10031

Telephone: (212) 281-0470; (212) 368-1444

The City College Research Foundation

The City College Office—Research Foundation of The City University of New York