Department of
Electrical Engineering

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Halifax, Nova Scotia

COMPARISON OF OBJECTIVE AND SUBJECTIVE CRITERIA FOR TELEVISION PERFORMANCE IN RADIO NOISE

F I N A L R E P O R T

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I. CHANGES OF TERMS OF CONTRACT

Late Delivery of Contract

The research project was scheduled to commence in 1st May, 1980. However, the full contract was not completed until 8th August 1980, hence a substantial part of the original proposal could not be fulfilled. The part of the project that could not be carried out due to the shortage of time is the measurement of subjective criteria for television viewing. It has been agreed between the investigators and the scientific authority that this part of the project would be carried out even after the official closing date of the contract (March 31, 1981). It has also been agreed that the test equipment should remain in the Technical University of Nova Scotia to facilitate the carrying out and continuation of the subjective tests.

Changes in Personnel

Dr. V.K. Aatre, who was to be one of the co-investigators, departed from the Technical University of Nova Scotia. It was agreed that Dr. D. Swingler, associate professor at St. Mary's University, Halifax, and a visiting staff member of TUNS, would take the place of Dr. Aatre as a co-investigator of the project.

Also due to the late delivery of the final contract, the original programmer had departed. It was decided that to maintain continuity of the project, the programming should be carried out by the investigators and that they are paid accordingly. Approval of the decision was obtained from the Scientific Authority.

II. GENERAL OUTLINE OF PROJECT

(1) Summary of previous study

The reception of television signals is usually degraded by electromagnetic interference. In our previous studies, a computer program has been written simulating the transmission and reception of a colour TV signal under various types of radio noise. Mathematical models for the transmitted colour TV signal, the various types of electromagnetic interference, and the process involved in the reception of the TV signal were developed. A number of tests have been carried out and the results examined. The following important observations were made:

(a) For all types of noise, the blue signal has the worst signal-to-noise (S/N) ratio after detection while the green signal had the best.

(b) For the same S/N ratio in the channel, impulsive noise was more destructive to TV signals than gaussian or uniformly distributed noise.

(2) Objectives of project

The results obtained from previous study are to be examined thoroughly. Analyses are to be performed to confirm and explain the observations. It is also decided that from the simulation, a study on the change in the received colour TV signal is to be carried out so that an objective criterion is to be established from such a study.

Apart from establishing an objective criterion for TV reception, experimental tests are also to be carried out on TV viewing so that a subjective criterion might also be established. Finally, a correlation between the objective and subjective criteria is to be performed so that limits or noise level for tolerable TV reception could be derived.

III. FURTHER INVESTIGATION ON THE SIMULATION PROGRAM

(1) Minor Corrections and Adjustments

The computer program simulating the transmission and reception of colour television signals under noisy conditions was re-examined closely. This led to the following modifications of the program:

(a) The sub-program DMOD for the demodulation of the colour TV signal produced unacceptable output due to the BP and LP filters being non-ideal, and also due to the gains of the chroma amplifiers being incorrect. These were corrected.

(b) The sub-program PLOTER (plotting routine) had to be completely rewritten to accommodate the PLOTIO hardware.

(c) The FFT subroutine was slightly modified to reduce the number of parameters.

With the accomplishment of these corrections and adjustments, the output of the program was found to be satisfactory. Figure III.1 to III.4 shows the plots of the detected Y (luminous), B (blue), R (red) and G (green) signals.

(2) Additional Subprograms

The three primary source files TSIG (video generation), DMOD (demodulation) and PLOT (plotting) have been augmented by noise generation and calculation source files. New subprograms added are:

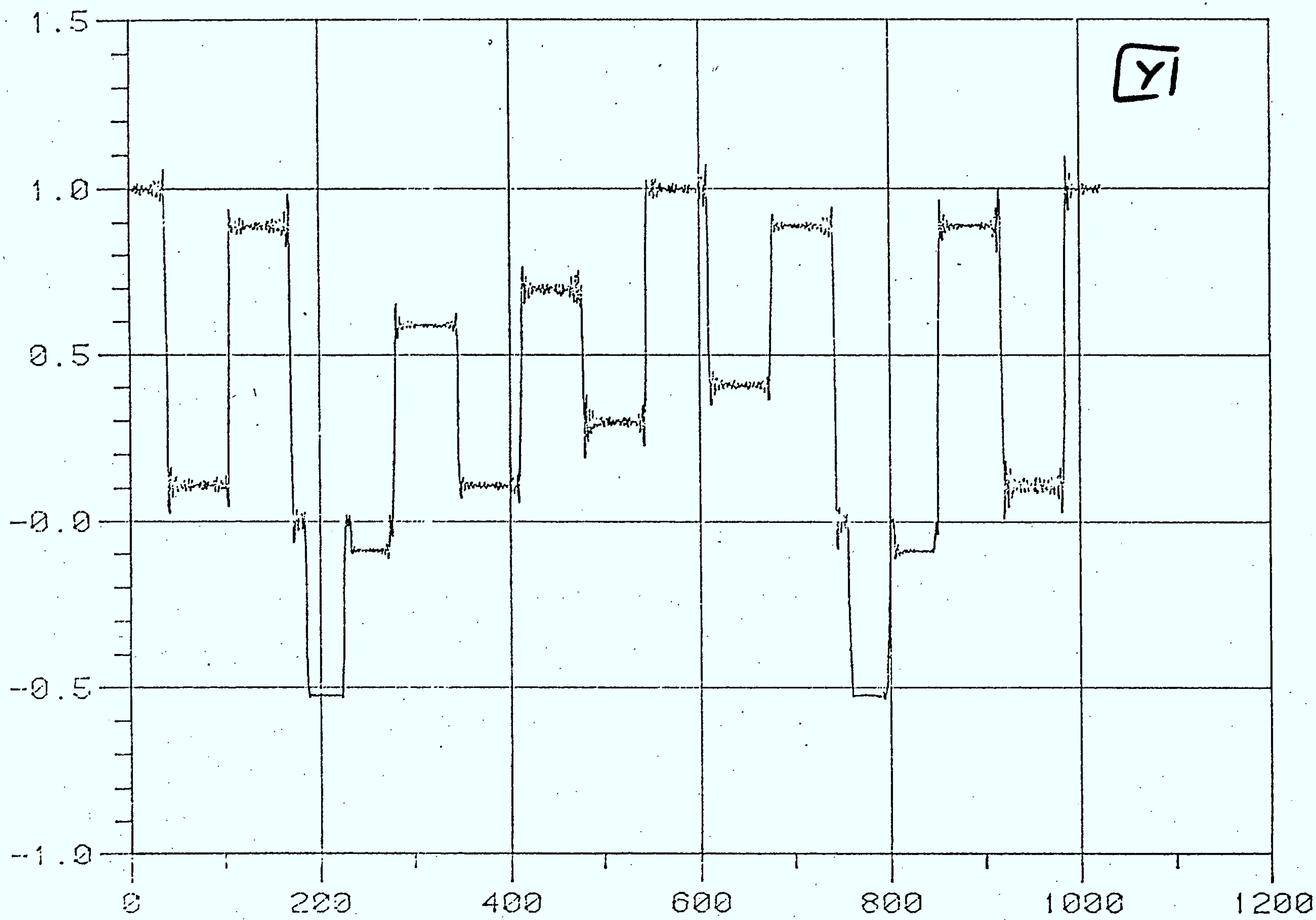


Fig III.1

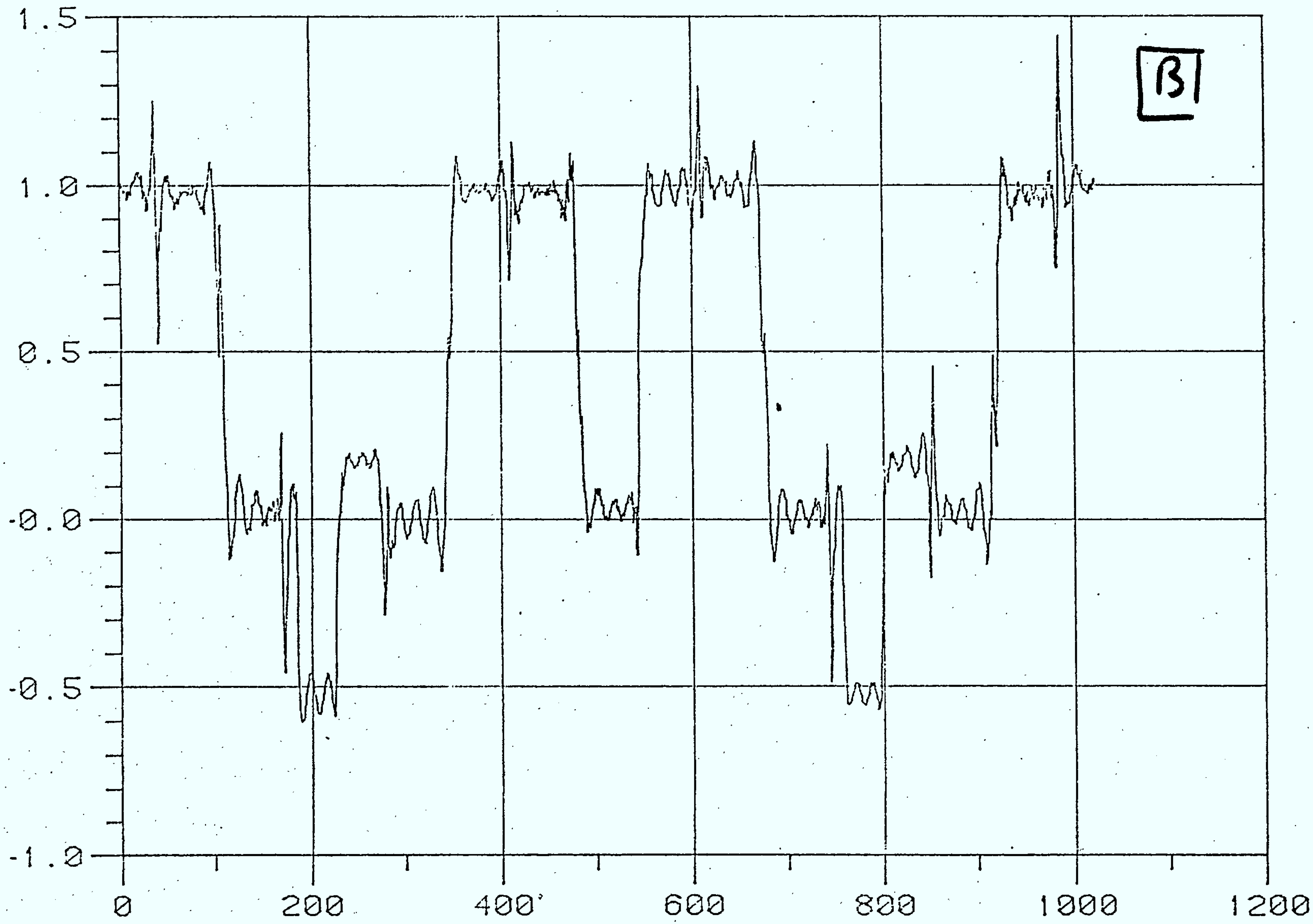


Fig III.2

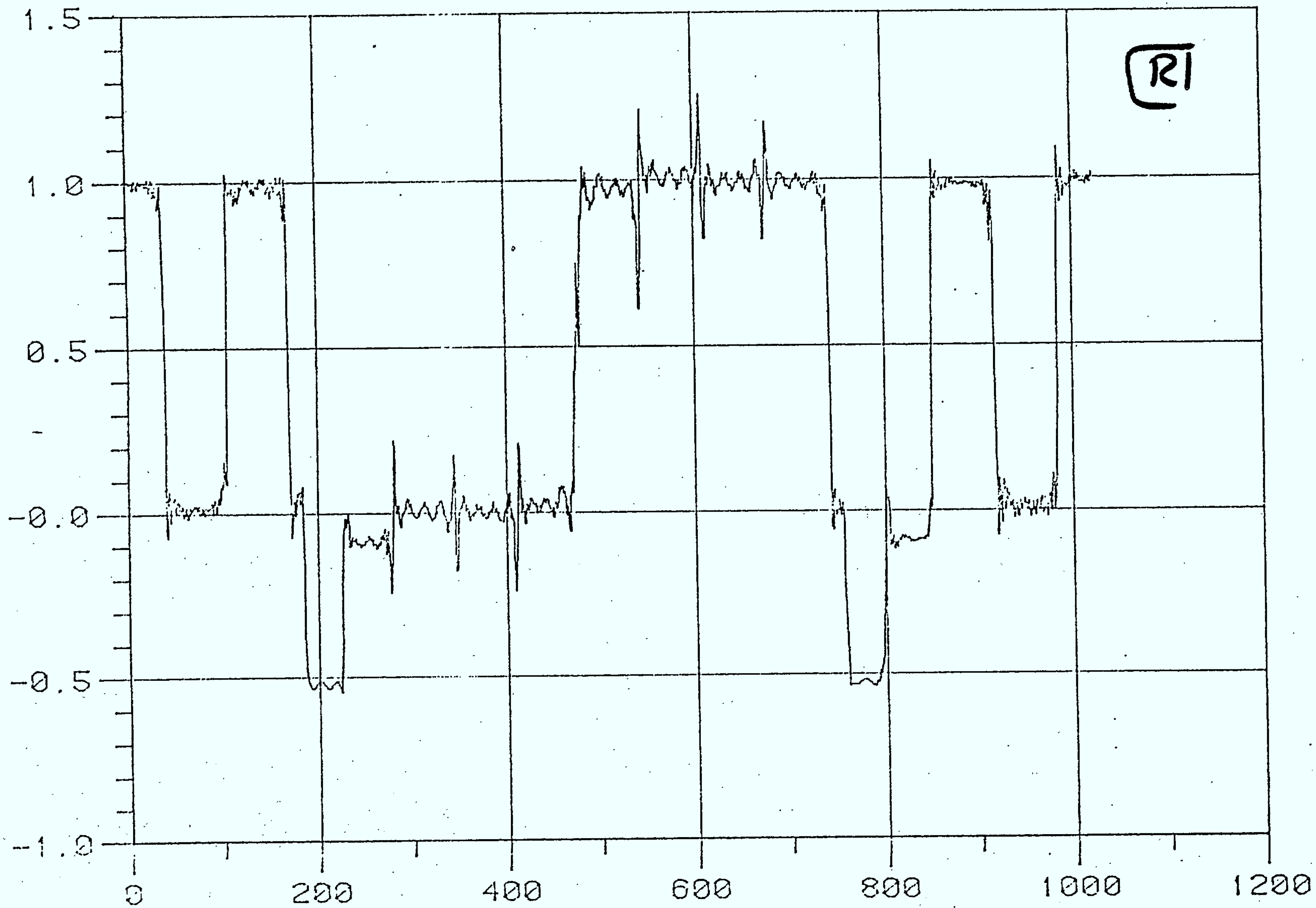


Fig III.3

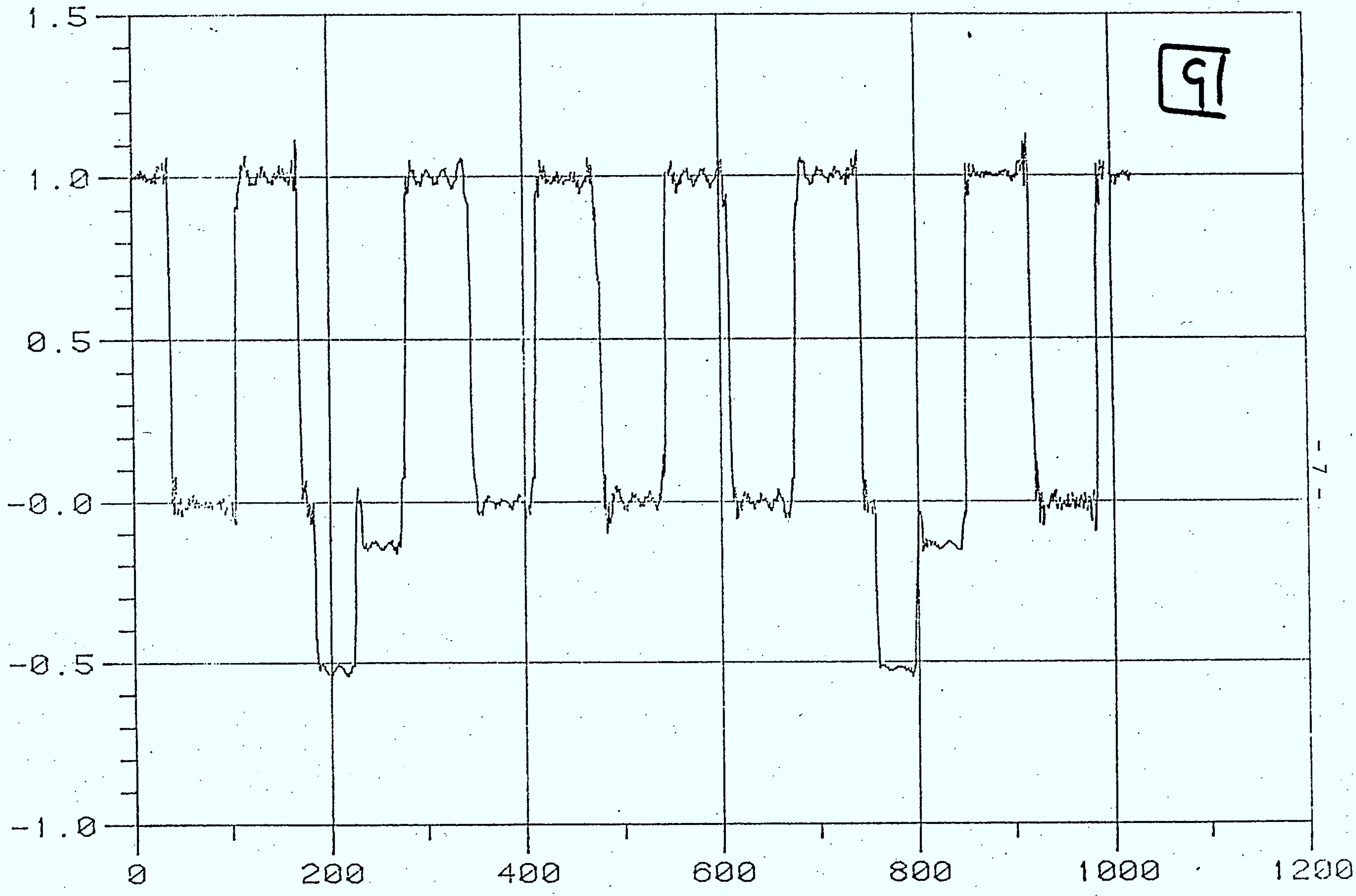


Fig III.4

(a) NSEADD which adds noise to output of TSIG

(b) DMODNSE which demodulates the noisy TV signal

(c) PLTNSE which plots the noisy signals

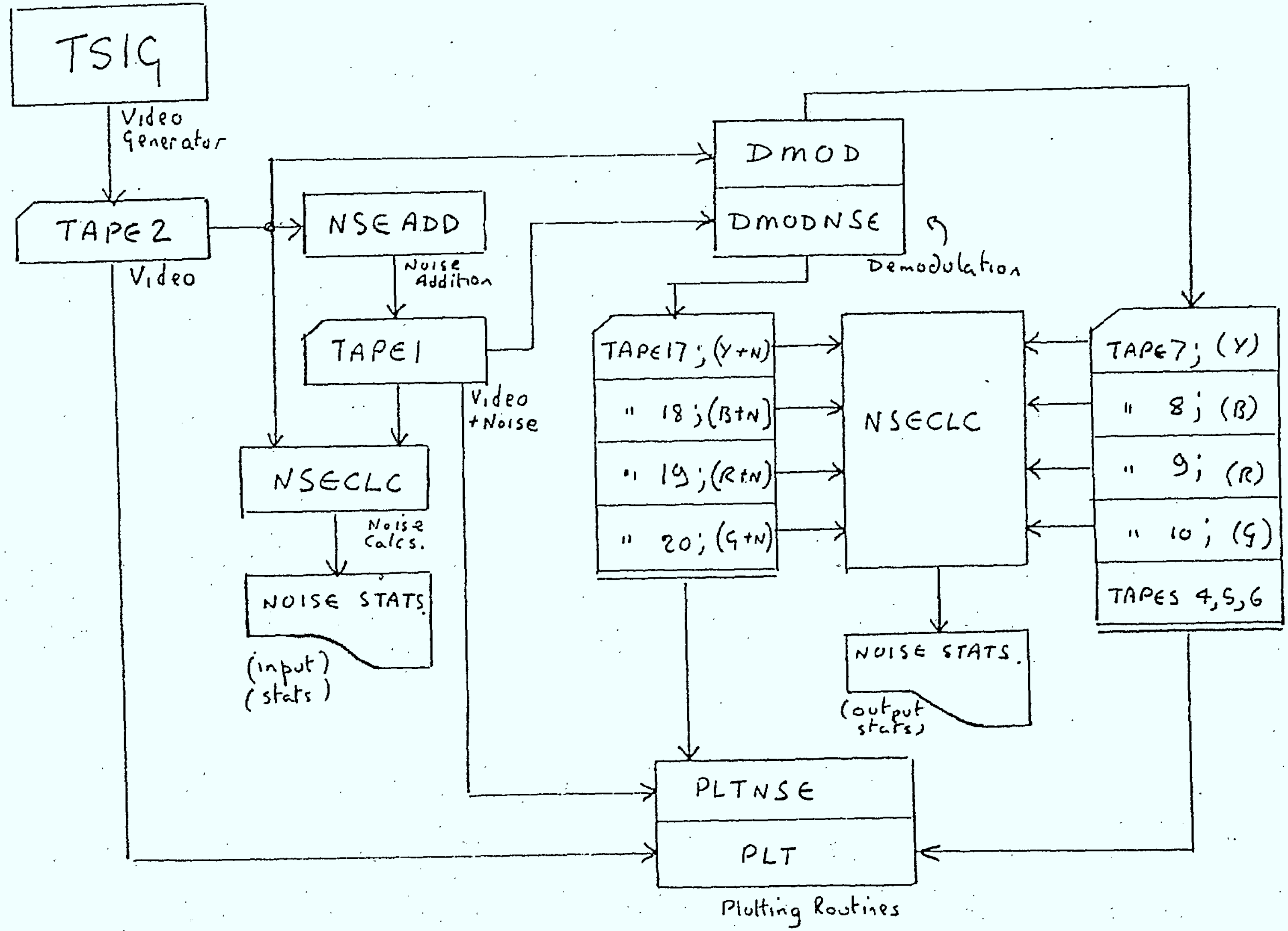
and (d) NSECLC which calculates noise statistics for input and output signals.

The inter-relationship between the various source and data files are shown in Figure III.5. This new system has been extensively checked for integrity.

The current data files are located as follows:

TABLE III.1

LOCATION	DESCRIPTION	LOCATION	DESCRIPTION
TAPE 1	video + noise	TAPE 8	B
TAPE 2	video generated	TAPE 9	R
TAPE 3	chroma demod	TAPE 10	G
TAPE 4	B - Y	TAPE 17	Y + N
TAPE 5	R - Y	TAPE 18	B + N
TAPE 6	G - Y	TAPE 19	R + N
TAPE 7	Y	TAPE 20	G + N



Television Signal Processing

Fig III.5

IV. THE NOISELESS B,R,G SIGNALS

It has been observed that demodulated noiseless blue signal B is worse (in the sense that larger amplitude of transient exists) than the red signal which is in turn worse than the green signal. This phenomenon can be explained as follows:

The luminous signal r_Y is composed of 59% green, 30% red and 100% blue, i.e.

$$r_Y = 0.11\psi_B + 0.30\ \psi_R + 0.59\ \psi_G \qquad \text{(IV.1)}$$

where ψ_B, ψ_R and ψ_G are the colour elements of unit strength corresponding to blue, red and green. Hence in the luminous signal, green is has the greatest intensity, then red and least blue. Thus it is expected that whenever green is at high intensity, the luminous signal will also be strong. This can easily be seen from comparing figures IV.1a and IV.1d where figure IV.1a shows the ideal luminous signal and figure IV.1d shows the ideal green signal. Hence, when the signal r_{G-Y} is formed after demodulation, it can be expected that this signal is relatively low in magnitude. On the other hand, the blue signal has the least contribution to the luminous signal and thus the signal r_{B-Y} will be relatively high in magnitude. The signal r_{R-Y} has, expectedly, a magnitude somewhere between r_{G-Y} and r_{B-Y}. Figure IV.1 e.f.g. shows the ideal signals r_{G-Y}, r_{R-Y} and r_{B-Y} respectively. These signals are not bandlimited.

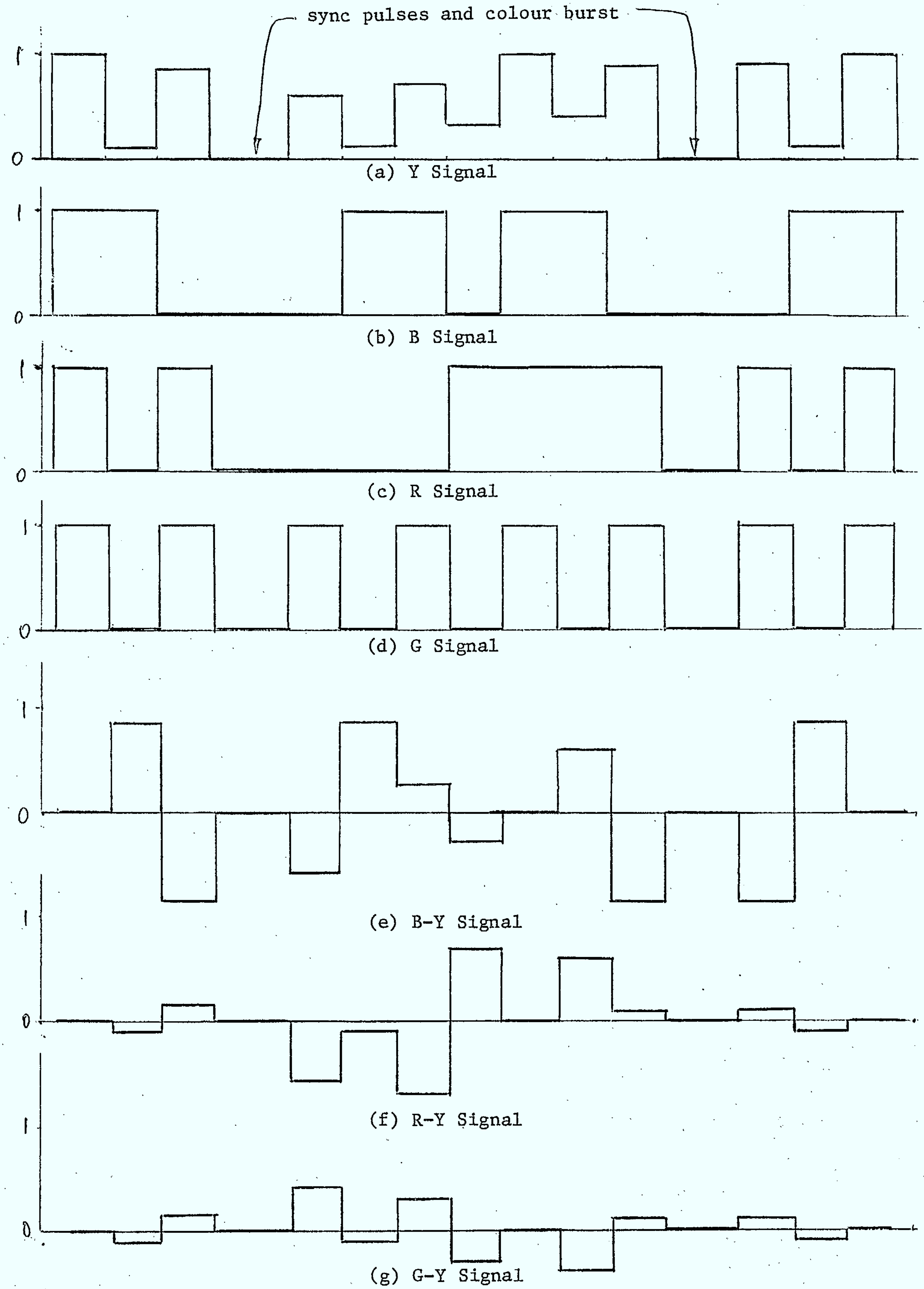


FIGURE IV.I IDEALISED TEST SIGNAL

However, during transmission and reception, the signals are bandlimited giving rise to transient "ringing". The luminous signal Y has the widest bandwidth, therefore the amplitude of the transient ringing is relatively small. The chrominance signals are much smaller in bandwidth, and thus the transient ringing is relatively larger, and the amplitudes of these ringings are proportional to the pulse amplitudes; thus the signal r_{B-Y} will have the largest ringing amplitude because of the relatively large pulse amplitude while r_{G-Y} will have the smallest (Figure IV.2 to IV.5). Since the luminous signal has a very small amplitude of ringing, the addition of the Y signal to the demodulated chrominance signals to form the blue, red and green signals will have little effect on the amplitude of ringing. Hence the blue gun will exhibit the largest transient ringing in general.

V. ANALYSIS OF NOISY RECEIVED SIGNALS FROM SIMULATION

(1) Gaussian white noise

A bandlimited gaussian white noise which is a gaussian noise process having a power-density given by

$$\mathcal{S}_n(\omega) = \begin{cases} \eta/2 & |\omega| < W \\ 0 & \text{otherwise} \end{cases} \tag{V.1}$$

The autocorrelation function $R_n(\tau)$, being the inverse Fourier transform of $\mathcal{S}_n(\omega)$, is given by

$$R_n(\tau) = \eta\, B\, \frac{\sin W\tau}{W\tau} \tag{V.2}$$

where

$$B = W/2\pi \tag{V.3}$$

Y

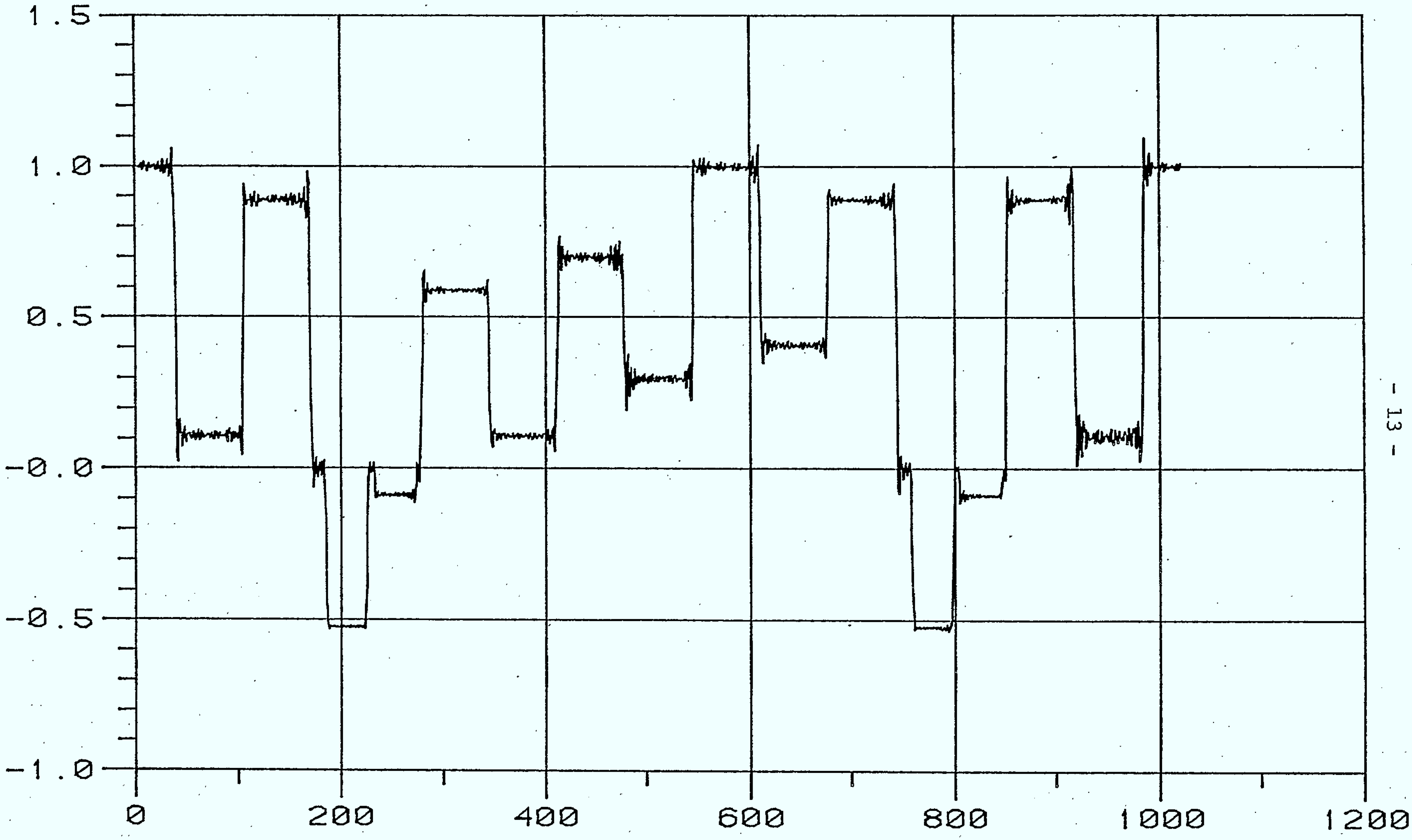


Fig IV.2 Actual Y Signal

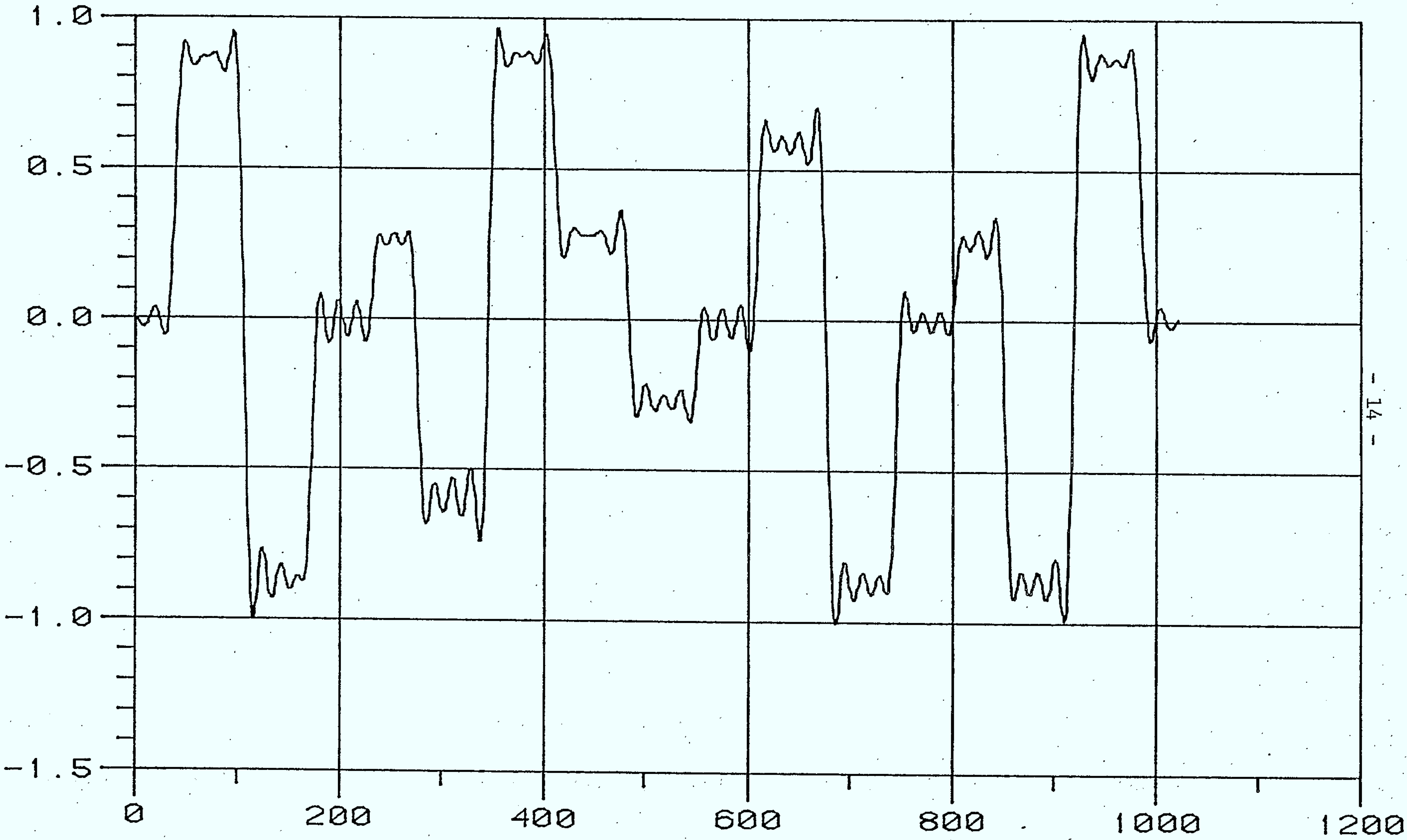


Fig IV. 3 Actual B-Y signal

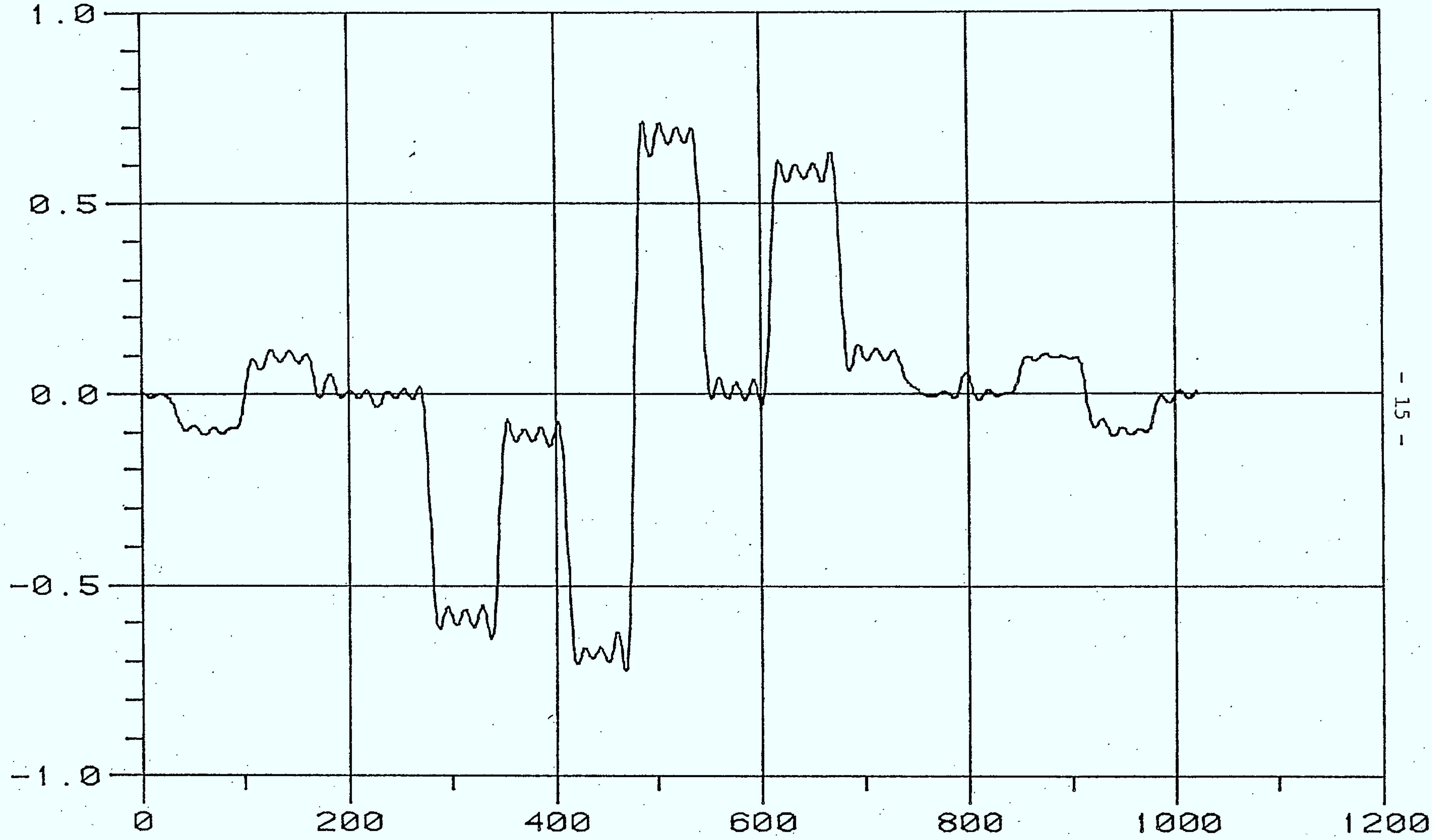


Fig IV.4 Actual R-Y Signal

G - Y

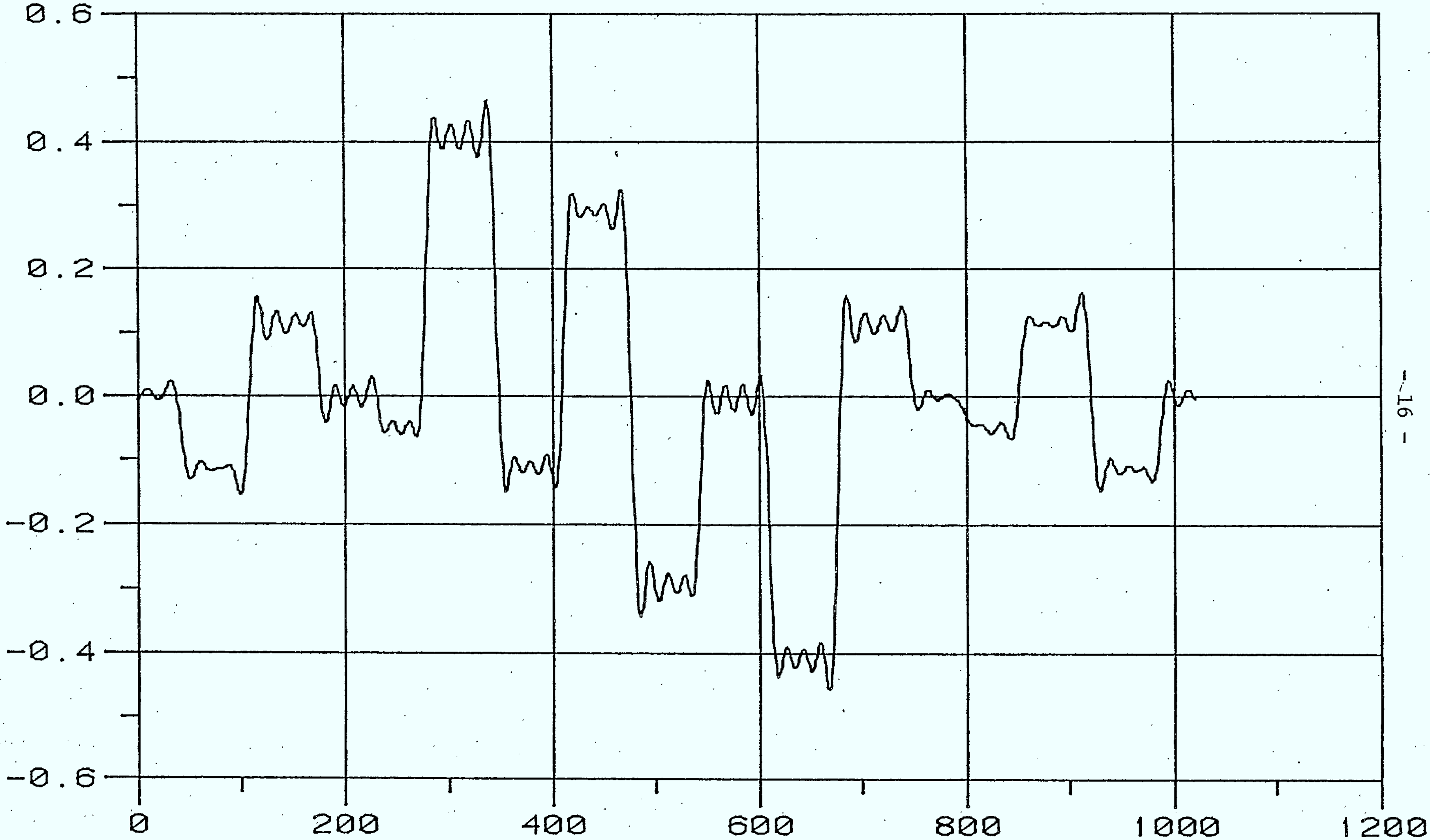


Fig IV.5 Actual G-Y signal

The power spectral density and the autocorrelation function of this process is shown in Figure V.1. The mean-square value of this process is given by

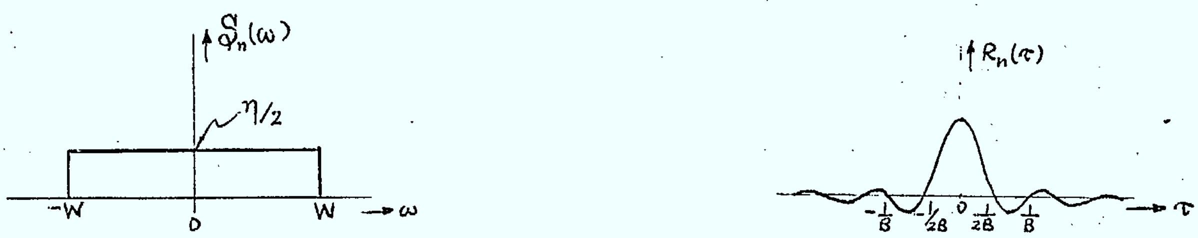
$$E[n^2] = R_n(0) = \eta B \qquad \text{(V.4)}$$

From the property of autocorrelation function,

$$\lim_{\tau\to\infty} R_n(\tau) = \{E[n]\}^2 \qquad \text{(V.5)}$$

it can be seen that this process has zero mean since

$$\lim_{\tau\to\infty} R_n(\tau) = \lim_{\tau\to\infty} \eta B \frac{\sin W\tau}{W\tau} = 0 \qquad \text{(V.6)}$$



(a) (b)

FIGURE V.1

It is observed (Figure V.1b) that the autocorrelation function for bandlimited gaussian white noise is zero for $\tau = \frac{1}{2B}$ and any integer multiple of $\frac{1}{2B}$. Hence samples taken at intervals $\frac{1}{2B}$ seconds apart are uncorrelated (and hence independent since the random variables are gaussian).

To express the noise in the output signal in terms of the input noise variance σ^2, the following analysis is performed:

It is assumed that the input video signal and the output B,R,G are all of the same maximum amplitude. The input white noise occupies a bandwidth of 0 - 4.5 MHz.

(a) <u>The luminance signal Y</u> Let f_y MHz be frequency band occupied by the Y signal. Then

$$\sigma_Y^2 = \frac{f_y}{4.5}\left(\frac{1}{0.575}\right)^2\sigma^2 = 0.67 f_y \sigma^2 \tag{V.7}$$

Now $f_y \simeq 2.68$ MHz hence

$$\sigma_Y^2 \approx 1.80\ \sigma^2 \tag{V.8}$$

(b) <u>The blue signal B</u> The (B-Y) signal is recovered by synchronous demodulation followed by LP filtering of bandwidth f_c MHz. Hence, including the system gains, the variance of noise in the (B-Y) signal is given by

$$\sigma_{B-Y}^2 = \frac{1}{2}\left[2 \times \frac{1}{0.575} \times 2.03\right]^2 \left(\frac{f_c}{4.5}\right)\sigma^2 = 5.54\ f_c\sigma^2 \tag{V.9}$$

In the simulation $f_c = 0.5$ MHz

$$\therefore\quad \sigma_{B-Y}^2 = 2.78\sigma^2 \tag{V.10}$$

Now, B is obtained from (B-Y) + Y and adding uncorrelated noise, the variance of the noise in the blue signal is given by

$$\sigma_B^2 = \sigma_{B-Y}^2 + \sigma_Y^2 = (2.78 + 1.80)\sigma^2 = 4.6\sigma^2 \tag{V.11}$$

(c) The red signal R Using exactly the same reasoning, we obtain

$$\sigma^2_{R-Y} = \frac{1}{2}\ [2 \times \frac{1}{0.575} \times 1.14]^2\ (\frac{f_c}{4.5})\sigma^2 = 1.75\ f_c\sigma^2$$

and for the red signal, we have

$$\sigma_R^2 = 0.88\sigma^2 + 1.80\sigma^2 = 2.7\sigma^2 \tag{V.12}$$

(d) The green signal G The (G-Y) signal is obtained by

$$(G-Y) = -0.19\ (B-Y) - 0.51\ (R-Y)$$

Now, the noise in (R-Y) and (B-Y) signal is uncorrelated, hence

$$\sigma^2_{G-Y} = (0.19)^2\ \sigma^2_{B-Y} + (0.51)^2\ \sigma^2_{R-Y} = 0.33\sigma^2$$

Hence

$$\sigma_G^2 = 0.33\sigma^2 + 1.80\sigma^2 = 2.1\sigma^2 \tag{V.13}$$

To verify the above theoretical consideration, a computer subroutine was written to generate uncorrelated gaussian random samples. This gaussian white noise with zero mean and standard deviation σ was injected to the transmitted TV signal. Three different noise sequences were generated and the result of each calculated. The average value of these results was evaluated and compared with the theoretical values. These are tabulated in Table V.1 and it can be seen that the agreement is marked.

Input noise $\sigma^2 = 0.25 \times 10^{-2}$

Output Noise Power	Input noise Sequence 1	Input noise Sequence 2	Input noise Sequence 3	Average	Predicted Value
$\sigma_Y^2(\times 10^{-2})$	0.43	0.47	0.46	0.45	0.45
$\sigma_B^2(\times 10^{-1})$	0.12	0.10	0.13	0.12	0.12
$\sigma_R^2(\times 10^{-2})$	0.67	0.64	0.61	0.64	0.68
$\sigma_G^2(\times 10^{-2})$	0.50	0.55	0.57	0.54	0.53

TABLE V.1

An input noise with larger variance was then added and the experiment again repeated. This led to similar agreement as before. A further experiment was performed with a white noise having a uniform probability density distribution (range -0.1 to $+0.1$). Again similar agreement was obtained. Figure V.2 - 5 show the output signal + noise in the Y,B,R,G signals respectively with the input noise being uniformly distributed between -0.1 to $+0.1$.

(2) Poisson impulsive noise

Single sample Poisson impulses with gaussian amplitude were generated by the source program NSEADD. If t is the random time interval between two impulses, then the probability density function of t is given by

$$p_t(t) = \lambda e^{-\lambda t}\ u(t) \qquad \text{(V.14)}$$

where λ is the mean number of occurences per unit time interval and u(t) is the unit step function. To generate these random points in time a uniformly distributed random variable x is chosen such that

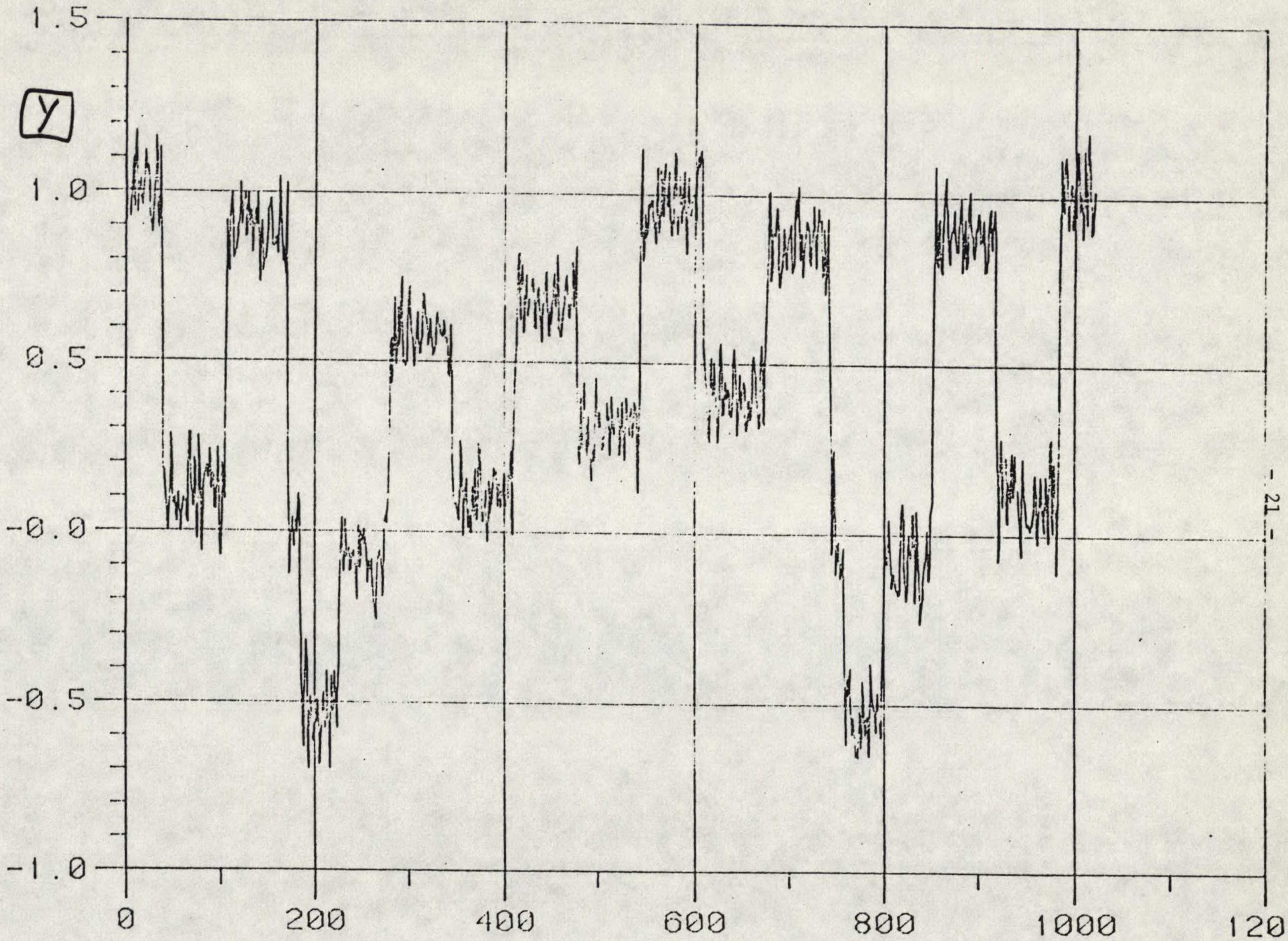


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Fig V.2 Y signal

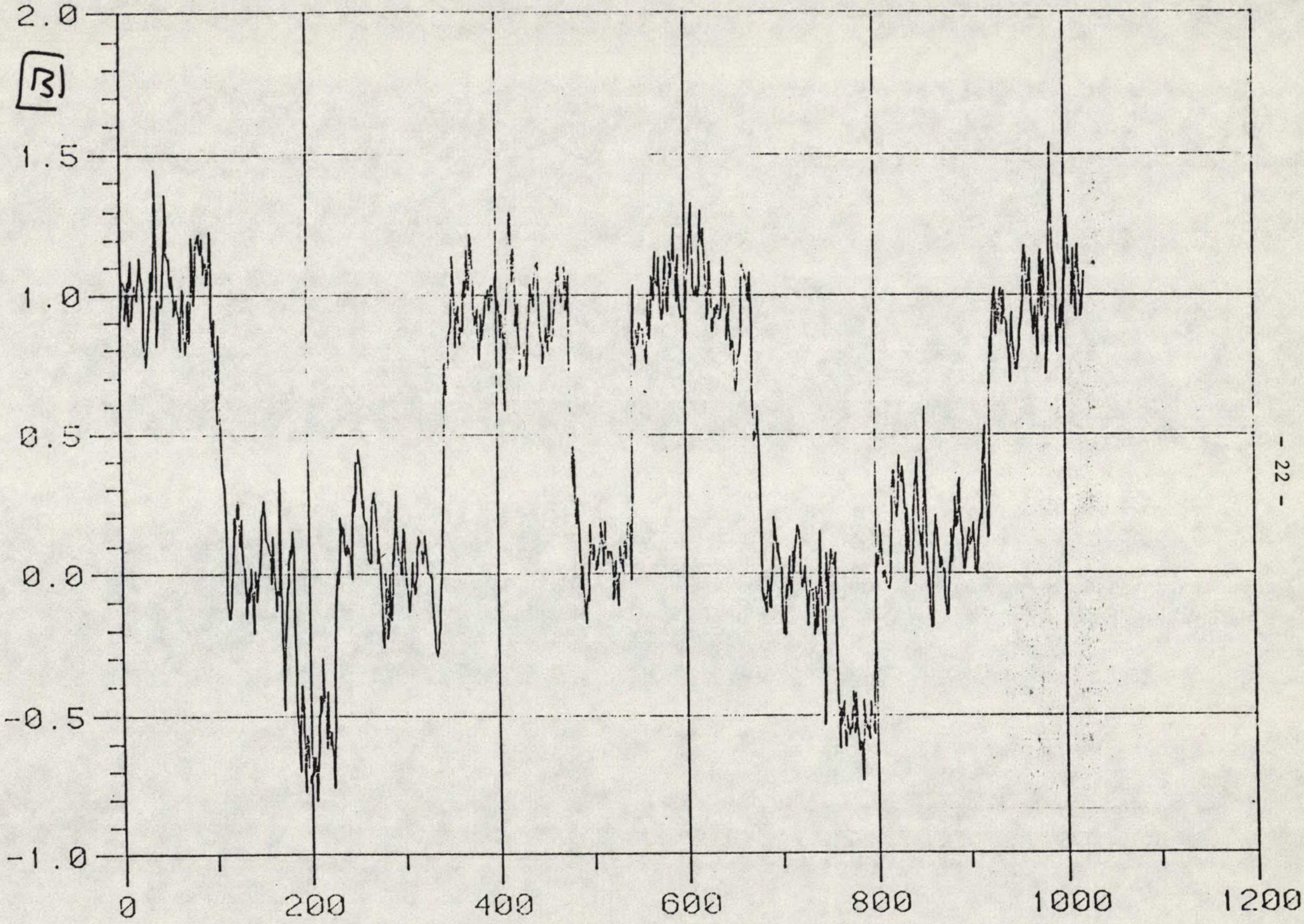

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Fig V.3 B signal

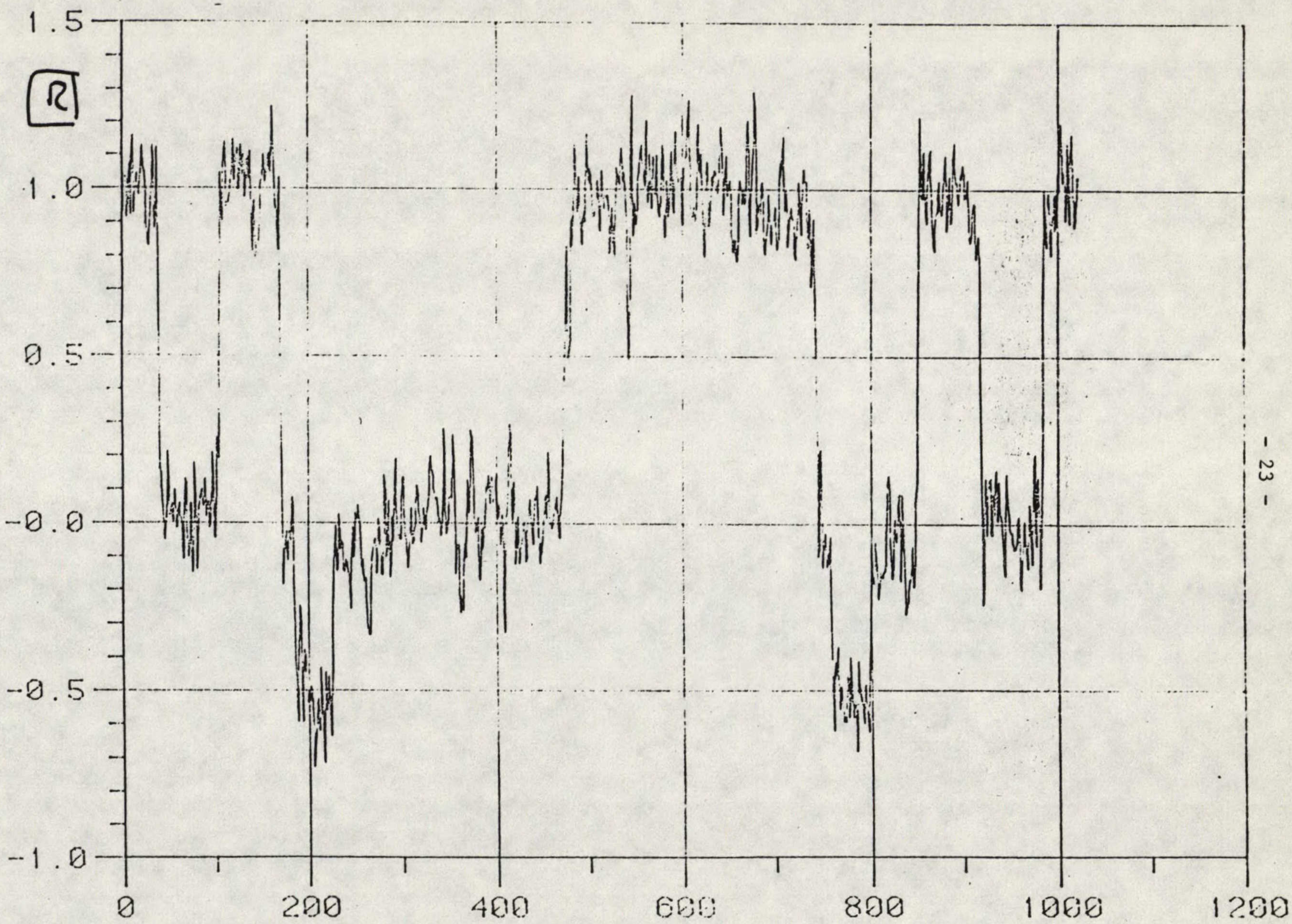

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Fig V.4 R signal

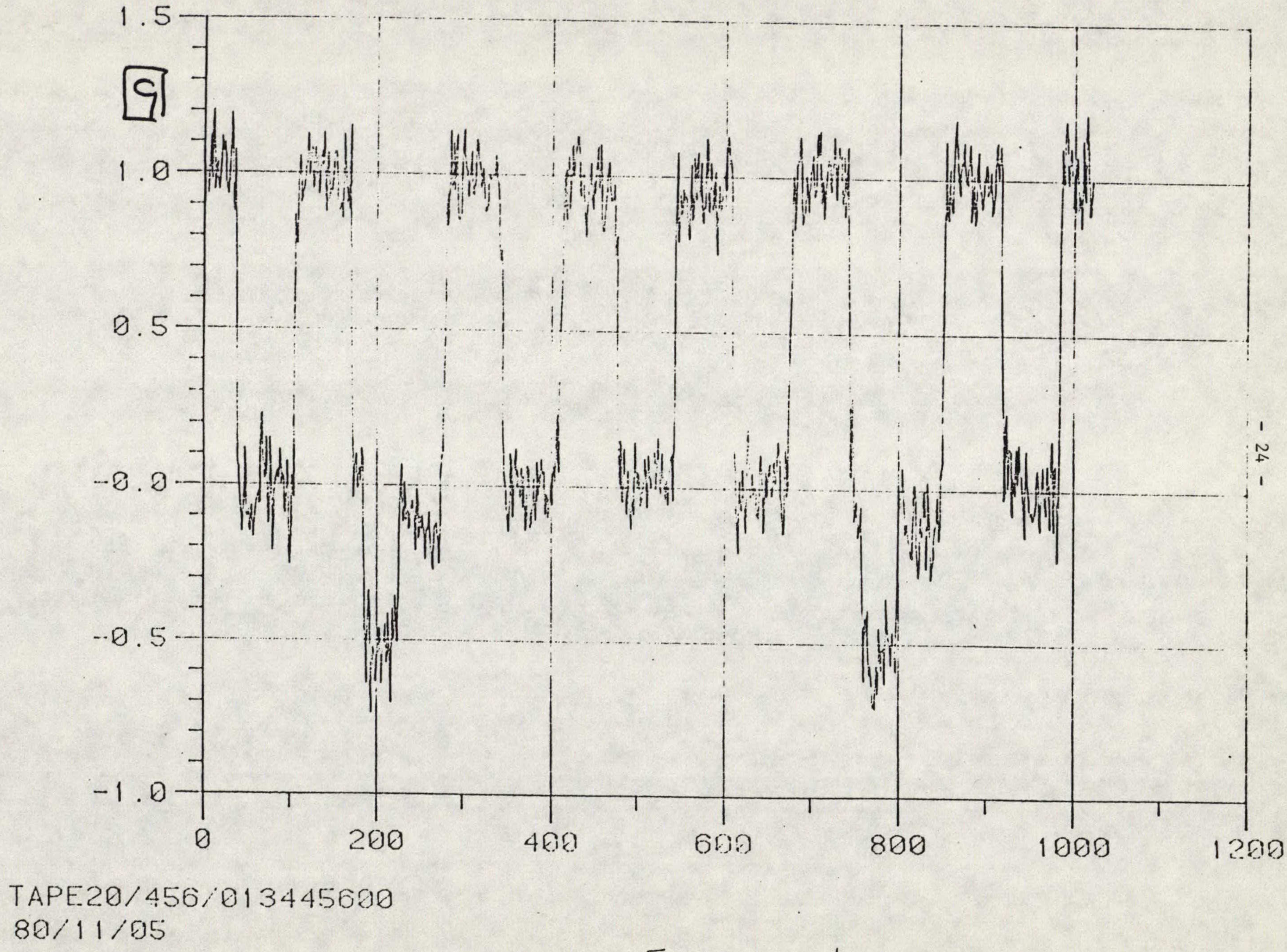


Fig V.5 G signal

$$x \in [0, 1]$$

$\therefore \quad p_x(x) = 1$

and $\quad p_x(x)dx = p_t(t)dt$

Hence
$$t = \lambda^{-1} \ln \frac{1}{1-x} \qquad \text{(V.15)}$$

This method was checked via MINITAB run and was found to be working.

A value of $\lambda = 0.2$ (i.e. an average of approximately 200 impulses in 1024 signal samples) was chosen. The variance of the impulse amplitude was set so that the total noise energy was equal to that of gaussian white noise of variance

$$\sigma^2 = 0.25 \times 10^{-2} \qquad \text{(V.16)}$$

Equation (V.16) is the same as that used in Section V.1. The results from such an input impulse noise and that of the gaussian white noise were computed and the comparison is shown in Table V.2. It is evident that the white noise and the impulsive noise results are sensibly identical.

	POISSON NOISE				Mean value with white noise as input (From Table V.1)
	1st Noise Sequence	2nd Noise Sequence	3rd Noise Sequence	Mean Value	
Input noise power ($\times 10^{-2}$)	0.27	0.24	0.25	0.25	0.25
σ_Y^2 ($\times 10^{-2}$)	0.45	0.43	0.45	0.44	0.45
σ_B^2 ($\times 10^{-1}$)	0.11	0.10	0.10	0.10	0.12
σ_R^2 ($\times 10^{-2}$)	0.74	0.57	0.63	0.65	0.64
σ_G^2 ($\times 10^{-2}$)	0.55	0.54	0.54	0.54	0.54
Actual No. of impulses	218	208	222		

TABLE V.2

Figures V.6 - 9 show the output at Y,B,R and G with Poisson impulsive noise whose amplitudes are of gaussian distribution. The input noise variance is again 0.25×10^{-2}, however the pulse occurrence rate λ is deliberately chosen to be small in order to show the effects of the individual impulses.

That the impulsive noise input and the white noise input both produce similar signal-to-noise ratios at the output signals is not in concurrence with the March 1980 report. The results here appear to be reasonable as the Poisson noise spectrum is essentially white. The source listings for the experiments of the March 1980 report are to be examined for possible errors.

(3) Spectral shaping effects

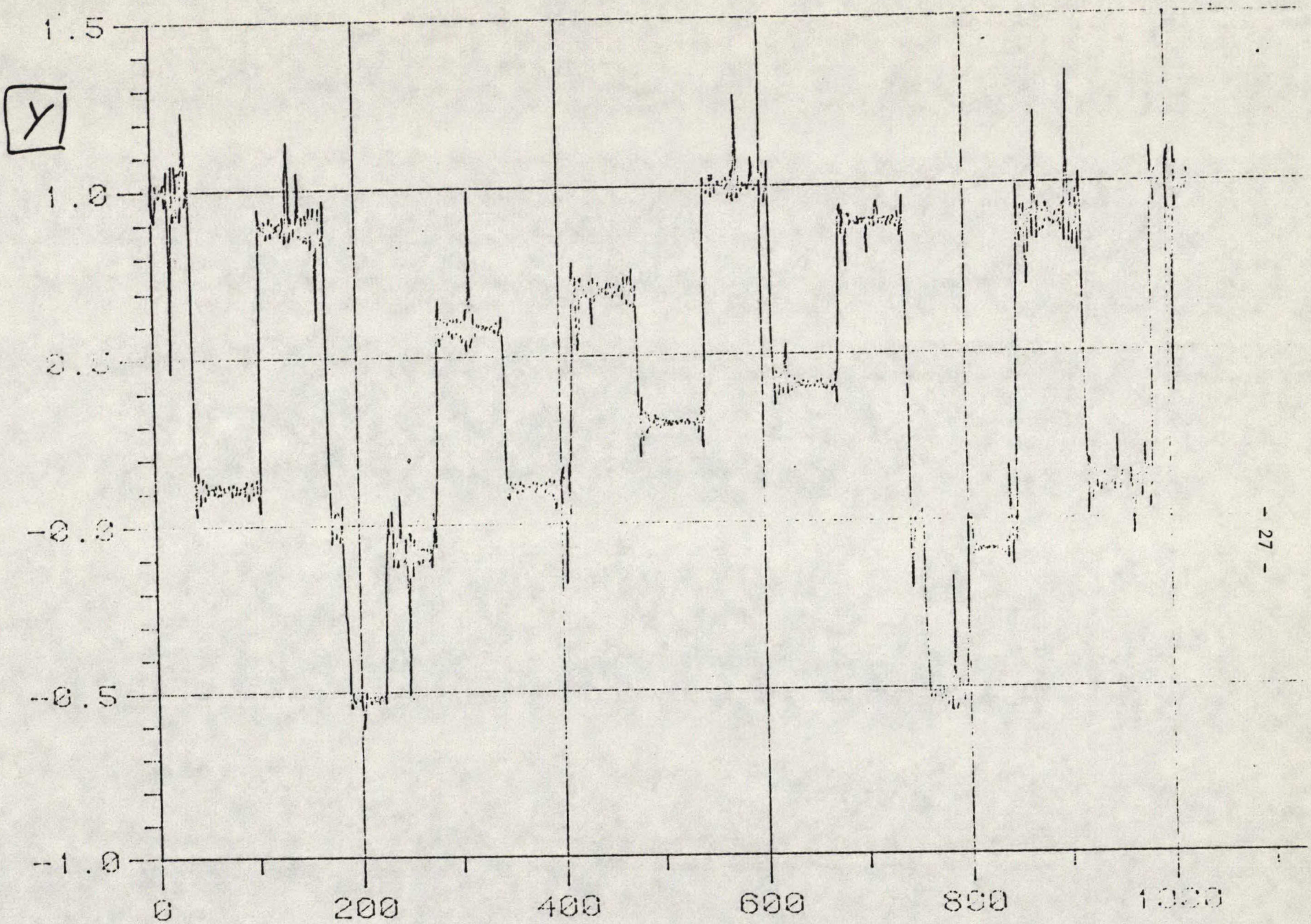
It has been shown in Section V.1 that the output noise in the three colour guns is a sum of a chrominance band contribution and a luminance band contribution. For instance, for the blue gun, we have

$$\sigma_B^2 = \sigma_{B-Y}^2 + \sigma_Y^2 \qquad (V.17)$$

Writing the figures out for each of the demodulated components, we have

$$\begin{aligned} \sigma_Y^2 &= 0 + 1.8\,\sigma^2 \\ \sigma_B^2 &= 2.8\sigma^2 + 1.8\,\sigma^2 \\ \sigma_R^2 &= 0.9\sigma^2 + 1.8\,\sigma^2 \\ \sigma_G^2 &= 0.3\sigma^2 + 1.8\,\sigma^2 \end{aligned} \qquad (V.18)$$

where the first term in each of the equations is the noise power from the chrominance band while the second term is from the luminance band.



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80/11/13 Poisson. $\lambda = 0.04$ Fig II.6
Effective $\sigma^{*} = .05$. (39 actual impulses)

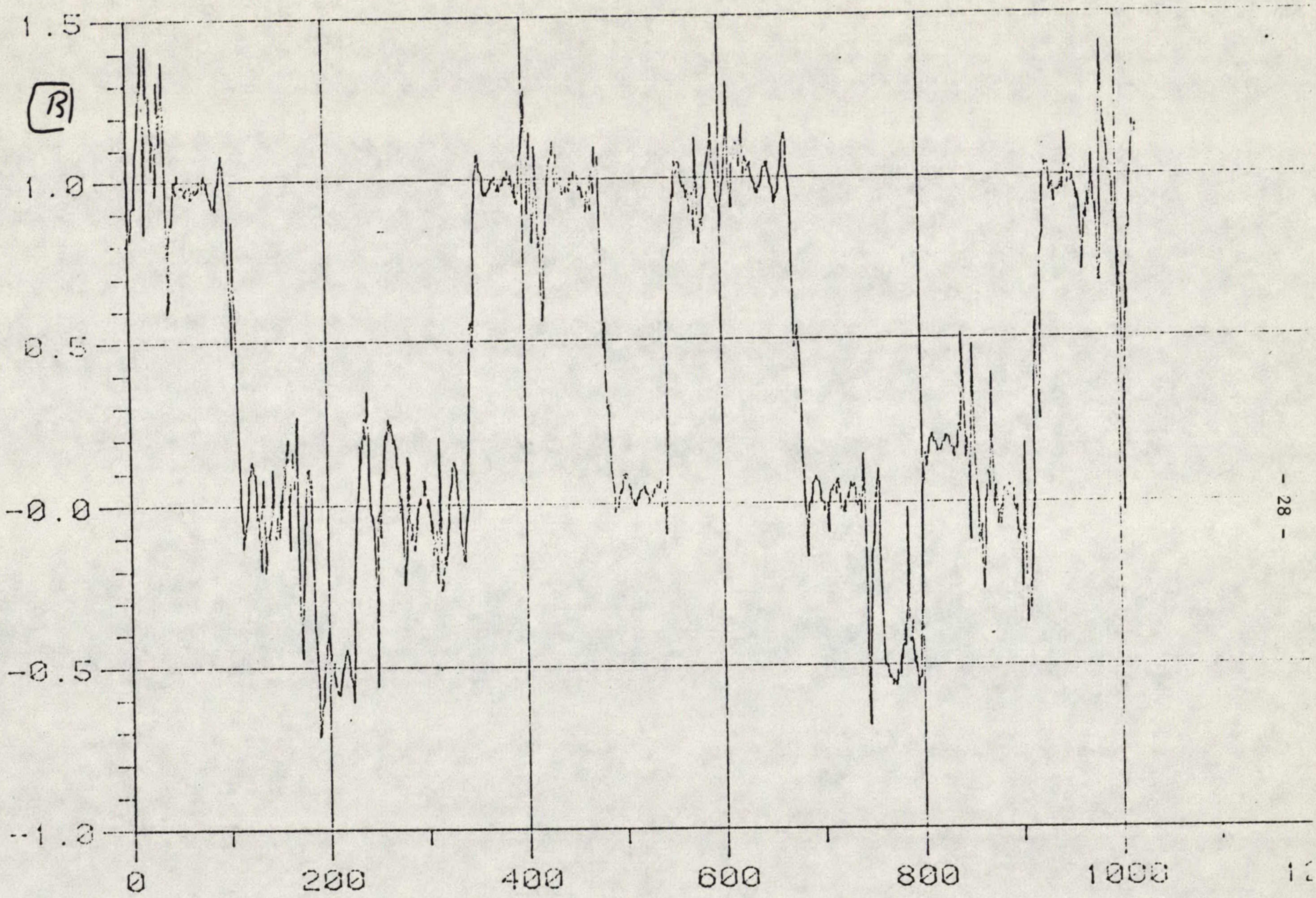

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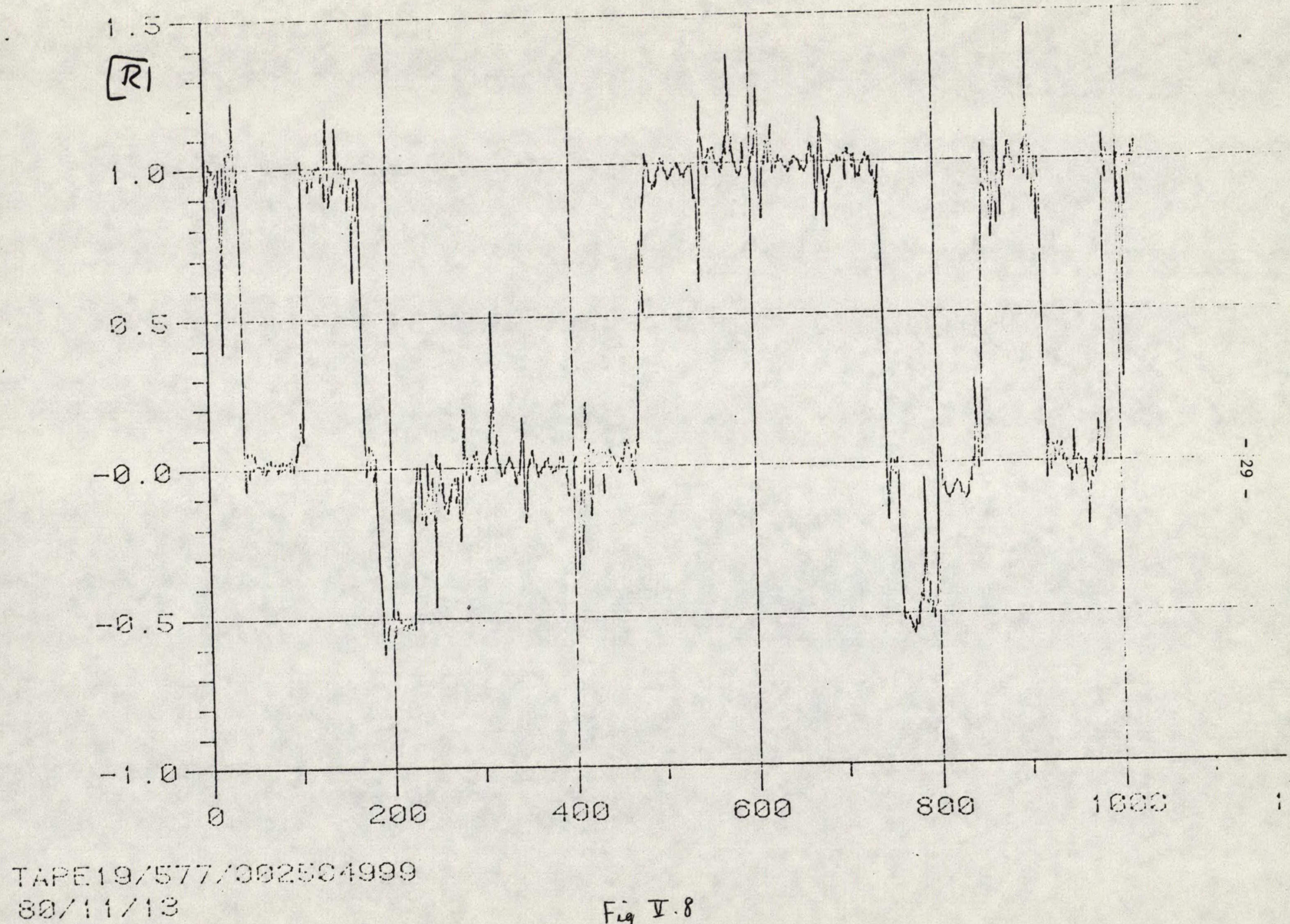
Fig V.7



[R]
1.5
1.0
0.5
-0.0
-0.5
-1.0
0
200
400
600
800
1000
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80/11/13

Fig V.8

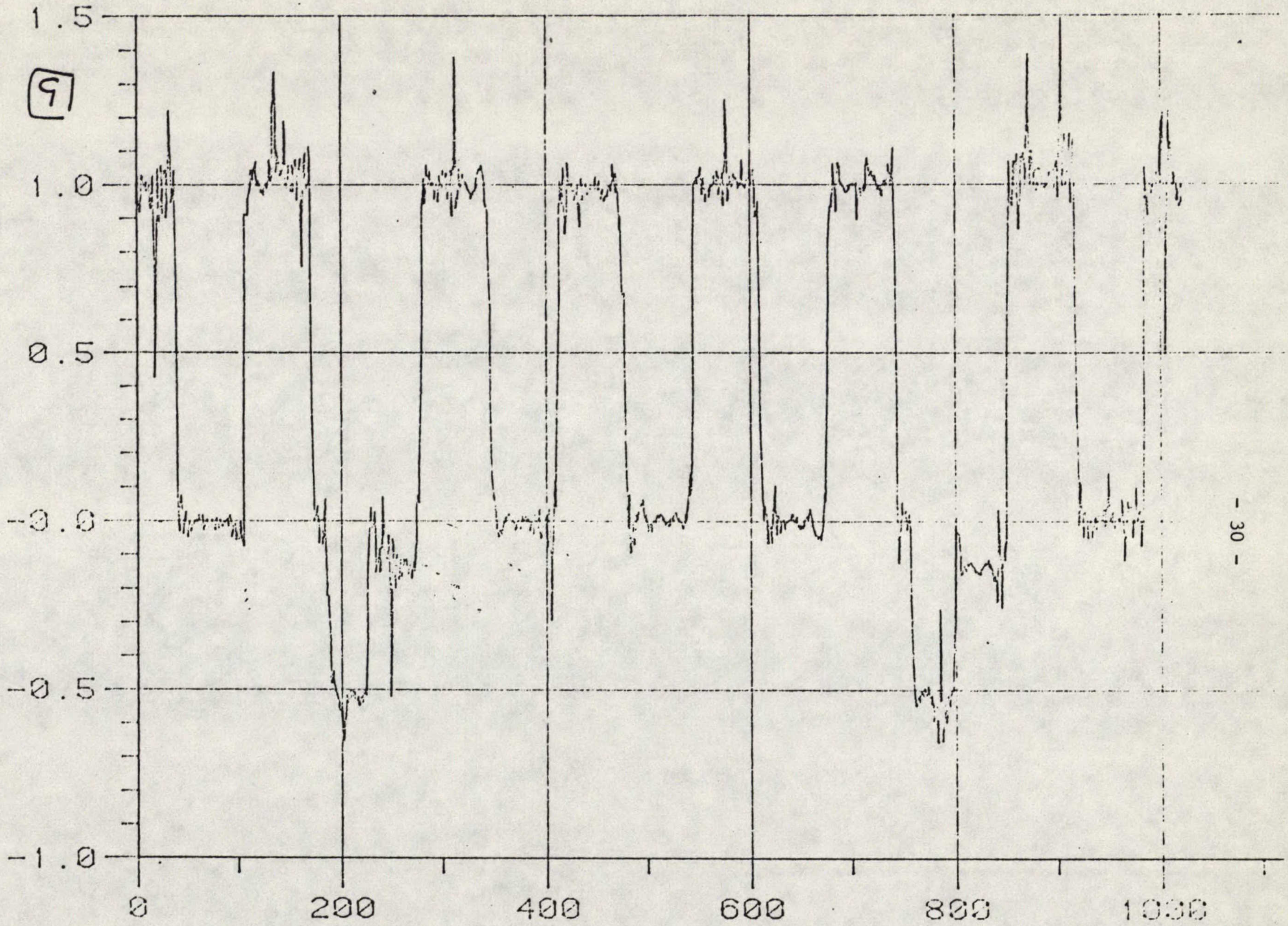

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Fig V.9

The effect of spectral shaping the input noise can be seen from the consideration of the following two cases:

(a) No luminance noise - Here $\sigma_Y^2 = 0$ and hence

$$\begin{aligned} \sigma_B^2 &= 2.8\ \sigma^2 \\ \sigma_R^2 &= 0.9\ \sigma^2 \\ \sigma_G^2 &= 0.3\ \sigma^2 \end{aligned} \qquad (V.19)$$

where σ^2 refers to the input noise prior to prefiltering. In this case, the output noise in the different signal components are all different. This case corresponds, roughly, to the case when the input noise spectrum increases with frequency.

(b) No chrominance noise - Here the first terms in σ_B^2, σ_R^2 and σ_G^2 in equation (V.18) are all zero, and hence

$$\sigma_Y^2 = \sigma_B^2 = \sigma_R^2 = \sigma_G^2 = 1.8\sigma^2 \qquad (V.20)$$

Thus in this case there is no difference between any of the output noise powers. This case corresponds, roughly, to the case when the input noise spectrum decreases with frequency.

The above results are in accord with the observations in the report of March 1980.

(4) Finite width Poisson pulses

If the unit sample impulses used in Section V.2 were extended to a finite duration, in particular if the pulses were triangularly shaped and of three samples wide, the relative weights being (1,2,1), then this amounts to the shaping of the noise spectrum in the video band. In order to examine this more closely, the current software simulation was modified (via NSEADD) to insert simple Poisson distributed pulses of width 3, and gaussian amplitudes. The realtive weights of the pulse samples were (1,1,1) in the first experiment and (1,-1,1) in the second.

Experiment 1 - With the (1,1,1) type pulses, the average input noise power spectrum is of the $\mathrm{sinc}^2(x)$ form (repeated, of course at a frequency interval of 9 MHz due to the sampled nature of the signal). This shape is sketched in Figure V.10.

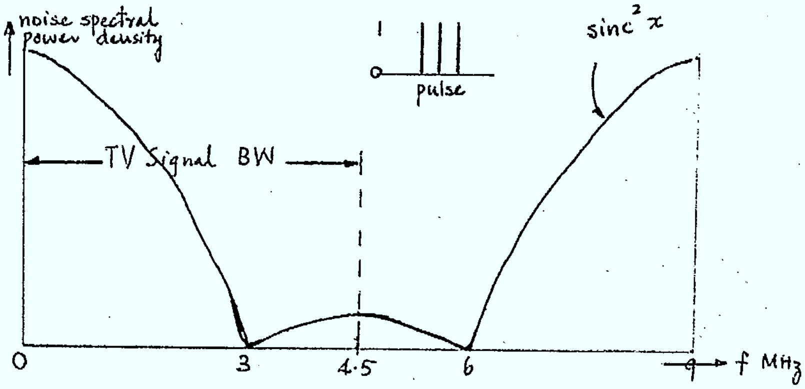

FIGURE V.10

It is obvious that the noise in the luminance band is much larger than in the chrominance band. Hence, using the reasoning of Section V.3, we should expect the output noises in Y,B,R and G to be relatively close in the value of their power.

Four runs were made with $\lambda = 1/16$ (i.e. approximately 60 pulses in 1024 samples of signal), fixed noise power, but with different noise realisations. The results are shown in Table V.3. Also included are the results from Section V.3 with white Poisson impulses for comparison. It is obvious that the (1,1,1) type of Poisson pulses do infact generate Y,R,B,G output noises which have very little difference in noise power.

POISSON PULSES (1,1,1)						White Poisson Impulses Sec. V.2
	1st Sequence	2nd Sequence	3rd Sequence	4th Sequence	Mean Value	
Input Noise $\sigma^2(\times 10^{-2})$	0.20	0.19	0.18	0.22	0.20	0.25
$\sigma_Y^2(\times 10^{-2})$	0.58	0.53	0.47	0.63	0.55	0.44
$\sigma_B^2\ (\times 10^{-2})$	0.65	0.52	0.54	0.68	0.60	1.0
$\sigma_R^2\ (\times 10^{-2})$	0.63	0.49	0.51	0.64	0.57	0.64
$\sigma_G^2\ (\times 10^{-2})$	0.57	0.59	0.47	0.64	0.57	0.54
	63 pulses	67 pulses	62 pulses			

TABLE V.3

Experiment 2 - In this experiment, the central element in the noise pulse was inverted to give a (1, -1, 1) noise pulse. Its spectrum is of the same shape and total energy as in experiment 1 but shifted in frequency as shown in Figure V.11.

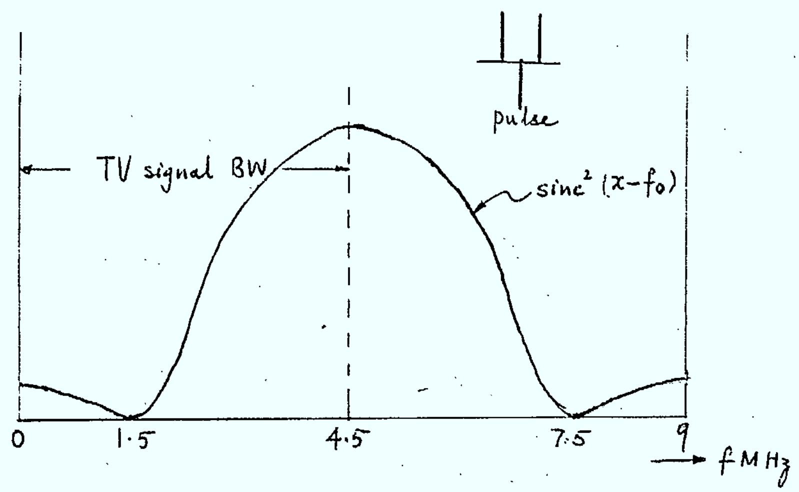

FIGURE V.11

Thus, the role of noise in the luminance and chrominance bands are reversed, there being much higher noise energy density in the chrominance band than in luminance band. Again using the same reasoning as in Section V.3, the Y,B,R, and G noise powers are expected to exhibit large differences. The results of four experimental runs are shown in Table V.4

	POISSON PULSES (1,-1,1)					White
	1st Sequence	2nd Sequence	3rd Sequence	4th Sequence	Mean Value	Poisson Impulse Section V.2
Input Noise σ^2 ($\times 10^{-2}$)	0.20	0.19	0.18	0.20	0.19	0.25
σ^2_Y ($\times 10^{-3}$)	0.73	0.72	0.74	0.87	0.77	4.4
σ^2_B ($\times 10^{-2}$)	1.1	0.90	0.92	1.3	1.10	1.0
σ^2_R ($\times 10^{-2}$)	0.55	0.37	0.51	0.44	0.47	0.63
σ^2_G ($\times 10^{-2}$)	0.20	0.28	0.21	0.22	0.23	0.54

TABLE V.4

In summary, we can say that spectral shaping of the input noise has a marked effect on the Y,R,B,G output noise levels. A bar-chart for the two types of Poisson noise pulses used here i.e., (1,1,1) and (1,-1,1) is given in Figure V.12 which is based on the average figures from Experiments 1 and 2.

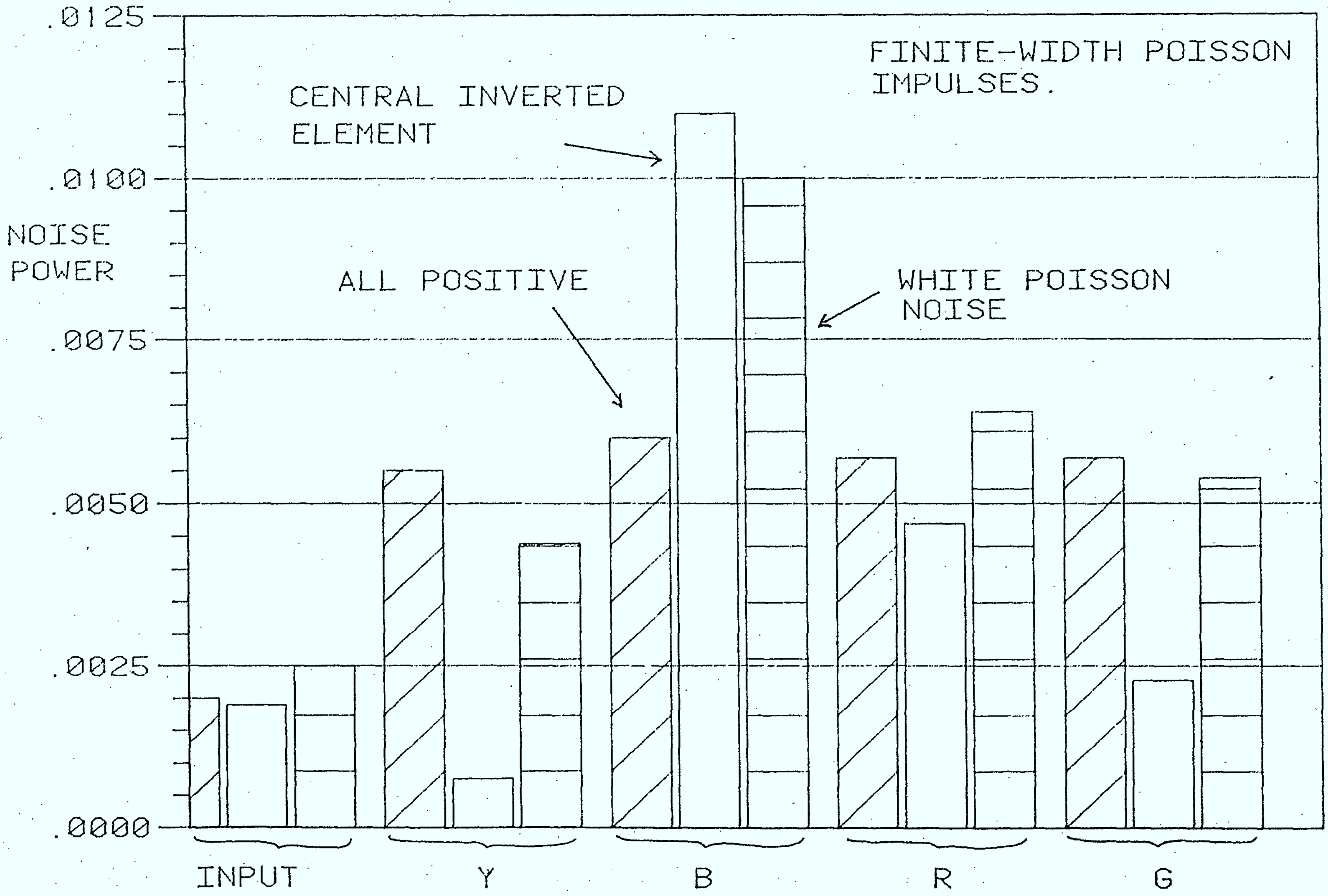
.0125
.0100
.0075
.0050
.0025
.0000
NOISE POWER
FINITE-WIDTH POISSON IMPULSES.
CENTRAL INVERTED ELEMENT
ALL POSITIVE
WHITE POISSON NOISE
INPUT
Y
B
R
G

Fig V. 12

VI. DISCUSSIONS AND CONCLUSIONS

(1) Summary

The computer simulation program has been modified slightly to suit the purpose of the investogators. Observations from the result of simulation confirms that the blue signal, even under noiseless conditions, exhibits the largest amplitude of transient oscillation while the green signal shows the least. An analysis was carried out and the reason for this phenomenon was established. Then, using the computer simulation program, several types of experiments were performed, and the results analysed. In contrast to the results reported in March 1980, the Poisson impulses exert similar degree of destruction to the output signals as the white gaussian noise. It is found to be reasonable from the consideration of the noise spectrum. The likely error in the report of March 1980 came from the choice of parameters in generating gaussian noise impulses. Then the spectral shaping of the input noise was considered and different computer experiments were carried out confirming the theory of spectral shaping developed here. This is also found to be in accordance with the report of March 1980.

(2) Future work

Due to the change in the time schedule, the subjective tests originally intended to be carried out could not be performed. Since TV viewing is fundamentally a subjective opinion, these tests have to be carried out if any meaningful conclusions are to be drawn.

Meanwhile, the computer simulation program serves as a valuable means of understanding the transmission and reception procedure in a TV system. One of the most important results discovered using the simulation program is that different colour signals are affected differently. This result can be investigated further. Work is, at present, being done to evaluate the probability of a colour signal being transformed into a different colour due to the interference of noise. This, when completed, will serve as a valuable course of information for the change in chrominance in a TV signal.