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Contribution to the method of flow light level TV system measurement

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This paper presents the method of low light level television system (LLL TV) measurements. LLL TV system consists of an optical coupling screen (by means of demagnifying fiber optics) of a 2nd generation image intensifier and a CCD. Investigation of such a system includes the measurement of transfer characteristics, *S/N* ratio, MTF and limiting resolution. In order to study the temporal and structural noise present in the LLL TV system, a digital oscilloscope TEKTRONIX 2430A was applied which also helped to process the digitalized videosignals.

1. Introduction

The paper presents the method of low light level TV system measurement. Such a system is applied in astronomy and other fields of science and technology. It is based on CCD TV camera operating at the sensor illumination level of about 1 Lx. The CCD element is connected to a 2nd generation image intensifier screen through fibre optics (taper). This enables image scanning at a level of 1 mLx on the scene. The transfer characteristics, *S/N* ratio, MTF has been studied and analysis of the videosignal digitalized by a TEKTRONIX 2430A oscilloscope is presented.

2. Elements of low light level TV system

2nd generation microchannel image intensifier

The microchannel image intensifier is equivalent to XX1500 PHILIPS Image Intensifier and consists of:

- S–25 photocathode,
- P–20 screen,
- photocathode sensitivity 230 μA/1 m,
- input window diameter: 18 mm.

Fibre optics and CCD

The taper as well as CCD, NXA 1011 type, have been supplied by the Photonic Science:

– number of pixels: $2 \times 288 \times 604$,
– pixel dimensions: $A = 156 \times 10^{-12}$ m^2,
– accumulation time: $t = 19.5 \times 10^{-3}$ s,
– taper demagnification: $M = 2.3$,
– experimentally determined detection of CCD output circuit: $P = 6–7.5$ μV/electron,
– photometric efficiency: $\tau = 0.15$,
– PHILIPS monochrome imaging module, type 56470 (this is a CCD television camera for normal use with daylight illuminance level).

3. Study of the low light level TV system

The assembly for TV system measurement (for TV system section refer to Fig. 1) is presented in Fig. 2. Hereafter the TV system shall be referred to as intensifier (I) ICCD camera (CICCD).

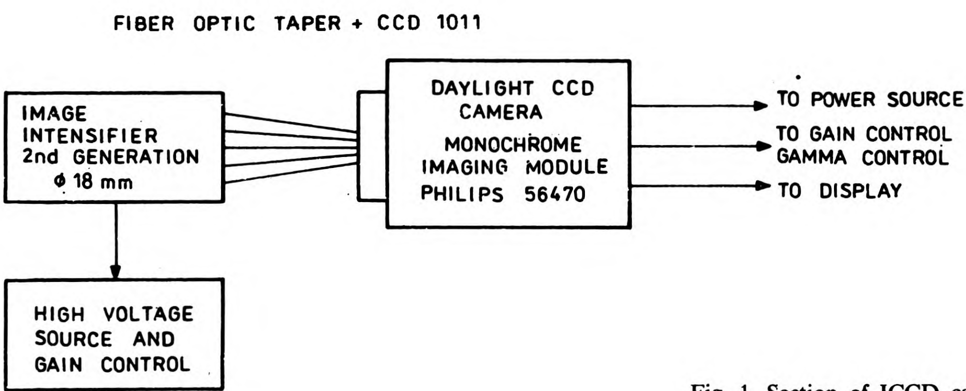

Fig. 1. Section of ICCD camera

The TEKTRONIX 2430A digital oscilloscope communicated via GPIB bus-bar with PC AT. Digitalized courses of TV lines were filed and subjected to digital analysis.

The videosignal represents four black and three white stripes of 0.5 MHz spatial frequency and 100% contrast. These stripes are sectioned from a signal line and are presented in Fig. 3 and Fig. 4 as the results of two different modes of oscilloscope measurements. Figure 3 demonstrates the presence of signal fluctuation due to photon noise, when illuminance of photocatode is $E_{PHOT} = 1.6 \times 10^{-4}$ Lx. Figure 4 shows the effect of the AVERAGING mode of the TEKTRONIX 2430A. The value of S_{CICCD}(mV) signal is determined by reading out the voltage levels between

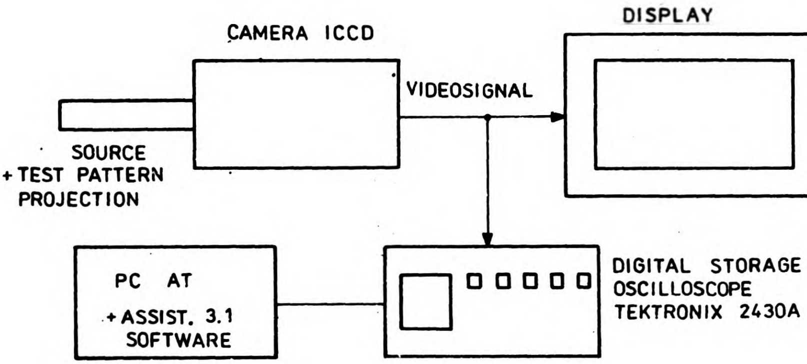

Fig. 2. Assembly for TV measurement

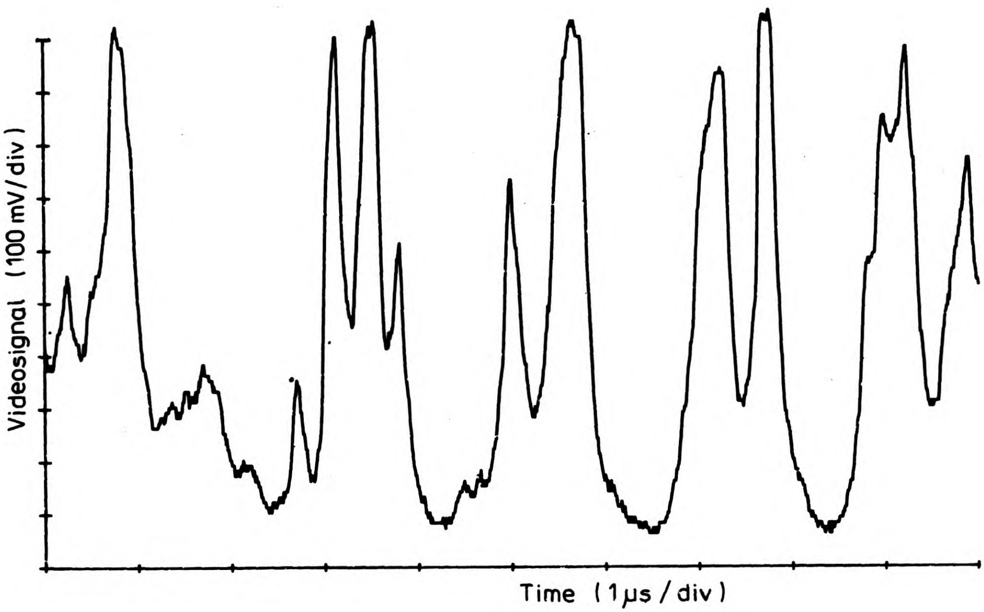

Fig. 3. Photon noise on digital oscilloscope display in the measurement of CICCD signal with 0.5 MHz test pattern

the black and white signal levels (white has a higher videosignal voltage level). ENVELOPE mode of the TEKTRONIX 2430A makes it possible to measure the peak-to-peak noise voltage of the videosignal, thus determining the root mean square (RMS) of the noise voltage present in the videosignal. In this mode, each time when signal from the selected line section is acquired and digitalized, the oscillo-

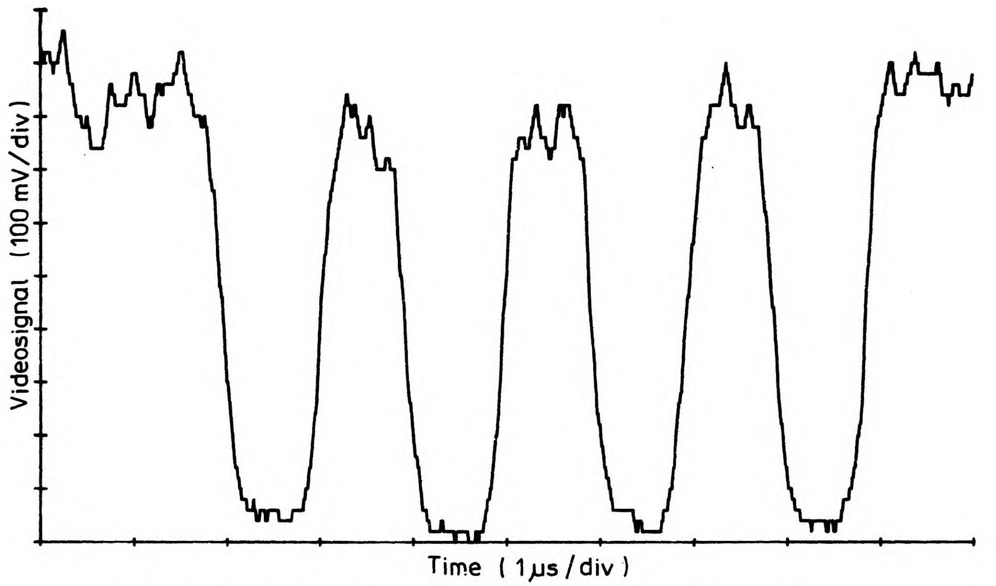

Fig. 4. Elimination of photon noise from videosignal with AVERAGING mode using TEKTRONIX 2430A digital oscilloscope

scope determines maximum and minimum values for every point corresponding to the sampling step. It is a case of any chosen number of acquisitions, which was 64. On the assumption that the noise present in the videosignal is of Gaussian type, the noise amplitude at every point and every acquisition may be described by a normal distribution. For normal noise distribution the standard deviation N_{RMS} of a noise amplitude is calculated from the maximum (N_{MAX}) and minimum (N_{MIN}) values of the noise amplitudes of all the acquisitions, as follows [1]:

$$N_{RMS} = \frac{N_{MAX} - N_{MIN}}{\beta} . \tag{1}$$

The constant β was determined by computer simulations of a normal process for 64 events. Taking into account 18 simulations, $\beta = 4.5$ was found with an error $\sigma = 0.39$.

3.1. ICCD module signal and noise

ICCD module signal was calculated using the measured transfer characteristics of the image intensifier between photocathode illuminance E_{PHOT} and energetic (or photometric) luminance of the screen. The relation for the calculation of ICCD module signal is as follows:

$$S_{ICCD} = aL_v KM^2 \tau R_{CCD} \tag{2}$$

where:

S_{ICCD} – ICCD signal voltage measured at any of the CCD outputs,

a – factor of angular distribution of luminescent screen radiation ($a = \pi$ for Lambert's distribution), estimated to be 2.0,

L_v – screen photometric luminance (cd m^{-2}), determined by the transfer characteristics of the image intensifier,

L_e – screen energetic luminance (W m^{-2} sr^{-1}), determined by the transfer characteristics of the image intensifier,

K – transfer factor between L_v and L_e, determined experimentally by measuring L_e and L_v of the screen image intensifier at identical illumination of the photocatode:

$$K = \frac{L_e}{L_v} = 2.41 \times 10^{-3} \left[\frac{\mathrm{Wm^{-2} sr^{-1}}}{\mathrm{cd\,m^{-2}}} \right],$$

M – taper demagnification, $M = 2.3$,

τ – photometric efficiency of the radiation energy transfer, experimentally determined to be 0.15,

R_{CCD} – spectral sensitivity of the CCD element at the wavelength of the maximum spectral emissivity of the image intensifier screen (530 nm), $R_{CCD} = 6$ V/Wm^{-2}.

Figure 5 shows how the curves for the measured and calculated ICCD signal vary. This may be explained by the presence of a powerful photo noise on the image

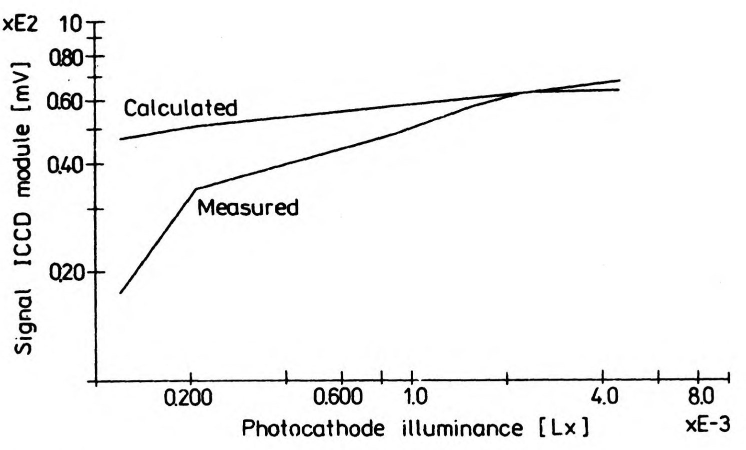

Fig. 5. Experimental measurement and theoretical prediction of ICCD modul signal against photocathode illuminance

intensifier screen at low light levels and by the mode of measuring the image intensifier luminance transfer characteristics. Here the values of L_v do not correspond to the actual luminance registered by the CCD during an accumulation time significantly shorther than the accumulation time of the PRITCHARD 1980A photometer which was used for the afore-mentioned measurement of luminance transfer characteristics. The same is the case for the CCD pixel registration surfaces and the photometer luminance probe.

Figure 6 shows a graph for both the measured and the calculated dependences of $(S/N)_{ICCD}$ versus E_{PHOT}. The relation for the calculation of $(S/N)_{ICCD}$ in the lumi-

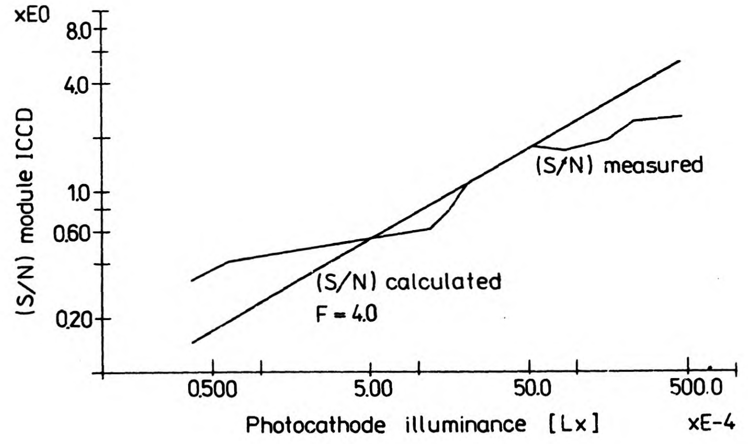

Fig. 6. Measurement of ICCD modul S/N ratio and calculation of S/N ratio against photocathode illuminance for $F = 4.0$

nance region E_{PHOT}, where the photon noise is significant, is as follows [2]:

$$(S/N)_{ICCD} = \left(\frac{S_p A t T E_{PHOT}}{q F M^2} \right)^{1/2} \tag{3}$$

where:

S_p – photocathode integral sensitivity, 230 μA/Lm,
A – pixel dimension, 156×10^{-12} m^2,
t – accumulation time, 19.5×10^{-3} s,
T – taper transmission of light, $T = 0.1$,
E_{PHOT} – photocatode illuminance (Lx),
q – electron charge, 1.602×10^{-19} C,
F – estimated intensifier tube noise factor ($F = 4.0$),
M – taper demagnification, $M = 2.3$.

Figure 6 shows a good agreement of the calculated and measured values within the range from 5×10^{-4} Lx to 1×10^{-2} Lx for estimated value of $F = 4.0$.

3.2. ICCD camera signal and noise

In this measurement, only a temporal noise was considered as represented by videosignal changes in time. Aside from it also a structural noise, represented by videosignal changes in space (e.g., along the line), is present in the CICCD TV system. Figure 7 shows the measured ICCD camera noise voltage signal. Figure 8

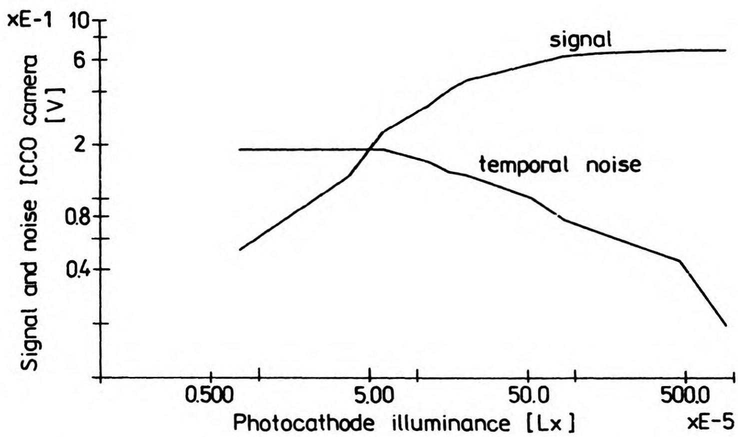

Fig. 7. Signal and noise of ICCD camera against photocathode illuminance

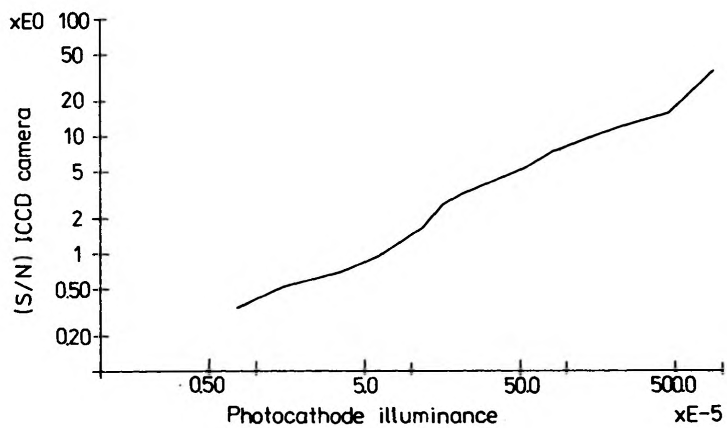

Fig. 8. S/N ratio for ICCD camera against photocathode illuminance

shows the curve $(S/N)_{\mathrm{CICCD}}$ depending on E_{PHOT} illuminance. The calculated ICCD camera dynamic range is approximately 100. The signal peak-to-peak voltage was measured within a 0.5 MHz window of a standard multibar test, with nearly 100% contrast. The noise was measured at 20% contrast within a 0.5 MHz test at black level. A 20 ns sampling window was selected which corresponds to the sampling step of the digital oscilloscope.

3.3. ICCD camera MTF

The CICCD Modulation Transfer Function (MTF) was investigated by a digital analysis of the videosignal displaying the edge response [3], [4]. The digitalized videosignal was subjected to filtration, derivation, and FFT.

First ten arguments of the complex numbers obtained through Fourier transformation correspond there to the frequency range of 5 MHz. Figure 9 shows

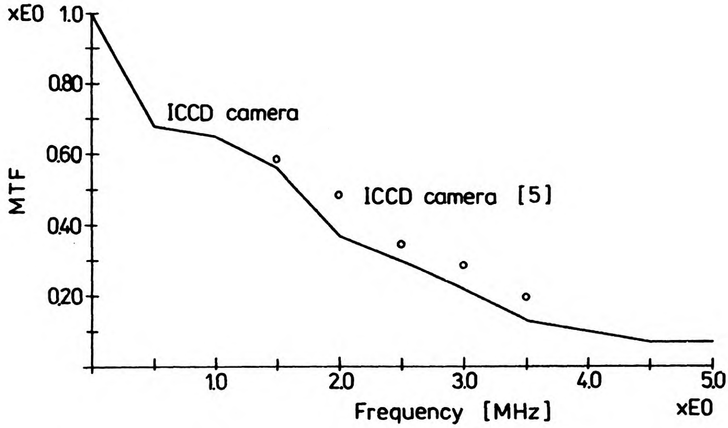

Fig. 9. MTF of ICCD camera calculated from edge response.

the calculated MTF of the edge response videosignal in the photocathode input window. For comparison, another MTF of a similar TV system is shown, obtained by measuring the signal modulation depth for tests applied at the image intensifier input [5].

3.4. CICCD limiting resolution

Figure 10 shows the dependence of the limiting resolution on E_{PHOT} for 100 per cent test contrast. For $E_{PHOT} = 4.6 \times 10^{-3}$ Lx a horizontal resolution of 4.5 MHz (350 television lines (TVL)) was measured and a vertical resolution of 300 TVL for gamma of CCD camera was equal to 1.

3.5. CICCD structural noise analysis

So far, in the measurements of the noise voltage we have considered only the presence of the temporal noise in the signal. The CICCD image quality is also affected by the structural noise. It is difficult to separate it during the measurements from other videosignal components. Using the AVERAGING mode and the signal digital processing structural noise can be separated as follows: from the original data file obtained by AVERAGING mode (500 data) representing a line section (Fig. 11), without test, a file is subtracted which is obtained from the original file by digital

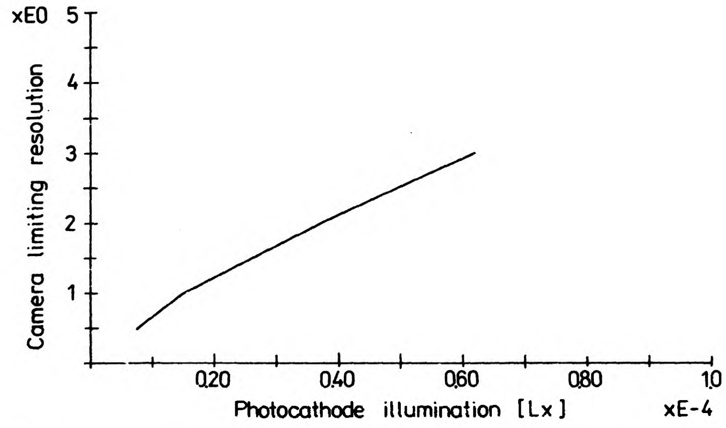

Fig. 10. Limiting resolution of ICCD camera against photocathode illumination

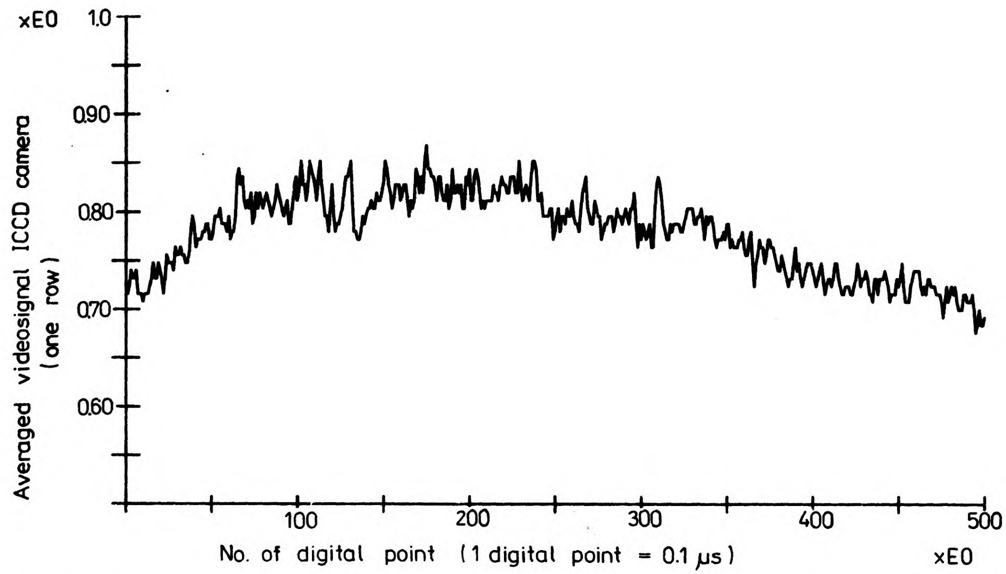

Fig. 11. Part of line of videosignal from ICCD camera. Temporal noise eliminated by applying AVERAGE mode

LF filtration (Blackman's window) of videosignal frequencies higher than 30 kHz (see Fig. 12). The obtained file corresponds to the HF CICCD structural noise which is subjected to statistical analysis, and RMS value of the structural noise σ_{SN} is determined. The file is subjected to spectral analysis, i.e., the calculation of power spectrum (Fig. 13). The RMS value of structural noise σ_{SN} increases with illuminance.

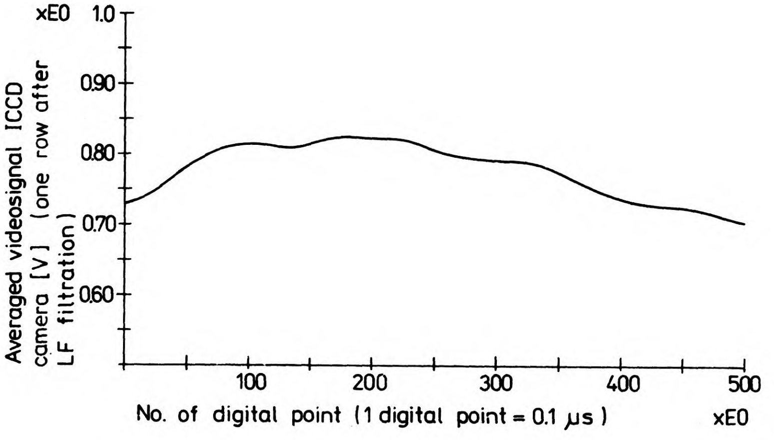

Fig. 12. Result of low frequency digital filtering of videosignal presented in Fig. 11

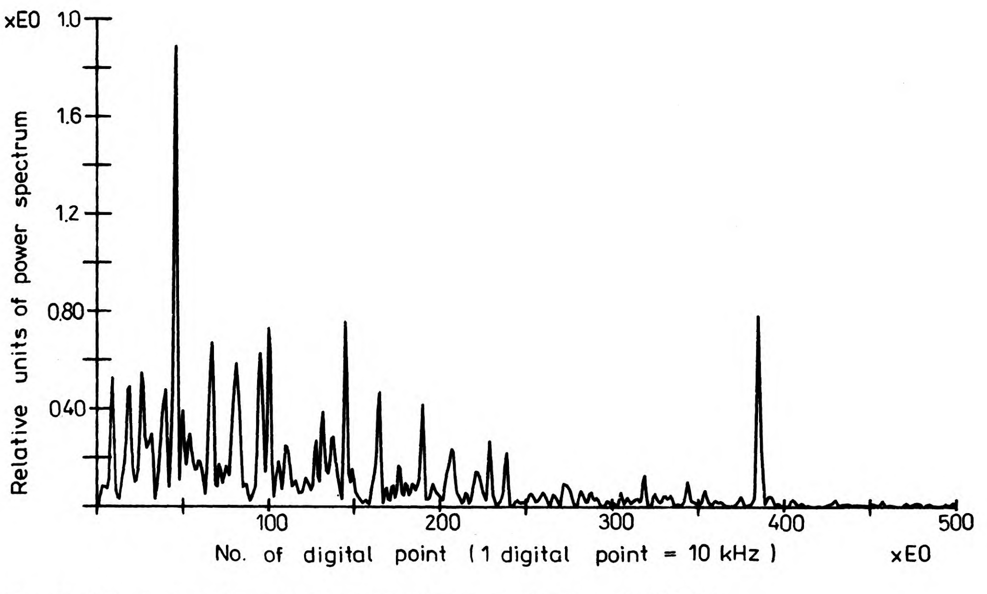

Fig. 13. Calculation of power spectrum of structural noise of CICCD

For instance, when $E_{PHOT} = 1.6 \times 10^{-3}$ Lx, the measured value of σ_{SN} was 20 mV, which is comparable with the signal at 3 MHz frequency and 20 per cent test contrast (60 mV after being calculated from signal value and MTF at 3 MHz). The structural noise power spectrum of each line was individual except for 400 kHz 3.8 MHz. The first value corresponds to the dimensions of the microchannel plate multifibres, the latter is characterized by the presence of parasitic switching impulses in CCD output circuit. The suppression of this parasitic frequency using DCS circuit (40 dB in contrast to 2 MHz) is insufficient in poor illuminance conditions. The resolution is significantly affected by uneven amplification in single multifibres of the microchannel plate which was demostrated by the accumulation of the spectrum energy within the lower frequencies of the structural noise power spectrum. A comparison of the calculated areas under the power spectra of structural and temporal noise (the area under the spectrum corresponds to the noise energy) for various illuminances indicates a higher output of the structural noise at illuminance greater than 2 mLx. The structural noise output decreases by one order with illuminance decreasing by two orders. With similar illuminance decrease the temporal noise output increases by three orders.

4. Conclusions

A method of ICCD-based low light level TV system measurement has been described. Using TEKTRONIX 2430A digital oscilloscope enabled separation of fluctuation (temporal) and determined (structural) noise components from the videosignal. The measurements and analysis of CICCD videosignal show significant effect of temporal noise within the range of low illuminance levels (below 1×10^{-4} Lx). This effect is a consequence of photon fluctuations at the TV system input. At higher illuminance levels (greater than 2×10^{-3} Lx) the structural noise of the image intensifier screen prevails. Its source is a microchannel plate, to be more specific, uneven amplification in particular multifibres. Another contribution to the investigation of structural noise is the creation of a network structure on the screen as a consequence of decreasing amplification on the multifibre edges [2]. In order to improve CICCD resolution, it is essential to upgrade MCP parameters (evenness of amplification of the particular multifibres, noise factor F). The method including $(S/N)^2$ and MTF measurements shown in [6] is, in our opinion, most suitable for such TV systems thanks to its comprehensiveness (both noise types are measured) and the comparatively modest requirements for the measuring equipment.

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References

[1] IVANOV S. A., Tekhnika sredstva sviazy, Ser. Televizionnaya tekhnika, 1983/4, p. 15 (in Russian).
[2] VAN GEEST L. K., [In] *9th Symposium on Photoelectronic Image Devices*, London, Sept. 1987, p. 42.
[3] CARELLAS P. T., Photonic Spectra **23** (1989), 133.

[4] DAINTY J. C., SHAW R., *Image Science*, Academic Press, London 1974.
[5] RICHARD J. C., Acta Electron. 27 (1987), 191.
[6] GELUK R. J., SPIE 467 (1983).

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К вопросу о методе измерений схем TV низкодо светового сигнала

В настоящей работе представлен метод измерений схем TV низкого уровня светового сигнала (LLL TV). Схема LLL TV состоит из оптического связывающего экрана (при помощи уменьшивающей волоконной оптики), усилителя изображения второй генерации, а также CCD. Исследование такой схемы охватывает измерения характеристики передачи, отношения сигнал/шум, модуляционной передаточной функции, а также предельной разрешающей способности. Для того, чтобы исследовать временный и структурный шумы, имеюшиеся в схемах LLL TV, был употреблен цифровой осциллограф TEKTRONIX 2430A, который также дигитализировал видеосигналы.

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