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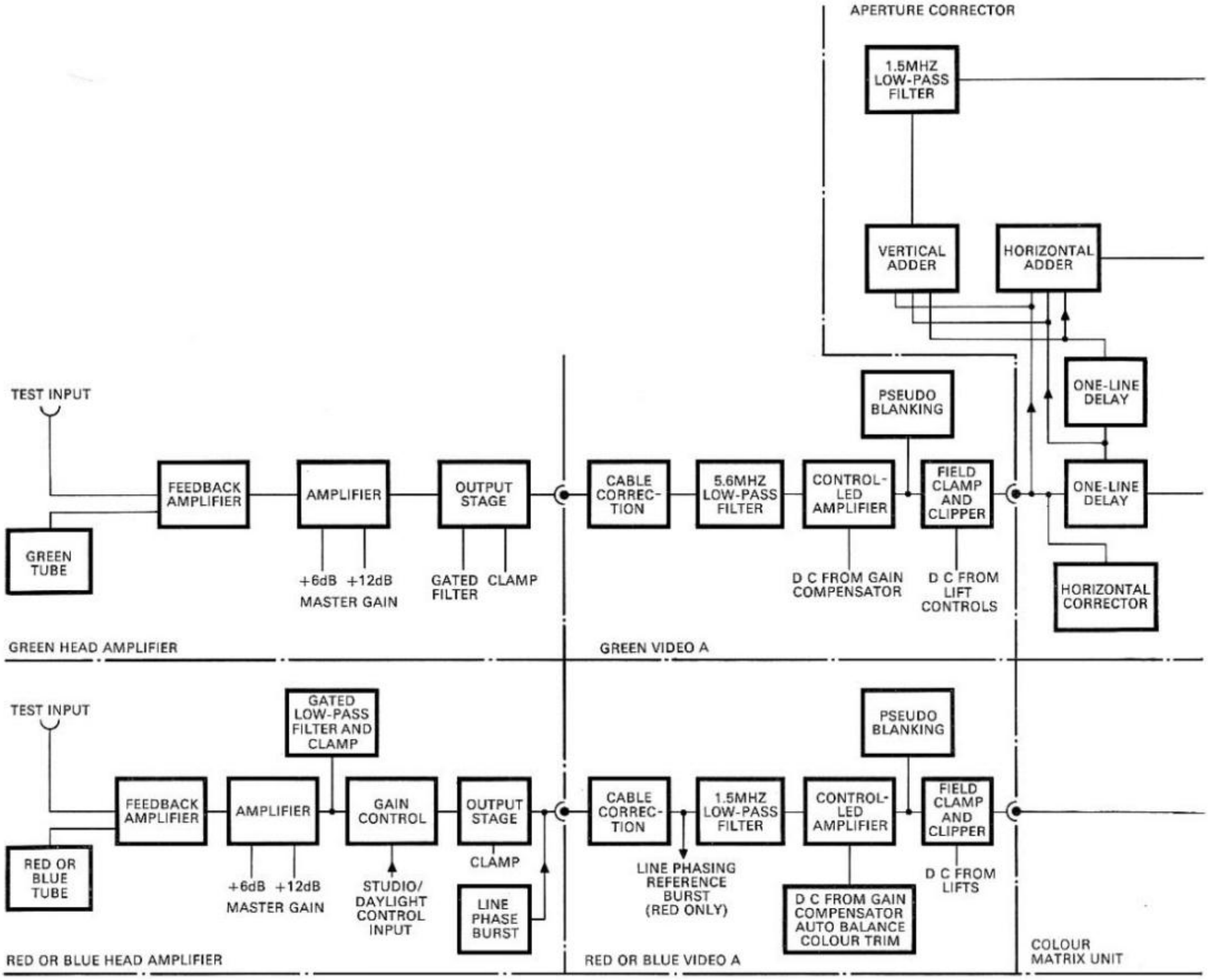
# THE MARK VIII CAMERA CHANNEL – DESIGN OF THE VIDEO CIRCUITS

## INTRODUCTION

A general outline of the video processing employed in the Mark VIII Camera Channel, and the reasons leading to the final choice of system, are given in previous articles in this series.[1,2] Briefly summarizing, size and weight considerations led naturally to the choice of a three-tube camera.

To overcome the vulnerability of conventional GRB cameras to loss of resolution due to registration errors, a video processing method in which the fine picture detail is derived from only one tube has been developed. The spectral response of the optics associated with this tube is made sufficiently broad to encompass the blue and red regions of the



spectrum. Thus, the two remaining tubes need provide only low-frequency video information in the blue and red regions respectively.

The high-frequency signals representing fine picture detail are extracted from the green channel, corrected for aperture loss, and then added to the three bandwith-limited channels to form three output signals, G, R and B, each effectively with the full video bandwidth.

## BASIC VIDEO SYSTEM

A simplified block diagram is shown in figure 1. The green channel is designed for the full video bandwidth of 5·5MHz. The minimum bandwidth needed for the red and blue channels is governed by the transmission system specification – bandwidths of 1·3MHz being typical. Consequently, video information must be provided by the camera colouring channels such that the colour encoder chrominance filters finally determine the red and blue channel responses. A suitable choice of bandwith is one with a level response to 1·5MHz and with the −3dB point at 1·8MHz.

The frequency response of the red and blue head amplifiers is made wider than 1·5MHz thus permitting low-pass filters to be used to define the overall responses of these channels. If a similar 1·5MHz low-pass filter is used in the green channel, the high-frequency detail information extracted from this channel will not only exactly complement the bandwidth-limited green, but also the red and blue channels, as shown in figure 2. With appropriate delay networks inserted in the aperture corrector, and with the three images correctly registered, the propagation delays are matched to provide red and blue signals with correctly-timed high-frequency signals which are also correctly timed with respect to green. Horizontal and vertical aperture correction signals, which are derived from the green signal, are mixed with the 'highs' information at the output of the aperture corrector. It is this combined signal of correction plus 'highs' which is added to all three channels.

## REQUIREMENTS OF THE AUTOMATIC SYSTEMS

The automatic facilities included in the Mark VIII Chain,[3] call for certain provisions in the video chain.

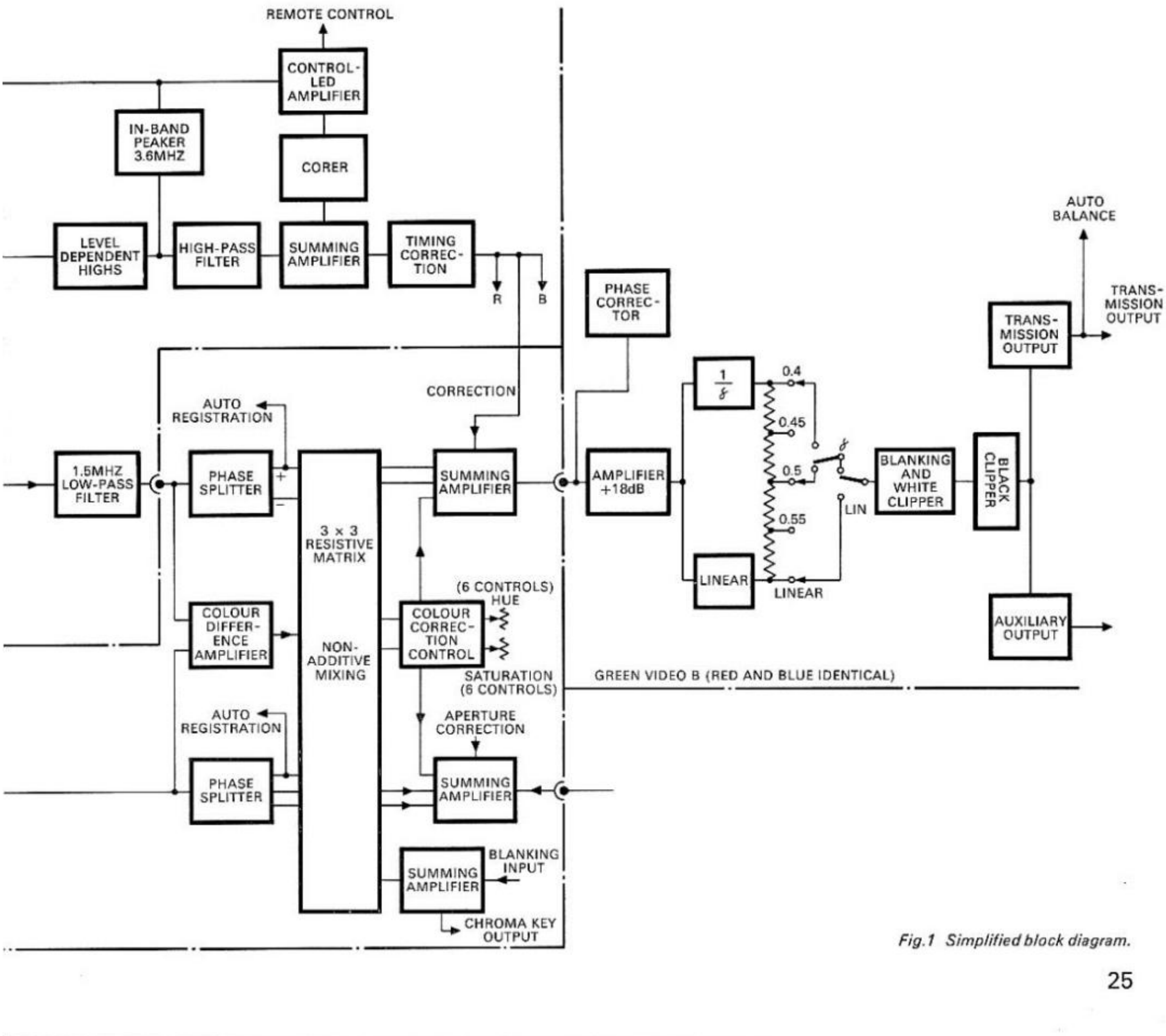



*Fig.1 Simplified block diagram.*

For accurate registration it is important that the three video signals be of equal amplitude. The sampling of a lower-amplitude red signal, for example, will register a later part of the transition in the red channel with that in the green reference channel, whereas a correct amplitude blue signal would produce the correct result. It is thus essential for the registration function to include a system automatically to balance the red and blue amplitudes to the green amplitude. Also, for maximum discrimination, the green signal level is always set to 0·65V, a value suitably below clipping level, by automatic control of the diascope lamp brightness. Exactly the same system is applied when a studio white balance is required except that the green signal amplitude is set by automatic control of the iris. The automatic balance system utilizes two motor-driven potentiometers controlling gain – one in each of the red and blue channels.

## PRESET CONTROLS

Close-tolerance resistors with excellent temperature coefficients, and semiconductors including integrated circuits with an inherently stable performance, are now readily available. Many of the variables often necessary to take up component tolerances can now be eliminated. Thus, not only undesirable components are eliminated, but also the possibility of their misadjustment. The three video channels are thus designed on a basis of constant gain. Apart from the motor-driven potentiometers the only operational control is the master gain control at the CCU – which increases all channel gains by +6dB or +12dB.

## CLAMP NOISE REJECTION

The type of clamp is such that, even at high master gain settings, the noise level at the clamping point in the head amplifiers is reduced to such a low level that the clamping in of low-frequency noise is prevented.[4] This is accomplished by switching a low-pass filter into the video signal path for the duration of the clamping operation. Clamp streaking is typical of operation with a normal clamp at high-gain settings but such streaking is virtually eliminated by the method described. The noise-free period which can be seen in figure 3 is used again at the CCU for line-clamping purposes prior to the addition to all three video signals of a pseudo blanking pulse. This pulse is timed to occur just inside the system blanking edges and is sufficiently large so that, when it is clipped away at a later point in the video path, all noise and other spurious signals are removed, leaving a clean interval for all subsequent clamps.

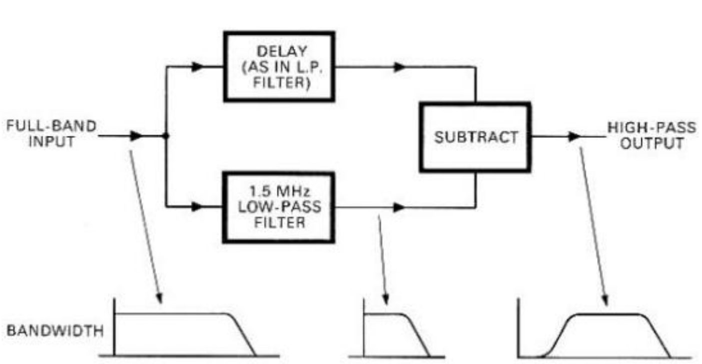



*Fig.2 High-pass filter system.*

### Sensitivity

Colour camera sensitivity is limited by two main factors, namely, signal-to-noise ratio and differential lag. The broader spectral responses and high-efficiency optical system of the Mark VIII, together with its good signal-to-noise ratio made possible by the new head amplifier design, coupled with the 100% combing used in the aperture correctors[5] ensure that, with respect to noise, broadcast quality pictures are obtainable with scene illumination levels as low as 50 to 100 lux. To reduce the differential lag to a level whereby picture degradation at extremely low light levels due to lag is subjectively similar to that due to noise it was decided to:

(a) use reduced-sized images on the red and blue tubes; and
(b) design the camera to accept tubes with a light bias capability.

The latter provision affects the circuit design since, when light-bias tubes are used, an artificial pedestal exists equivalent to between 5nA and 15nA signal current. Since this pedestal will vary with any change of bias causing black level variations, particularly when the master gain is changed, it was decided to use an optical black clamping system.[6] The method is illustrated by figure 4. Although masks are used in the optical path they cannot be fitted in the actual image plane and will thus produce out-of-focus edges on the target. An area spaced away from the normal rectangle must therefore be scanned – a strip of eight lines between 10% and 15% above the normal rectangle. A field clamp[7] is used with two clamp pulses on successive lines, once per field. The pulses used are shorter than an active line period to avoid clamping on any spurious signals which may result from scanning the target mesh ring. The tube is not cut off with beam blanking pulses during the eight-line excursion period, and output signals are obtained which represent the sum of the current due to light bias and the dark current. This artificial black level is automatically clamped to the same d.c reference regardless of variations in light bias or dark current.

## HEAD AMPLIFIERS

Careful head amplifier design was needed to take full advantage of the light inputs to each camera tube. A good result is essential here as no amount of subsequent video processing can overcome a poor head amplifier design. The requirement of low noise, particularly at the lower frequencies which subjectively degrade the picture disproportionately, is well known. The first critical area is mechanical and involves the design of rugged but low-capacitance contacts, which convey the extremely small signal currents from tube to head amplifier input. The design of the input stage printed circuit

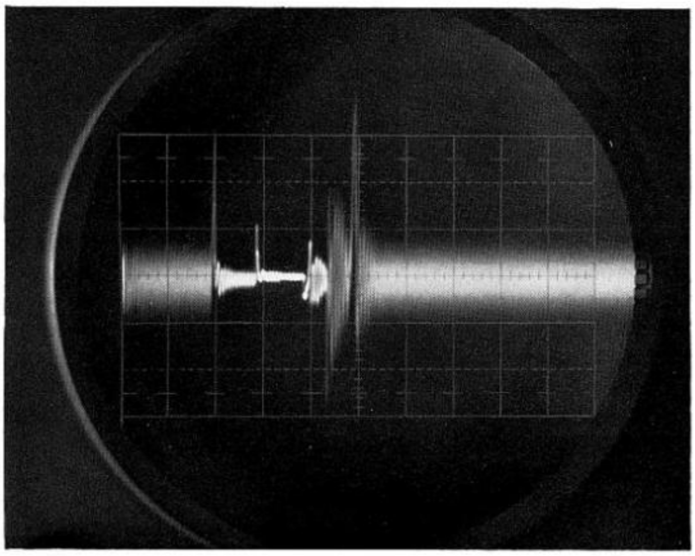


*Fig.3 Video waveform showing noise rejection period.*

requires similar attention to mechanical detail. The stray capacitance associated with the tube and input stage must be minimized. Also, the use of a Percival coil, the choice of input stage transistor and operating conditions which obviate the use of a heat sink, are steps which contribute to the reduction of noise to a point where the camera tube characteristics, rather than head amplifier noise, determine the absolute sensitivity of the camera. Correction for the high-frequency loss due to the input capacitance is achieved by the use of shunt negative feedback. This method of correction makes compensation for the Percival circuit less critical and thus improves, in particular, the phase stability of the head amplifier against camera tube changes and drift with time.

The remaining processing before transmission to the control unit raises the signal level from, typically 0·3V to 0·7V peak-to-peak into the camera cable. An amplifier accepts the master gain logic signal from the CCU by operating on the feedback network via electronic switches to give increases of +6dB and +12dB. Limiters are included to provide for the Highlight Overload Protection type of camera tube, and to limit peak drive to the camera cable. The bandwidth reduction during clamping periods is effected after the gain control amplifier and just prior to the line clamp. This clamp sets the bias for the output stages so as to permit maximum signal handling capacity.

The red and blue head amplifiers are identical, but differ from the green in that no Percival coil is used, and provision for change between studio and daylight illumination requires an extra gain control. The appropriate normal gain for the red and blue channels is automatically set on plugging in the head amplifier. The form of construction of the head amplifier is shown in figure 5.

## SIGNAL PROCESSING: VIDEO A

### Cable Correction

Signals from the three head amplifiers are received on the 'Video A' boards along a maximum of 900 metres of camera cable. The design of the three boards is fundamentally the same; component value differences follow from the greater video bandwidth of the green channel as compared to the red and blue. Correction for cable loss is made in three groups of 300 metres, selected by a rotary switch, with a fine control from zero to 300 metres to equalize cable lengths which lie between the 300-metres multiples. The characteristics required in a cable corrector depend upon the particular cable in use. To facilitate the use of alternative cables, the components concerned are mounted on a small mating board contained within the 'Video A' board, (Fig.6). Following equalization for cable loss are band-defining filters of 5·6MHz cut-off for green and 1·5MHz for red and blue. Before the filters a camera line scan phasing reference burst of 8Hz at 5MHz is fed to a small receiver forming part of the channel pulse circuits. This burst is only present on the red channel, and then only during part of the line blanking period.

### Gain Compensation and Control

The video output from the band-defining filters is reduced in level for application to a variable-gain stage. This is the only variable gain control within the whole camera channel. The controlling d.c voltage is a combination of signals from the master black controls, individual lift controls and the flare controls. All of these are gain compensated to give a constant output, for example, increased lift is compensated by reduced gain. A further potentiometer is provided as a preset gain control. This is only adjusted to take up manufacturing tolerances and spread in the characteristics of the gain control element which is mounted inside a small oven to provide the requisite temperature stability.

Additionally, in the red and blue channels, further d.c control signals are applied to the variable gain stage which are derived from the automatic gain balance controls and the colour trim controls. When internally generated test signals are switched into either the CCU or the camera, all variable controls are returned to earth reference with the only operational controls being the preset gain and master black thus allowing an overall channel gain check.

### Field Clamp and Black Clipper

The video signals are amplified to a suitable level for the clipping of spurious signals and noise in the

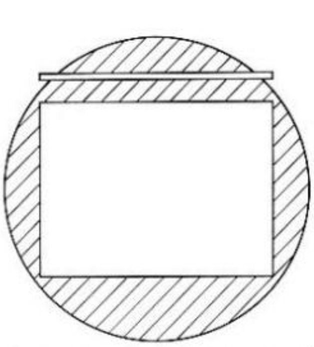


*Fig.4 Target scanned area with the eight-line strip 10% above. Unscanned areas shown shaded.*

line blanking interval. This is accomplished by a novel arrangement employing a locally generated pseudo blanking pulse, a field clamp[7] and a black clipper. The field clamp employs field effect transistors to give the exceptionally long time constant needed to avoid field tilt, and yet enable a rapid change of state from one field to another to stabilize mean level changes. A special clamp[7] driver stage has been designed to ensure accurate and rigid stabilization of the clamping level. The black clipper removes a variable amount of the pseudo blanking pulse depending on the settings of the lift controls. The clipper is of a new design and affords good signal linearity right down to the clipping point. This is essential to maintain good black level and gamma tracking between channels. The clipped signal is attenuated to standard level and fed from the board at 75Ω impedance.

## APERTURE CORRECTION

The aperture correction circuits provide a correction signal for compensation of the aperture loss in the green channel, and also supply to the red and blue channels a signal representing the fine detail in the scene.

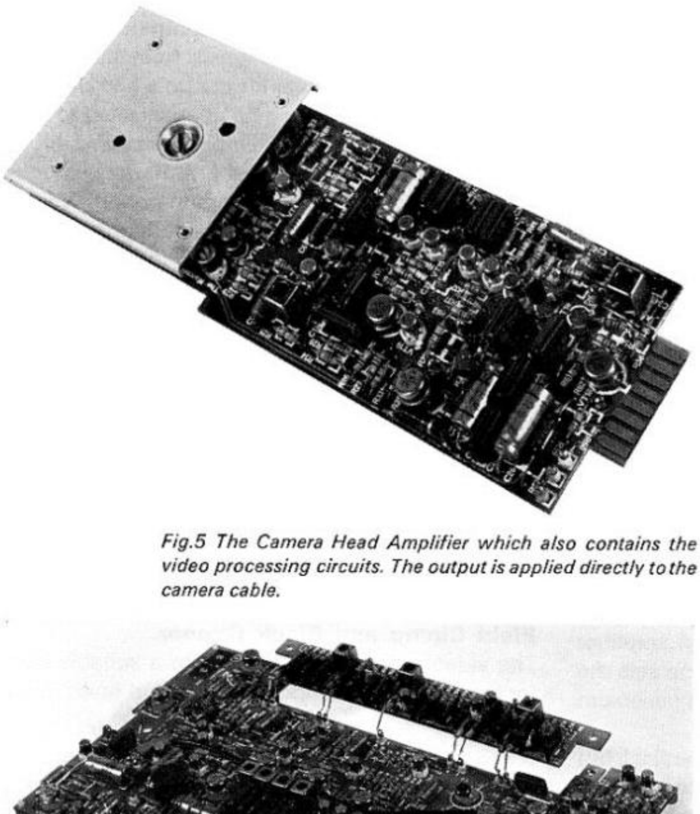


*Fig.5 The Camera Head Amplifier which also contains the video processing circuits. The output is applied directly to the camera cable.*

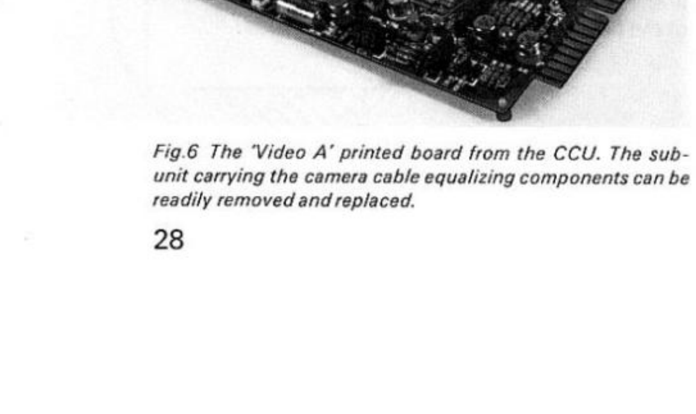


*Fig.6 The 'Video A' printed board from the CCU. The sub-unit carrying the camera cable equalizing components can be readily removed and replaced.*

Correction, at a maximum boost frequency of 10MHz, is provided for horizontal aperture loss, up to 12dB being available on a pre-set control. The horizontally corrected signal is applied to an r.f modulator for driving in series the two glass delay lines, each delay being equivalent to one horizontal scan period. Demodulated, delayed and undelayed signals are utilized in two ways, firstly to provide correction for loss of vertical detail[8] and, secondly, in a novel arrangement whereby horizontal combing is provided.[5,9] This combing gives a measured 3dB signal-to-noise ratio improvement.

The vertical correction signal is band limited and added to the output of the 'In-Band-Peaking' circuit, the amount of peaking being adjustable within the range zero to +6dB. The output from the horizontal adder is fed to the level-dependent circuit which only passes signals above a certain level, typically 5%, to the 'In-Band Peaker' and the line detail separation circuit. The mixed vertical correction and the 'In-Band-Peaking' signals are applied to a d.c controlled amplifier for the remote control of aperture correction, and then applied to a coring circuit for the reduction of noise in the correction signal. The high-pass filter is compounded from a low-pass filter of the type used in the red and blue 'Video A' circuitry and a subtraction circuit (Fig.2). Full band video signals, suitably delayed to match the delay of the low-pass filter, are applied to one input of a differential amplifier whose other input is the output of the low-pass filter and is complementary to the low-pass filters in the red, green and blue channels. The variable aperture correction signal is added to the output of the simulated high-pass filter and fed to the matrix circuit to reassemble the fully corrected video signal.

## COLOUR CORRECTION MATRICES

Two forms of colour correction are employed. One uses a fixed value matrix computed from the measured responses of each individual optical system to produce a minimum overall colour error – in either the studio illumination of 3000K or, by an alternative fixed matrix, in daylight at 5500K.

The alternative correction method allows for adjustment to be made to the hue and saturation of individual colours without disturbing the white point to which the camera is colour balanced. If required this variable correction facility may be used in conjunction with the fixed matrix. Thus considerable scope is given to the operator for the colour correction of very difficult subjects.

The two separate colour correction techniques used do not interact electronically with each other.

### Fixed Matrix

In case of the fixed matrix, the low-band G, R and B signals are applied to amplifiers giving equal and opposite outputs for each primary. The use of integrated circuits is convenient since the same amplifier configuration is repeated several times for each colour. Outputs from these amplifiers are fed to one of two 3×3 colour correction matrices calculated respectively for studio and daylight colour

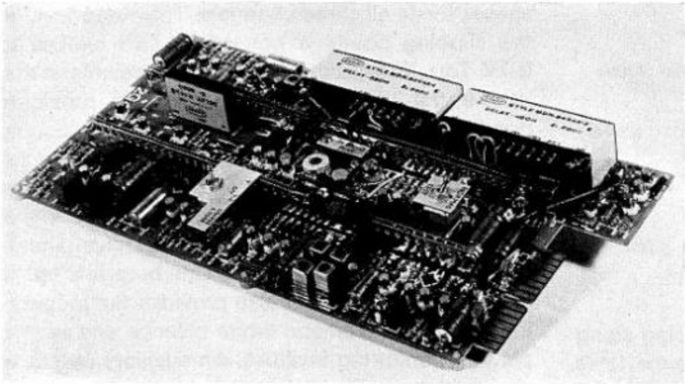


*Fig.7 A part of the Aperture Correction Module – the 'Adders' board.*

temperatures, as well as correcting for individual camera optical responses. Accordingly, the particular matrix factors are related to a specific optical assembly. Resistors constituting the matrix are mounted on a small sub-module carried on the main matrix board and should always accompany the camera optic for which it is specifically designed. A single toggle switch sets the matrix factors for studio or daylight operation, and is accessible just inside the tray containing the matrix. This switch also relays a signal to the red and blue head amplifiers for associated gain switching to achieve colour balance. The signals from the resistive network which forms the corrected primary signal are added in a summing stage which also employs an integrated circuit amplifier. Here the separated image enhancement signals from the aperture corrector are fed to one input on each summing amplifier whose output is thus a full band video signal including aperture correction. Finally, the video signals are clamped and passed to the gamma corrector module, Video B, at 0·7V level. A chroma-key signal is provided from the matrix board which can be adjusted to provide any combination of the colour signals for keying purposes to an output socket on the CCU rear panel.

### Variable Matrix

The variable matrix system operating on colour difference signals only is also carried on the matrix board. Processing is effected by taking the same three red, green, and blue inputs as are used for the fixed matrix and applying them to the appropriate inputs of an integrated differential amplifier. Four such amplifiers are used providing outputs G–R, G–B, B–R, and R–B. The mechanism by which particular hues are selected is illustrated for the red correction signal with the use of colour bars. Figures 8(a) and 8(b) show respectively green and red colour bar signals which are added algebraically to give the waveform shown in figure 8(c). It is observed that zero output results only when G and R are equally present; this results from a specific yellow hue or a grey signal. A similar process, not illustrated, results in figure 8(d) for blue and red signals. Only when a red signal is present does either the G–R or B–R signal go negative, but both only go negative simultaneously for a pure red. Clamping the colour difference signals to a common reference d.c level enables a process of non-additive mixing to select and pass only that part of the video signal in both G–R and B–R which results from a red hue. Thus the more positive signal of G–R and B–R is separated by a diode network. (Fig.8(e)), and is only passed when this output is negative (Fig.8(f)). The six correction signals thus produced are added to the main path red, green, and blue signals using the same summing amplifiers that are used for the 3×3 fixed matrix.

## SIGNAL PROCESSING: VIDEO B

### Gamma Correction

The 0·7V input signal is applied, via a phase corrector which corrects for the total channel phase errors, to a feedback amplifier whose output is used to drive the current generator feeding the gamma corrector. Black-level clamping just prior to the gamma corrector sets the video at the correct point on the 0·4 pure power law function generator. The gamma corrector operates by switching resistances through biased diodes as the signal progresses from black to white. The four diodes are arranged in an array and are mounted in a small thermostatically controlled oven which ensures that the gamma law is constant and reduces tracking errors between channels to better than 0·25%. The gamma-corrected output is again clamped and applied to one end of the resistor chain to the other end of which is applied the linear video signal. This linear signal is tapped off prior to gamma correction and fed through delay equalizing networks before being

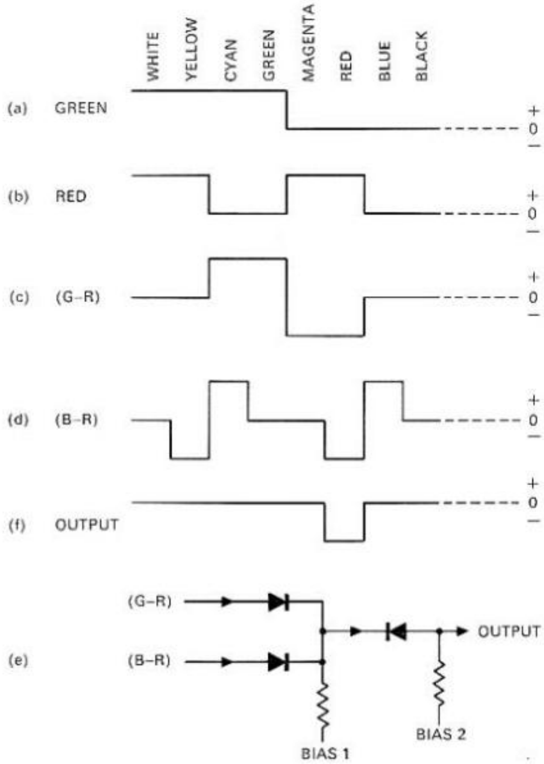



*Fig.8 Waveform of the variable matrix section of the Colour Matrix Unit. Also shown is the diode network in which the signals are non-additively mixed.*

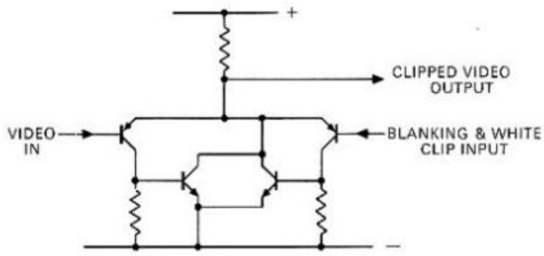



*Fig.9 The basic circuit of the video clipping amplifiers.*

recombined with the gamma signal. Tapping along the resistor chain provides the four gamma laws any two of which may be preselected inputs to an electronic switch for simultaneous change of law in all three channels. A further input to the electronic switch is the linear signal which completes the gamma/linear control.

### Blanking Insertion

Black and white clipping, together with blanking insertion, are carried out using emitter-coupled transistors arranged in differential fashion (Fig.9). White clipping and blanking insertion are carried out in one stage. A single white clip control sets the d.c position of the input blanking signal. No signal is passed which is greater than the instantaneous blanking level, thus, for a line of peak white, blanking will be added due to linear coupling through the emitter follower. White clipping and blanking insertion are combined in the equivalent of a logic OR function. This method enables the rise times of blanking to be accurately determined, thus ensuring a clean blanking interval. Incoming system blanking pulses are reconstituted to eliminate hum and spurious signals by operating a Schmitt trigger from the blanking transitions only. The resulting waveform has a very rapid rise and fall and is shaped by passing through a sine-squared filter to produce the specified output rise times. The signal blanking shaper feeds all three channels. The video level at the clipping points is precisely +6dB relative to 0·7V, 75Ω. The design of the clippers is similar to that used in the 'Video A' signal processing, providing good linearity to the point of clipping. Black clipping is performed in a similar way but using a complementary design to that of the white clipper, the reference input being earth potential. The signal then divides two ways and feeds identical shunt-regulated 75Ω output stages. One output is fed to the colour encoder and also provides the monitoring point for automatic white balance and normal picture monitoring facilities. An auxiliary output of similar high quality is also available.

## ACKNOWLEDGEMENT

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