COLOUR CAMERAS EMPLOYING TWO CCD/CID IMAGERS

Ulrich Reimers

ABSTRACT

The number of picture-elements available in todays solid state imagers makes the development of a colour camera with only one sensor for the generation of the red, green and blue video information a thankless task. At least two CTD-elements are needed for a picture with acceptable resolution. Different principles of two-chip colour cameras have been investigated, both theoretically and in experiment, by the author during the last two years. Imagers used are RCA's frame-transfer CCD SID 52501, Fairchilds CCD 211, an interline-transfer device, and the TN 2000 camera CID-chip produced by General Electric. The different types of cameras are presented, the pros and cons of the imagers used are considered and results of the work are shown.

INTRODUCTION

One of the great advantages of solid state imagers over conventional pick-up tubes is the fact, that the location of every picture element is fixed and that the origin of a video signal appearing at the output of such a device can be determined by simply counting the number of clock pulses needed to read out this signal. So the use of colour coding filters in front of the sensor allows the generation of more than one colour signal with only one imager and - what is even more worthy - the separation of these signals by simple electronic means. Imagers available today posess about 200 to 350 pixels per line, and some of them have a number of active lines sufficient for the use in standard TV-systems. The resolution in pictures taken with these devices is just good enough for low quality black and white imaging, and so it does seem to be unrealistic to think of getting more than one signal out of such an imager. This certainly is true if one tries to generate red, green and blue with one chip, but it is not, if only red and blue are extracted from this sensor, green being read out of another with full resolution. This is due to the eye's ability to see a high-resolution colour picture mixed from a sharp green and two blurred red and blue signals. So a two-chip-solution seems to be a good compromise between resolution and expense, at least today. A welcome benefit of such a system is the fact, that the problems of unsymmetrical dark current generation - leading to nasty coloured backgrounds - decreases as the number of imagers decreases, and that optical alignment becomes less sophisticated as well. A lot of work had been going on in the Institut für Nachrichtentechnik of the Technical University Braunschweig concerning the evaluation of colour cameras with one or two electron-beam tubes in the last couple of years (ref 1). The background of this work was of course very useful for the development of solid state cameras. The separation of more than one colour signal generated with a conventional pick-up tube is normally possible only if different colours can be found in different frequency ranges of the video signal. The frequency-multiplex is accomplished by the use of subtractive filters with stripes opaque for

Institut für Nachrichtentechnik, Technische Universität Braunschweig,
Pockelsstraße 4, D-3300 Braunschweig

one colour, we call these filters green stops or red-stops etc. As the frequency-multiplex is not necessary in solid state imaging, additive filters are used with stripes transparent only for red, or for blue or for green. A result of our former work was the proof, that a two-imager-system in which green is generated in the one pick-up element and red and blue in the other (G(RB)-System) is superior to all other solutions (Y (RB), Y (GRB), etc.). So consequently all our experiments were done using such a system. Fig. 1 shows the experimental equipment. The striped filter needed to separate red and blue in the RB-channel is projected on the imager by means of a relais optic. The green light is separated by a dichroic mirror. To avoid resolution-loss due to infrared light absorbed in the RB-imager an IR-stop filter is used (ref 2). The green channel can easily be equipped with any camera system available, for example with a conventional tube-system to get pictures with excellent resolution. The detailed description following this introduction reflects a chronological development, which was caused by the availability of the different imagers.

RB-SYSTEM USING A FRAME-TRANSFER CCD

Fig. 2 shows the model of a frame-transfer CCD SID 52501 manufactured by RCA. The device uses 3-phase transfer elements and polysilicon electrodes, the serial readout is accomplished by a BCCD structure whereas the imaging area and the storage area are SCCDs. There are two evident ways how to divide the imaging area into a blue and a red part using striped filters: either line-sequential with horizontal stripes or dot-sequential with vertical stripes. We chose a horizontal striped filter because of many reasons. The number of pixels per line is only 320 while there are 512 lines per frame. So a partition of the number of lines into 256 for red and 256 for blue does seem to be more tolerable than a partition of the pixels. The commutation from red to blue can be done during the horizontal blanking interval, so it remains invisible during the active line time. The doubling of each line, necessary to generate simultaneous red and blue signals, can be carried out by means of a CCD-delay-line which for example could be on the chip itself. As a matter of fact the SID 52501 posesses such an additional delay-line, which is not connected to the outer world, though.

The system described above failed to produce good colour pictures because of two reasons. The one reason is the spectral response of the SID shown in fig. 3. The curve shown - as do the other curves in this paper - refers to a tungsten halogen lamp with a correlated colour temperature of about 3200 K. Two lines indicate the ranges in which the red and the blue filter stripes are transparent. The tiny portion of signal in the blue channel is evident. As the dynamic range of the imager is limited (blooming) and the signal-to-noise-ratios for both colours have to be in the same order of magnitude, an adaption of signal-levels has to be done using colour-correction-filters with full transparency in the blue and about only 5% in the red, and by increasing the illuminance in the scene to about 40000 Lux. The other problem, even worse than the well known problem of spectral sensitivity, is the smearing between the blue and the red lines due to transfer losses in the imaging and the storage area. Fig. 4 shows the vertical modulation transfer function of the SID. Both curves were measured with a pattern of black and white stripes projected on the imager exactly in phase with sensor lines, so no aperture loss is included. The strong decrease of the curves is mostly due to transfer losses, and these lead to red information being mixed with blue signals. As the decrease is a function of the number of charge transfers a charge packet has to undergo, the MTF depends on the origin of the measured signal. Matrixing of the red and the blue channel was tried as a counter-measure against smearing, but it failed to work in a sufficient way because of the local dependence of this effect.

The use of vertical striped filters can probably minimize the problem of crosstalk between colours to a certain degree. Transfer losses leading to this phenomenon will occur only in the readout-register, which is of the BCCD-type, and therefore has an inefficiency-coefficient ε much lower than the SCCD-structures within the image and the storage area. Moreover the number of transfers in this readout channel is limited to about 960 for the "worst case"-charge packet. The decrease of the horizontal MTF has been measured to be 50% at the Nyquist limit.

Fairchilds CCD 211, an interline-transfer device with 244 active lines and 190 pixels per line was investigated for its qualification as a possible substitute in the RB-channel. The small number of lines prohibits the use of horizontal striped filters as will be shown in the next chapter. The spectral response curve, compared to that of the SID in fig. 5, does not make the use of this device very attractive, and the horizontal MTF in fig. 6 shows some inferiority to RCA's SID 52501.

EMPLOYMENT OF A CID IMAGER IN THE RB-CHANNEL

General Electric sells a solid state black and white camera TN 2000 which uses a CID imager with 244 lines and 188 pixels per line. Great advantages of this device are its relatively flat spectral response curve - due to a smaller amount of polysilicon on the surface exposed to light - and the fact, that readout of this sensor is not accomplished by charge transfer but by sensing of the potentials of pixel-electrodes. A number of drawbacks has to be accepted, though.

Again it is not reasonable to use horizontal striped filters. Fig.7 gives an impression of the equipment needed for such a system. As the number of lines has to be doubled to satisfy normal television standards, and the colours have both to be available simultaneously, 3 delay-lines are unavoidable. Fig. 7 shows two special features of the type of CID device considered here: there are two outputs, and after the readout of one line containing video information and fixed pattern noise (R', B'), there is always one line merely consisting of fixed pattern noise (r, b). Subtraction of two following lines is therefore necessary to cancel the noise. As a matter of fact the preinjection-readout of the CID makes signal processing rather complicated (ref 3, ref 4). It has been shown, that the use of more complex striped filters can minimize the number of delay-lines used in a system with horizontal filters, but still this solution remains inattractive.

A close look at the sensor itself, shown in fig. 8, makes clear why there are two outputs to one chip: the pixels of each line are alternately connected to one of these outputs by the vertical enable switches. Vertical striped filters therefore make the separation of red and blue possible on the chip so that each colour is read out at its own output port. Fig. 9 shows the equipment adapted to this system. Two delay-lines and a switched subtraction circuit are again necessary for fixed pattern noise reduction.

The system described above performs very satisfactory. Crosstalk between the colours is scarcely measurable due to the miss of charge transfer processes for the readout. The spectral response curve - again compared to that of the SID - is given in fig. 10. Fig. 11 shows the ratio between the red and the blue signal after some colour-correction aimed at suiting the resulting curves to the corresponding EBU-curves. The loss in sensitivity due to this filtering is adequate to 1.5 stops of the camera's objective. Amplification is needed to assimilate the red to the blue signal, this results in a loss of about 6.5 dB in the signal-to-noise-ratio of the blue channel.

ACKNOWLEDGEMENTS

The author wants to thank the director of the Institut für Nachrichtentechnik, Prof. Dr.-Ing. H. Schönfelder, and his colleague Dr.-Ing. G. Brand for their encouragement and support and the ROBERT BOSCH GMBH, Geschäftsbereich Fernsehanlagen, for its promotion of the work described.

REFERENCES

ref 1 Schönfelder, H.; Bock, G.: Einröhren- und Zweiröhren-Farbkamerasysteme. Funkschau, Volume 47, 1975, No. 18, pp. 111 - 114, No. 19, pp. 59 - 63.

ref 2 Dyck, R.H.; Steffe, W.: Effects of Optical Crosstalk in CCD Image Sensors. Proceedings of the 1978 International Conference on the Application of Charge Coupled Devices, San Diego, 1978, pp. 1 - 55 - 1 - 61.

ref 3 Manual of the Model TN 2000 Closed Circuit Television Camera, General Electric Company, Syracuse, September 1976.

ref 4 Solid State Television Camera (CID), Final Technical Report to Contract No. NASA 9-14757, General Electric Company, Syracuse, August 1976.

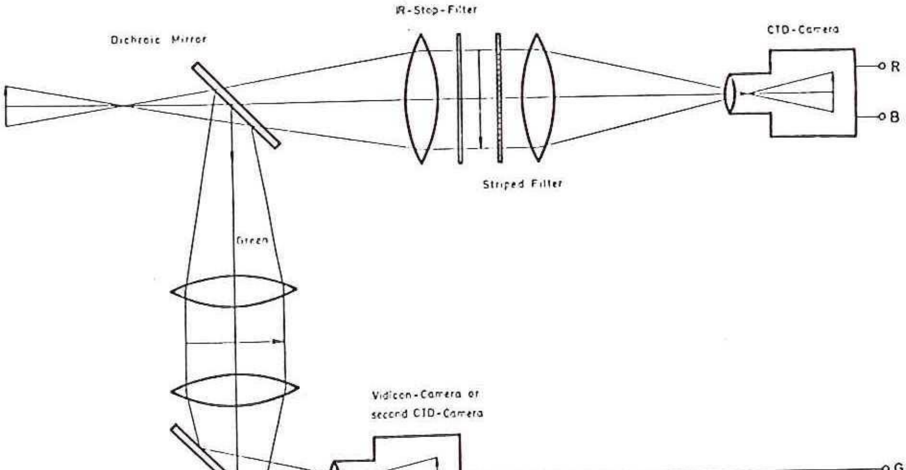

Figure 1. Experimental Equipment Used to Test Two-Sensor Colour Cameras

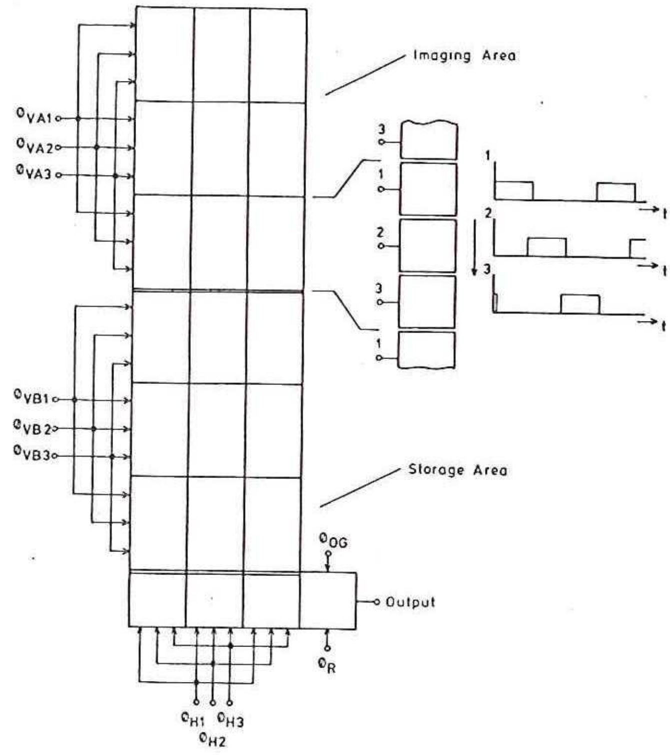

Figure 2. Organization of a „Frame-Transfer" Imager

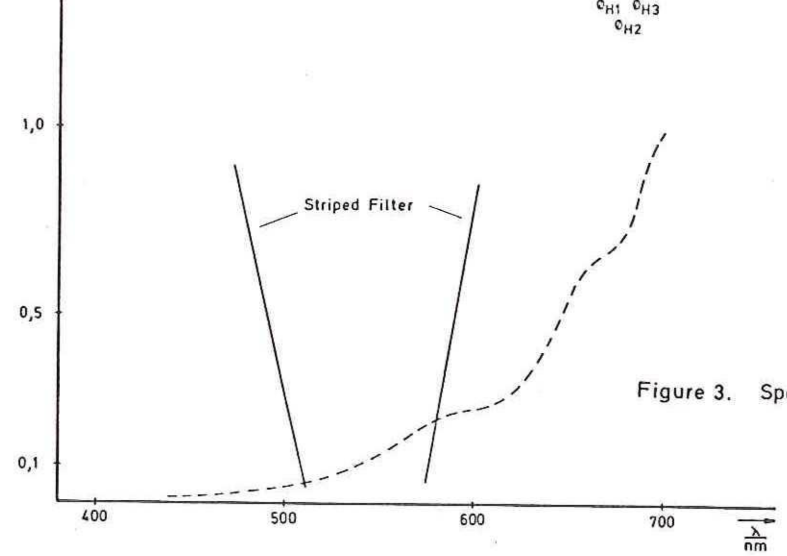

Figure 3. Spectral Response Curve of the FT-CCD SID 52501 (RCA)

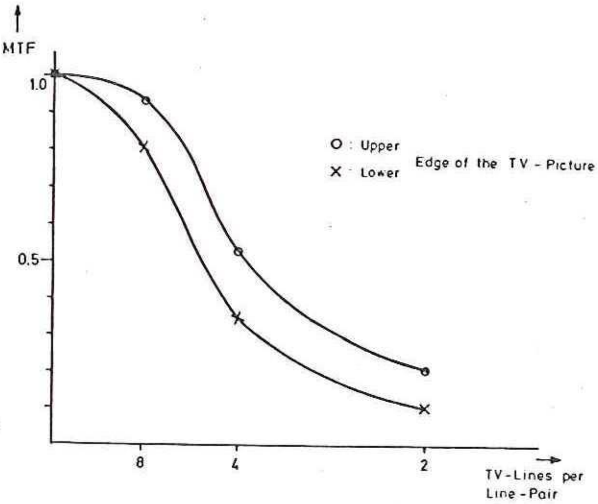

Figure 4.
Vertical Modulation Transfer Function of the SID 52501

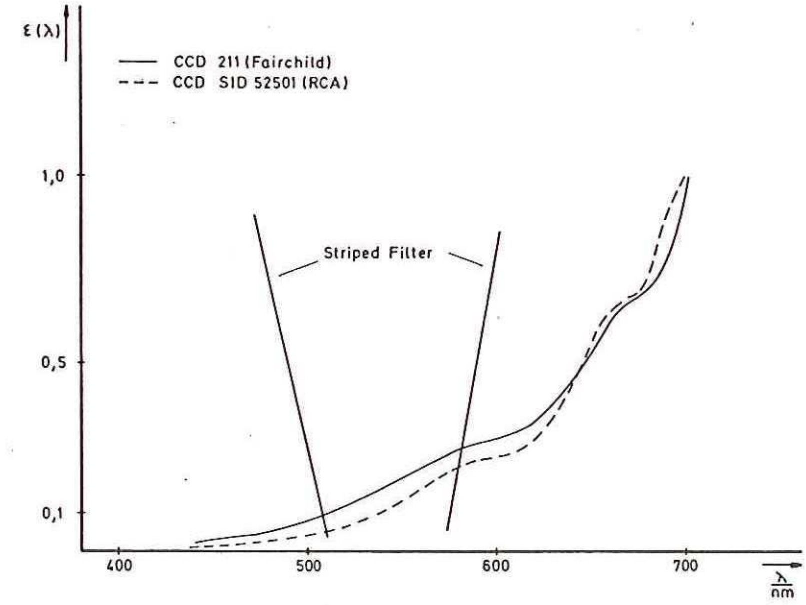

Figure 5. Comparison of the Spectral Response Curves :
FT-CCD SID 52501(RCA) - CCD 211 (Fairchild)

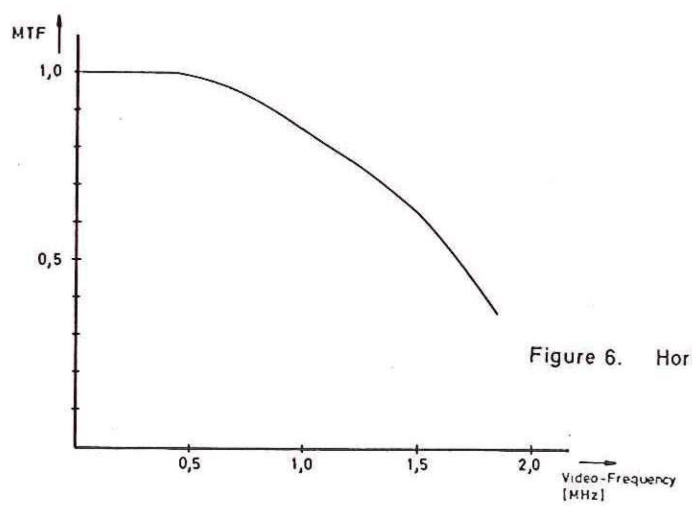

Figure 6. Horizontal Modulation Transfer Function of the CCD 211

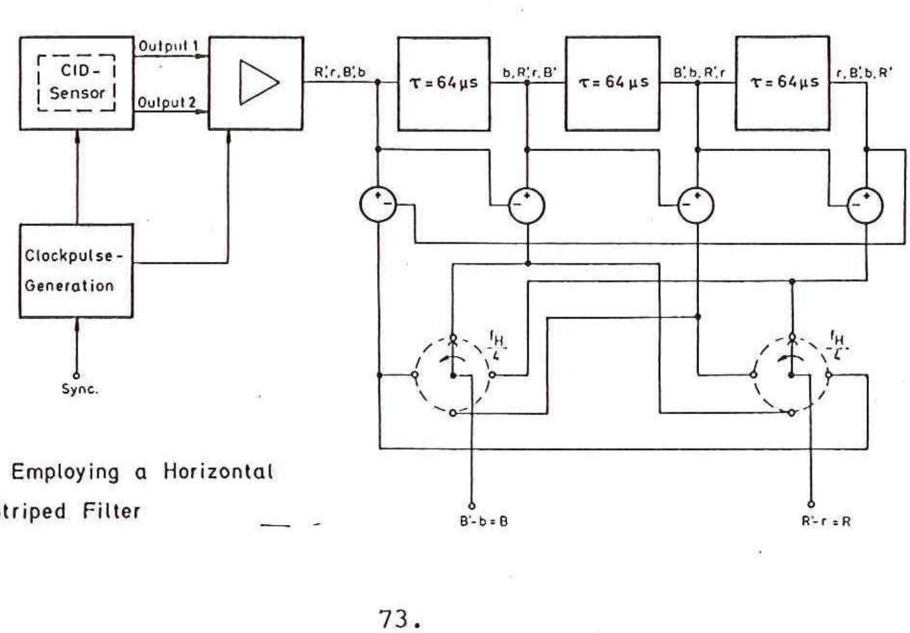

Figure 7. CID-System Employing a Horizontal
RB-Striped Filter

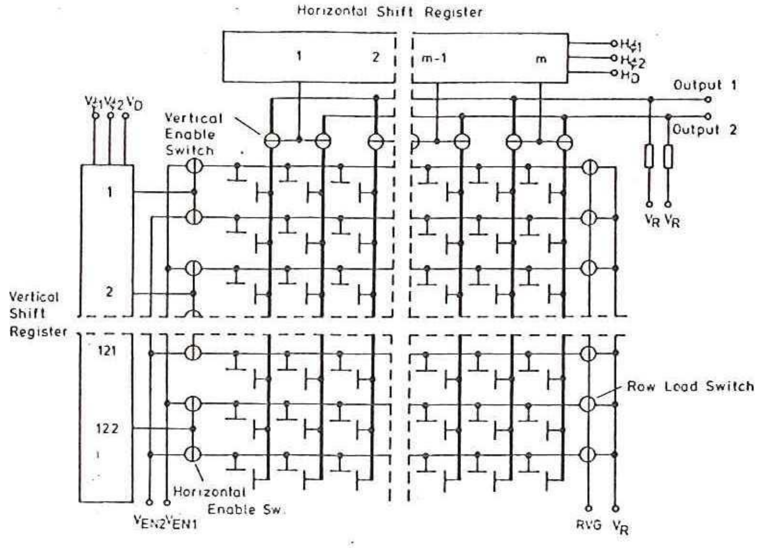

Figure 8. Model TN 2000 Camera CID Sensor (GE)

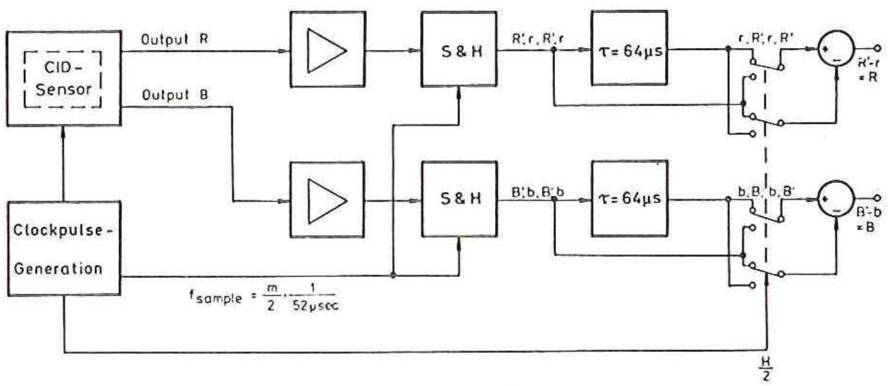

Figure 9. CID-System Employing a Vertical RB-Striped Filter

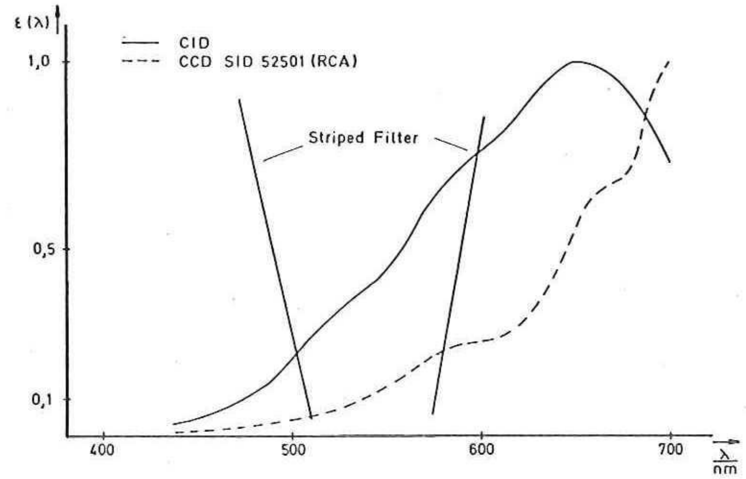

Figure 10. Comparison of the Spectral Response Curves: FT-CCD SID 52501 (RCA) - CID (GE)

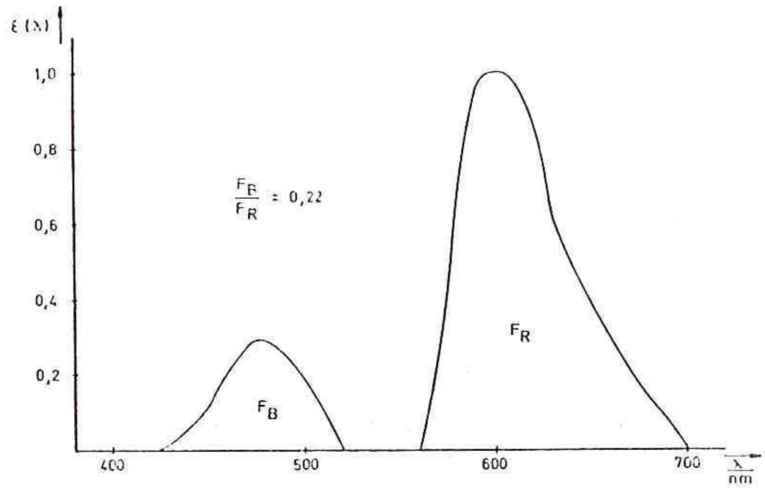

Figure 11. Sensitivity Curves of the CID - System's R - and B - Channel