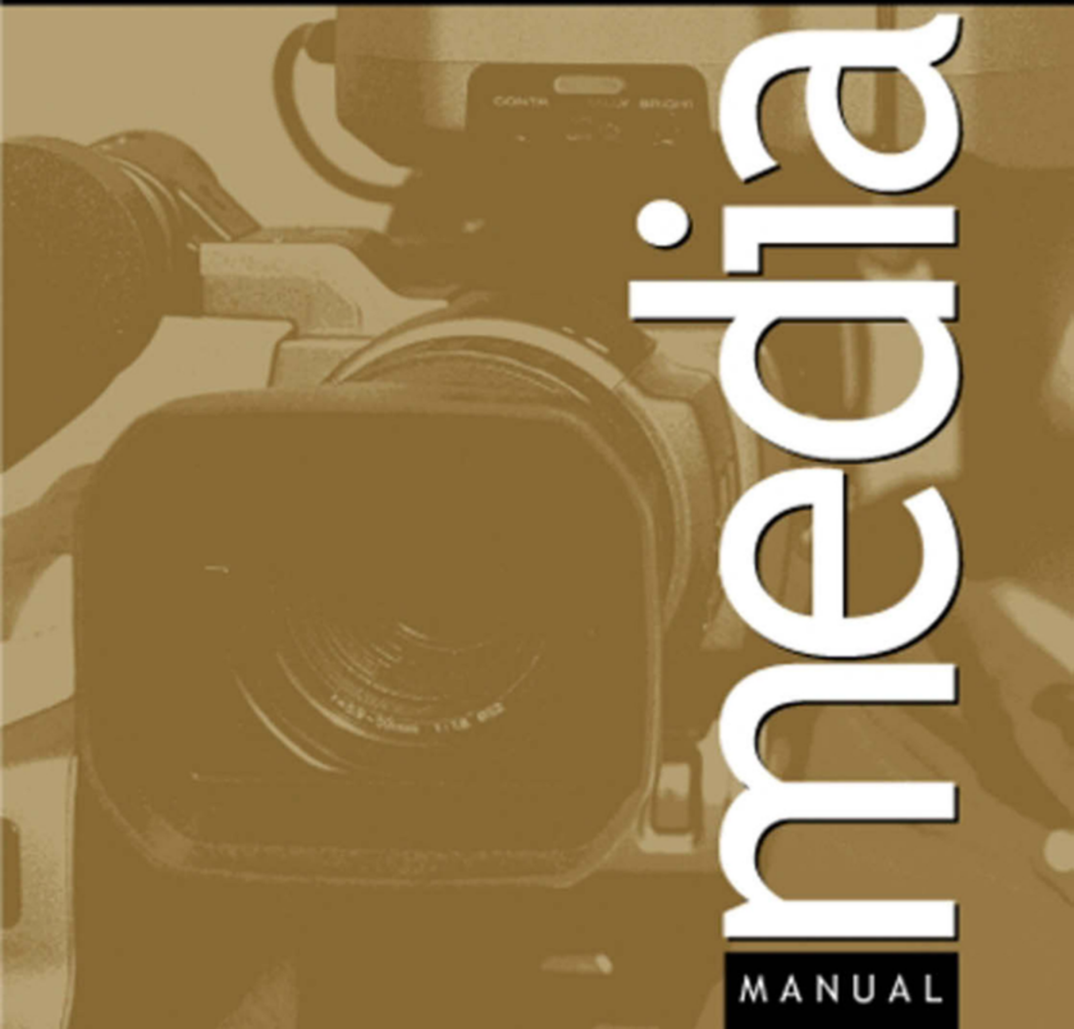
digital video camerawork

peter ward



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Introduction

This is a manual about digital camerawork techniques used in television or video production. Within this context, television applies to the system of broadcasting programmes by terrestrial transmitters, satellites or cable to an audience who can watch the production at the time of transmission or record for future viewing. Video usually describes a production which is intended to be sold and used as a cassette. Confusingly, it also describes programme making using video cameras as opposed to film production.

We are in a period of transition between analogue and digital acquisition/recording formats. The price of equipment is an overriding factor in an industry that is forced to become more competitive chasing fewer viewers scattered across a greater number of channels. This requires smaller programme budgets, cheaper equipment, and has generated interest in DVCPro, Digital-S, DVCam, and DV format cameras. However, the existing format competition may be a false battle as all the present competing formats are tape. Disk cameras are in production but it is not only a format battle, there is also a compression battle.

'Digital' is sometimes mistakenly used as an adjective for quality, but picture quality is dependent on a number of factors. How the signal is digitalized, the amount of compression employed and the affect of coding/decoding several times along a signal path will have an impact on picture quality. The initials *DV* can stand for digital video and are also used to identify 'DV', a recording format. In this manual the initials are restricted to the DV recording format. Most digital formats are covered except Digi beta and BetacamSX which are discussed in *Basic Betacam Camerawork* in the Media Manual series.

With such a diversity of recording formats and camera design, choosing the appropriate camera/recorder format will depend on budget and the production requirements. Technique is dependent on technology and therefore an understanding of different production techniques and the variation in shooting styles is required for each genre. Each production type requires some specialist technique and possibly a specific format. It is essential to have an understanding of all the controls on the camera and how to record a technically acceptable image (e.g. exposure, gain, shutter, etc.). Also the programme making importance of camera peripherals such as batteries, camera mounts, microphones and tape.

The digital camera has become a computer. Data manipulation before recording is similar to the action of a computer, and can be applied to video because the signal is in a digital form. Digital manipulation of the image allows customizing the image through the camera menu and an expansion of automatic facilities such as exposure zones, speed of iris response, precise control of face tone, the removal of blemishes and picture zones. Digital manipulation also allows selective contouring, and softer transitions between auto functions. We can also expect the growth of specialized software that can be loaded into the camera for specific needs or to expand the camera's facilities. Disk recording allows in-camera digital manipulation of the image after recording. This includes loop recording; editing on disk; position and shot size; editing in the field.

Good production technique is understanding and exploiting the basic skills of camerawork, lighting and sound to serve the specific needs of a production. Providing a story structure and shot variety, to enable flexibility in editing, are basic standard techniques required from the ENG/EFP cameraman. Editing in the field based on the low-cost DV format is a useful time-saver for news bulletins, as is SNG. There is an essential need to shoot with editing in mind and to have a working knowledge and familiarity with different production styles and their requirements.

The manual does not assume that the reader will have had extensive analogue camerawork experience or a knowledge of TV engineering fundamentals. With low-price digital formats available, DV working may be the first experience many people have of television camerawork and therefore an account of perennial camerawork technique is included.

The responsibility for acquiring and editing television material often rests with a number of people. Sometimes a single person will shoot and cut an item. On other programmes there will be many more people involved in getting the material 'on-air'. Traditionally there has been a division of 'production' labour shared between different crafts skills. In this manual, camerawork and editing are descriptions of production activities and need not necessarily refer to a particular craft skill. Throughout the manual, terms such as 'cameraman' are used without wishing to imply that any production craft is restricted to one gender. 'Cameraman' for example is the customary title to describe a job practised by both men and women and 'he', where it occurs, should be read as 'he/she'.

Technique and technology

There is an urban myth of an American tourist hiring a car in a foreign land and driving 200 miles in first gear. When the engine eventually overheated and seized up he was asked if did he not suspect somewhere along the journey that something was wrong. He said he thought it was noisy and slow compared to his own car with automatic transmission back home, but having never driven a car with a manual gear change he had no way of comparing the car's performance.

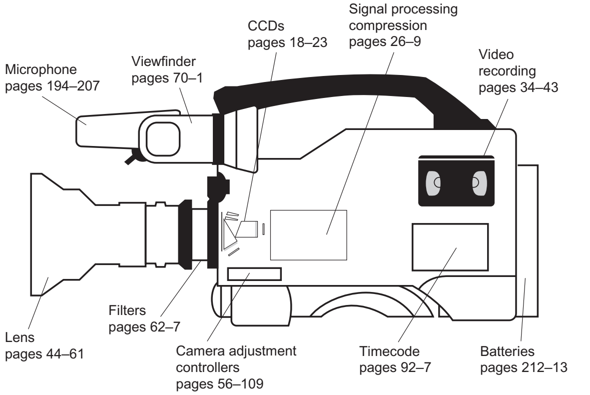
A basic knowledge of television technology is required to avoid a similar foul-up when new to programme making. Technology is simply a means to an end; the end being a programme that communicates with its audience. Without an understanding of the camera equipment employed or an over-reliance on automatic features, the end result may be less than satisfactory.

In 1888 the Kodak camera was launched as an easy, simple method of taking photographs. 'You press the button, we do the rest', was a sales slogan to demystify the arcane process of photography. In the early days of the craft, would-be photographers had to prepare their own glass plates, and then develop them in a combined camera/darkroom. After 1888, anybody could press a button and the camera and the chemist would do the rest. Training in photographic competence was condensed to the few minutes required to be instructed on which button to press.

Over 100 years later, in response to the needs of the TV industry, the craft of camerawork is promoted as a simple matter of knowing the position of a couple of buttons on the camera. After a very short training period, anybody can become a competent television cameraman. If this was true about photography and broadcast camerawork, there should be no visual difference between a holiday snapshot and an advertising brochure of a resort, or a holiday video and a feature film shot at that resort.

Technology and technique intertwine. How you do something in broadcasting depends on what equipment you are using. It is not simply a question of being told which button to press in order to get a professional result. In television camerawork, an understanding of camera technology plus the ability to exploit and take into consideration the attributes of the camera and the lens characteristics is the basis of practical programme production. Most camera equipment is now wrapped up with auto features in the hope of being user-friendly to technophobic customers, but camera operators should aim to understand what is happening when they are using a camera rather than trust the old slogan of 'you press the button, the equipment will do the rest'.

Simplified figure of a DV camera/recorder



Lens system: The design of the lens affects resolution, image quality, focal length, zoom ratio, exposure and control of zooming. Also important is the lens fitting to allow interchangeability with other lenses.

Charge coupled device: The choice of pick-up sensors (e.g. FIT, HAD, etc.) will determine how light is converted into electricity and will control the quality of image, definition, highlight handling, contrast range and sensitivity.

Television system: How the signal is read from the CCDs will depend on the video system chosen and how it will be seen by its potential audience. Choice of systems range from decisions on colour system (PAL, NTSC, SECAM), line structure (625, 525, 1088, etc.), aspect ratio (4:3 or 16:9), interlace or progressively scanned.

Digital conversion: Choice of sampling rate and how the colour information is sampled will affect how the material is displayed and edited.

Signal processing: How the signal is processed and modified such as knee, linear matrix, gamma will affect the appearance of the final displayed image.

Compression: Digital signals require compression before recording and the compression ratio chosen for the camera and the design and method of compression all affect the signal output.

Video recording format: There are many methods of recording video onto tape or disk (e.g. Betacam SX, DVCPro, DV, Digital-S, etc.). The method and format used in the camera will control the quality of recording and editing format.

Sound: An effective method of recording and monitoring audio levels is needed and the facilities for microphone inputs will affect the final edited audio presentation.

Camera controls: A range of controls are required to achieve a good technical quality image (e.g. white balance, shutter, gain, exposure, menus, set-up cards, built in filters, method of genlocking and monitoring outputs, etc.).

Viewfinder: A quality viewfinder to monitor all aspects of the image output.

Timecode: A method of setting up and recording timecode information on the tape is essential for editing.

Power supplies: Batteries and monitoring the state of charge of batteries is required. Also an input to use an AC adaptor if required.

Pan/tilt head and support system: Adaptor plate on the base of the camera to enable it to be mounted on pan/tilt head and tripod.

Robust mechanical design: A camcorder used for everyday programme production is subjected to much harder wear and tear than a camera used for holidays and family events.

Light into electricity

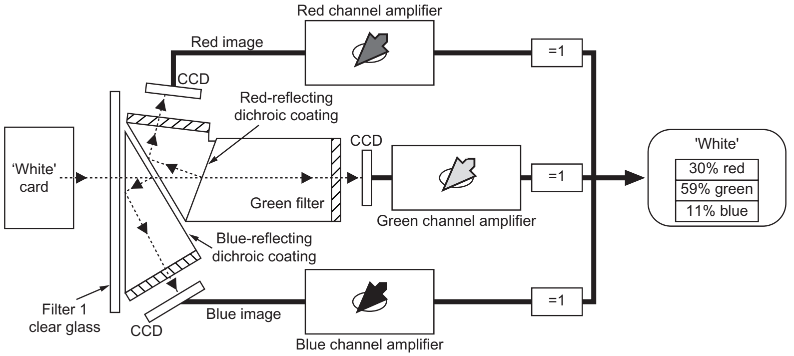
Light reflected from the subject in view will pass through the lens and be focused on the charge-coupled devices fitted in the camera. The effect of the lens and lens characteristics are discussed later. This page details how light is turned into an electrical signal.

How the eye sees colour
There are many nerve endings in the retina which respond to visible light including red, green and blue receptors which respond to a range of wavelengths. Colours are seen as a mixture of signals from these three types of receptors. Colour television adopts the same principle by using a prism behind the lens to split the light from a scene into three separate channels (see figure opposite).

White balance
In colorimetry it is convenient to think of white being obtained from equal amounts of red, green and blue light. This concept is continued in colour cameras. When exposed to a white surface (neutral scene), the three signals are matched to the green signal to give equal amounts of red, green and blue. This is known as white balance. The actual amounts of red, green and blue light when white is displayed on a colour tube are in the proportion of 30 per cent red lumens, 59 per cent green lumens and 11 per cent blue lumens. Although the eye adapts if the colour temperature illuminating a white subject alters (see Colour temperature, page 64), there is no adaptation by the camera and the three video amplifiers have to be adjusted to ensure they have unity output.

Colour difference signals
To avoid transmitting three separate red, green and blue signals and therefore trebling the bandwidth required for each TV channel, a method was devised to combine (encode) the colour signals with the luminance signal.

The ability of the eye to see fine detail depends for the most part on differences in luminance in the image and only, to a much smaller extent, on colour detail. This allows the luminance (Y) information to be transmitted at high definition and the colour information at a lower definition resulting in another saving on bandwidth. Two colour difference signals are obtained, Er (red) – Ey (luminance) and Eb (blue) – Ey, by electronically subtracting the luminance signal from the output of the red and blue amplifiers. These two colour signals are coded into the luminance signal (Ey) and transmitted as a single, bandwidth-saving signal. Different solutions on how to modulate the colour information has resulted in each country choosing between one of three systems – NTSC, PAL and SECAM. At the receiver, the signal can be decoded to produce separate red, green, blue and luminance signals necessary for a colour picture. A receiver is a television set that derives its signal from an RF (radio frequency) source (e.g. a transmitter). A monitor is a visual display that is fed with a video signal via a coaxial cable (see Monitor termination, page 17).



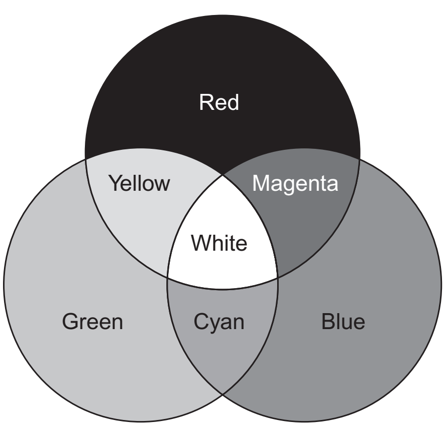
Light into electricity

The amplitude of the three individual colour signals depends on the actual colour in the televised scene. Colours are broadband and the light splitting block divides this 'broad' spectrum into red, green and blue light to produce three optical images on the respective red, green and blue CCDs. The CCD converts the optical image into an electrical charge pattern. A fourth signal, called the luminance signal, is obtained by combining proportions of the red, green and blue signals. It is this signal which allows compatibility with a monochrome display. The amplitude of the signal at any moment is proportional to the brightness of the particular picture element being scanned.

Additive colour

A composite video signal is an encoded combined colour signal using one of the coding standards – NTSC, PAL or SECAM. This can be achieved using the luminance (Y) signal and the colour difference signals of red minus luminance (Er – Ey) and blue minus luminance (Eb – Ey). The signals are derived from the original red, green and blue sources and this is a form of analogue bandwidth compression.

A component video signal is one in which the luminance and the chrominance remain as separate components, i.e. separate Y, R – Y and B – Y signals.



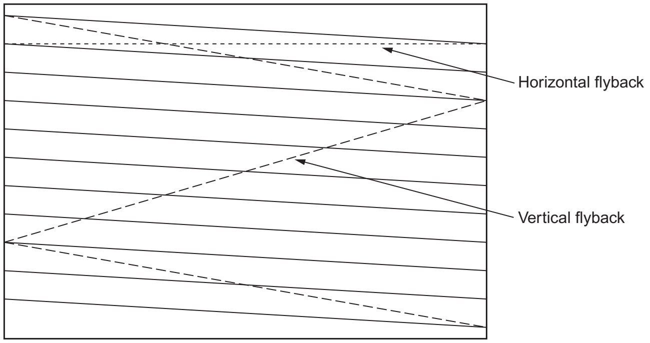
The video signal

Television translates light into an electrical signal and then back into light. In its journey from initial acquisition to the viewer's TV set, the television signal is subjected to adjustments and alterations before it is converted back into a visible image. Like all translations, something is lost along the way and a two-dimensional viewed image can never be an exact visual equivalent of the original. The amount of signal adjustment that occurs in broadcast television is a result of the historical need to ration and allocate transmission bandwidths. These technical restraints set limits to image definition and tonal range. The deliberate subjective creative choices made in creating the programme image also affect the picture viewed by the audience. There are continuing attempts to upgrade the existing various standard TV signals to a higher definition origination and transmission system, but the cost of re-equipping all production and receiving equipment and the lack of agreement on standardization inhibits rapid change.

The technical accuracy of the transmitted image depends on:

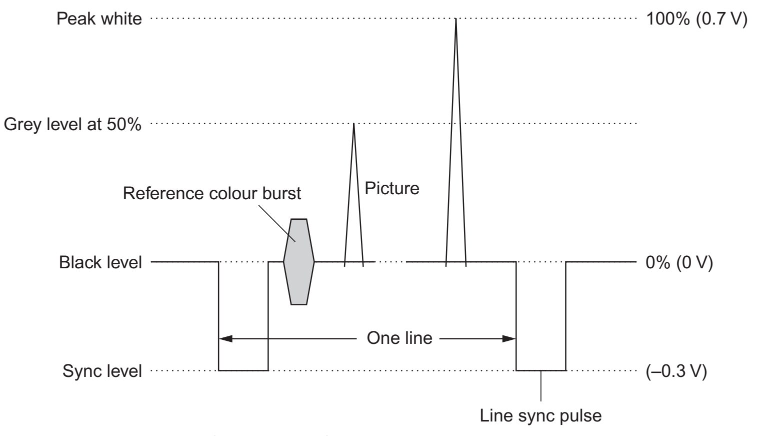
- **Time:** Human vision cannot instantaneously perceive a complex image and intuitively scans a field of view in order to visually understand what is presented. A video camera requires a mechanism to scan a field of view in a precise, repeated line structure.
- **Detail:** The choice of the number of lines and method of scanning is critical to the definition of the captured image and ultimately is dependent on the method chosen to relay the picture to its intended audience. The shape of the screen, the ratio of picture width to picture height, will determine line structure and resolution.
- **Movement:** Human perception requires that the repetition rate of each image must exceed approximately 40 pictures per second to avoid flicker and to provide a convincing simulation of smooth movement of any object that changes its position within the frame.
- **Synchronization:** The displayed image watched by the viewer must have a mechanism to stay in step with the original scanning of the televised image.
- **Accuracy of the tonal range:** Human perception is able to accommodate a wide range of brightness. The television system is only able to replicate a limited range of tonal gradations.
- **Colour:** A television electrical signal requires a method of accurately conveying the colour range of the reproduced image. As colour superseded black and white television, the colour system chosen was required to continue to provide compatible pictures for those viewers watching on black and white receivers.
- **Subjective creative choices:** The final production images can be customized in an almost limitless way to suit the creative requirements of the programme originator. The line structure and synchronization however remain unaltered.

The television scanning principle



The television picture is made up of a series of lines which are transmitted with synchronizing pulses to ensure that the display monitor scans the same area of the image as the camera. In the PAL 625 line system, each of the 25 frames per second is made up two sets of lines (fields) that interlace and cover different parts of the display. The electrical 'picture' is scanned a line at a time and at the end of each line a new line is started at the left-hand side until the bottom of the picture is reached. In the first field the odd lines are scanned after which the beam returns to scan the even lines. The first field (odd lines) begins with a full line and ends on a half line. The second field (even lines) begins with a half line and ends on a full line.

The television waveform



Diagrammatic representation of the signal waveform – not to scale

The waveform of the 1 V television signal divides into two parts at black level. Above black, the signal varies depending on the tones in the picture from black (0 V) to peak white (0.7 V). Below black, the signal (which is never seen) is used for synchronizing the start of each line and frame. A reference colour burst provides the receiver with information to allow colour signal processing.

Image quality

Video images are eventually displayed on a television screen. The quality of the screen, how it has been aligned and adjusted, any reflections or ambient light on the surface of the screen, the size of the screen and the distance at which it is viewed will all affect the quality of the image as seen by the viewer. Some compensation can be built into the video signal to mitigate receiver limitations (see Gamma and linear matrix, page 102), but other factors affecting viewing conditions are outside the control of the programme maker.

Unlike film, where the projected image consists of light reflected from a screen, a television tube emits light. The maximum white it can emit depends on its design and how the display has been adjusted. Black is displayed when there is an absence of any signal, but even when the set is switched off, there is never a true black. The glass front surface of the tube, acting like a mirror, will reflect any images or light falling on the screen degrading 'black'. These two aspects of the display, its maximum high intensity white and how much ambient light is reflected from its screen set the contrast range that the display will reproduce independent of its received signal.

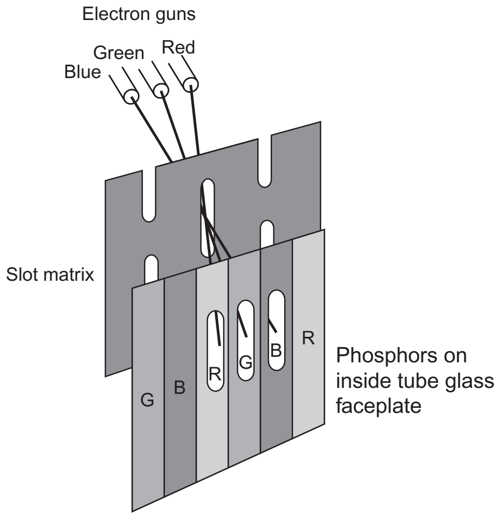
Resolution

The size of the display screen and its viewing distance will be one factor in how much detail is discernible in a televised image. Due to the regulation of television transmissions, the design of the system (e.g. number of lines, interlace, etc.) and the permitted bandwidth will affect the detail (sharpness) of the broadcast picture. Bandwidth will determine how much fine detail can be transmitted.

The active number of lines (visible on screen) in a 4:3 PAL picture is 575. However, a subject televised that alternated between black and white, 575 times in the vertical direction would not necessarily coincide with the line structure and therefore this detail would not be resolved. The limit of resolution that can be achieved is deduced by applying the Kell factor which for the above example is typically 0.7. This results in a practical resolution of 400 lines/picture height. The horizontal resolution will be 4/3 of 400 equalling 533. The number of cycles of information/line equals 533/2, resulting in 266.5 taking place in 52 µS (time taken per line). This results in a bandwidth requirement of 266.5/52 µS – approximately 5.2 MHz for 625 4:3 picture transmission.

5.2 MHz bandwidth will be required for each channel broadcast using PAL 625, 4:3 picture origination. Other systems will have different bandwidth requirements such as 1250 HDTV PAL which has twice the resolution and needs 30 MHz. Digital transmission allows some bandwidth reduction using compression (see Compression, page 26).

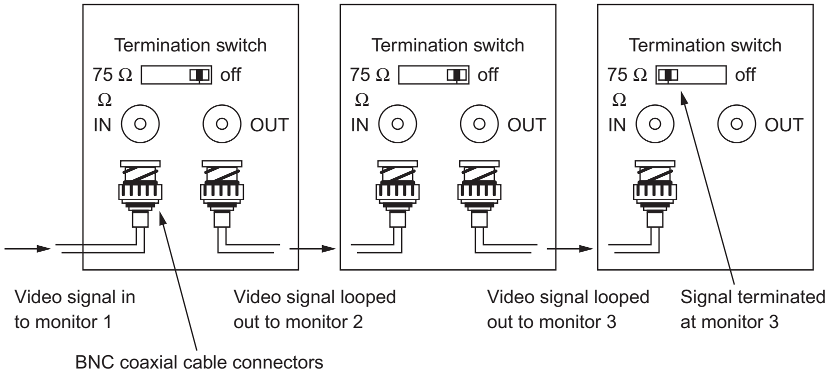
Slot-mask colour tube



Colour is created on a TV screen by bombarding three different phosphors (red, green and blue) that glow when energized by an electronic beam. The screen may be one of three designs, shadow mask, aperture grill or slot-mask (illustrated above), depending on how the pattern of phosphor dots are arranged on the inside face of the tube. The slot-matrix vertical slots are arranged so that each beam only strikes its corresponding phosphor line on the screen.

NB: a video monitor refers to a visual display fed with a video signal. A receiver refers to a display fed with a radio frequency signal.

Monitor termination



A video signal fed to a monitor must always be terminated (usual value is 75 Ω) unless it is looped through to another monitor. The last monitor in the chain (monitor 3 above) must be terminated to avoid signal distortion.

Charge-coupled devices

MOS capacitors

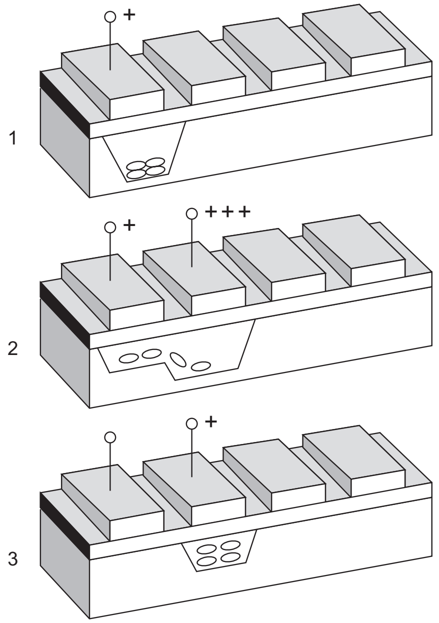
A MOS capacitor (see figure opposite) is a sandwich of a metal electrode insulated by a film of silicon dioxide from a layer of P-type silicon. If a positive voltage is applied to the metal electrode, a low energy well is created close to the interface between the silicon dioxide and the silicon. Any free electrons will be attracted to this well and stored. They can then be moved on to an adjacent cell if a deeper depletion region is created there. The ability to store a charge is fundamental to the operation of the charge-coupled device plus a method of transferring the charge.

Charge-coupled device

If a photosensor replaces the top metal electrode, and each picture element (abbreviated to pixel) is grouped to form a large array as the imaging device behind a prism block and lens, we have the basic structure of a CCD camera. Each pixel (between 500 and 800 per picture line) will develop a charge in proportion to the brightness of that part of the image focused onto it. A method is then required to read out the different charges of each of the half a million or so pixels in a scanning order matching the line and frame structure of the originating TV picture. Currently there are three types of sensors in use differing in the position of their storage area and the method of transfer; they are frame transfer, interline transfer and frame interline transfer (see page 20).

- **Frame transfer:** The first method of transfer developed was the frame transfer (FT) structure. The silicon chip containing the imaging area of pixels is split into two parts (see figure opposite). One half is the array of photosensors exposed to the image produced by the lens and a duplicate set of sensors (for charge storage) is masked so that no light (and therefore no build up of charge) can affect it. A charge pattern is created in each picture field which is then rapidly passed vertically to the storage area during vertical blanking. Because the individual pixel charges are passed through other pixels a mechanical shutter is required to cut the light off from the lens during the transfer. An important requirement for all types of CCDs is that the noise produced by each sensor must be equivalent, otherwise patterns of noise may be discernible in the darker areas of the picture.
- **Interline transfer:** To eliminate the need for a mechanical shutter, interline transfer (IT) was developed. With this method, the storage cell was placed adjacent to the pick-up pixel (see figure on page 21), so that during field blanking the charge generated in the photosensor is shifted sideways into the corresponding storage element. The performance of the two types of cell (photosensor and storage) can be optimized for their specific function although there is a reduction in sensitivity because a proportion of the pick-up area forms part of the storage area.

MOS capacitors

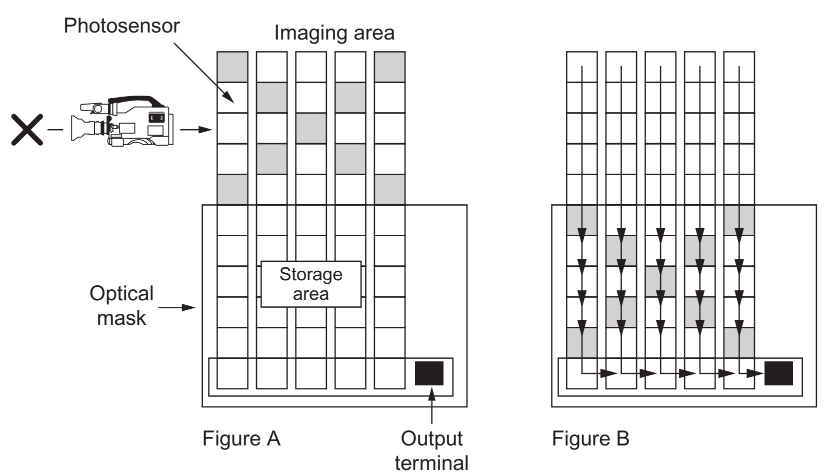


1: After a positive voltage (e.g. 5 V) is applied to the electrode, a low-energy well is created below the oxide/semiconductor surface, attracting free electrons.
2: If 10 V is applied to the adjacent electrode, a deeper low-energy well is created, attracting free electrons which now flow into this deeper bucket.
3: If the voltage on the first electrode is removed and the second electrode voltage is reduced to 5 V, the process can be repeated with the third cell. The charge can be moved along a line of capacitors by a chain of pulses (called a transfer clock) applied to the electrodes.

By replacing the electrode with a light-sensitive substance called a 'photosensor', a charge proportional to the incident light is transferred using the above technique.

Schematic of frame transfer CCD

The imaging area of a frame transfer CCD is exposed to the subject (X) and each photosensor is charged in proportion to the incident light intensity. A mechanical shutter covers the photosensors during vertical blanking and each photosensor transfers its charge to the sensor below until the storage area duplicates the imaging area. The shutter is opened for the next field whilst each sensor in the storage area is horizontally read out in turn. What was a two-dimensional grid of variations in light intensity has been converted into a series of voltage variations.



FIT and HAD CCDs

Vertical smear

One problem with interline transfer is vertical smear. This occurs when a very strong highlight is in the picture and results in a vertical line running through the highlight. It is caused by the light penetrating very deeply into the semiconductor structure and leaking directly into the vertical shift register. Since only longer wavelength light is able to penetrate deeply into the silicon, the vertical smear appears as a red or a pink line.

Frame interline transfer

In an attempt to eliminate the vertical smear the frame interline transfer (FIT) was developed (see figure opposite). This combines the interline method of transferring the charge horizontally to an adjacent storage cell but then moves the charge down vertically at 60 times line rate into a frame store area. The charge is therefore only corrupted for a sixtieth of the time compared to IT CCDs.

Resolution

To reproduce fine detail accurately a large number of pixels are needed. Increasing the number of picture elements in a 2/3-in pick-up device results in smaller pixel size which decreases sensitivity.

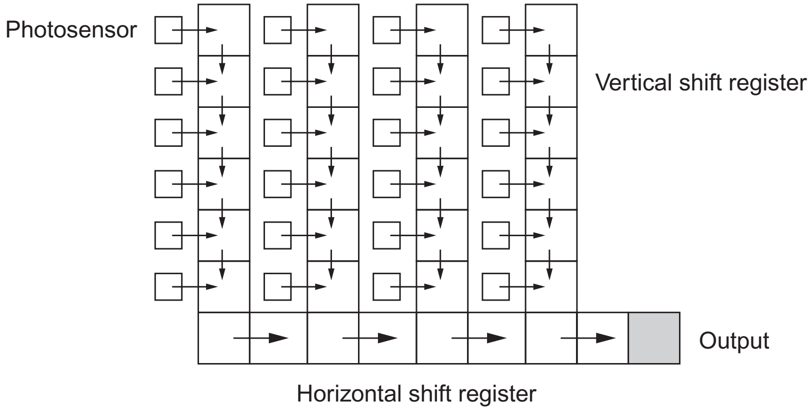
Aliasing

Each pixel 'samples' a portion of a continuous image to produce a facsimile of scene brightness. This is similar to analogue-to-digital conversion and is subject to the mathematical rules established by Nyquist which states that if the input signal is to be reproduced faithfully it must be sampled at a frequency which is greater than twice the maximum input frequency. Aliasing, which shows up as a moiré patterning particularly on moving subjects, is caused by a high input frequency causing a low 'beat' frequency. It is suppressed by offsetting the green CCD by half a pixel compared to red and blue. Another technique is to place an optical low pass filter in the light path to reduce the amount of fine detail present in the incoming light.

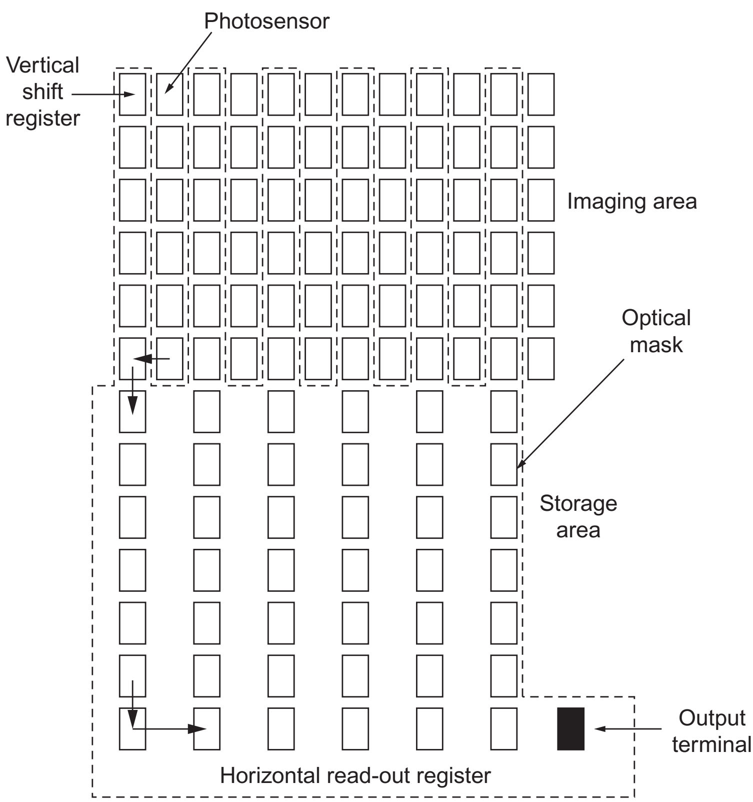
HAD

The hole accumulated diode (HAD) sensor allows up to 750 pixels per line with an improvement in the photosensing area of the total pick-up (see figure on page 23). Increasing the proportion of the surface of the photosensor that can collect light improves sensitivity without decreasing resolution. The HAD chip also helps to avoid vertical smear. Hyper HAD chips increase the sensitivity of cameras by positioning a tiny condensing lens on each individual pixel. This increases the collecting area of light.

Interline transfer



Frame interline transfer



CCD integration

Switched output integration
A PAL television picture is composed of 625 interlaced lines. In a tube camera, the odd lines are scanned first then the beam returns to the top of the frame to scan the even lines. It requires two of these fields to produce a complete picture (frame) and to synchronize with the mains frequency of 50 Hz, the picture or frame is repeated 25 times a second.

CCD frame transfer (FT) devices use the same pixels for both odd and even fields whereas interline transfer (IT) and frame interline transfer (FIT) CCDs use separate pixels with a consequent increase in resolution. There are two methods to read out the stored charge:

- **Field integration:** This reads out every pixel but the signals from adjacent lines are averaged. Although this decreases vertical resolution, motion-blur will be less.
- **Frame integration:** This reads out once every frame (two fields) and therefore will have more motion-blur as the signal is averaged over a longer time span than field integration but may have better vertical resolution on static subjects. Enhanced vertical definition systems offer a higher resolution of frame integration without the same motion blur. It is obtained by blanking off one field with the electronic shutter, reducing camera sensitivity by one stop.

Colorimetry
The transparent polysilicon covering the photosensor of the IT chip progressively filters out the shorter blue wavelength and therefore is less sensitive to the blue end of the spectrum compared to its red response. On HAD sensors there is no polysilicon layer and therefore the spectral response is more uniform.

Flare
Each element in a zoom lens is coated to reduce surface reflections but stray light reaching the prism causes flare, lightening the blacks, and a consequent reduction in contrast of the optical image. Flare is to some extent a linear effect and can be compensated for electronically. Flare can also occur at the surface of CCD devices where light is reflected between layers or scattered by the etched edges of sensor windows.