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A REMOTELY CONTROLLED CAMERA SYSTEM

INTRODUCTION

Less than a generation has elapsed since the concept of remotely controlled television broadcast cameras became a reality. The BBC Designs Department developed a number of prototype control systems which were applied with considerable success and even controlled cameras several miles away. Commercially, however, the first step was the electronic control of the lens zoom and focus elements. The cameraman was provided with a zoom shotbox, attached to one of the pan bars, which incorporated a rate zoom and positional focus control. The iris control was and still is situated together with master black level at the camera control unit (CCU).

The early sixties saw the first of the commercially developed remotely controlled camera systems. These generally comprised four or five preset shots for pan, tilt, zoom and focus, together with a manual selection which gave the operator control via the hand controls, rate control for pan and zoom, and positional control for tilt and focus. The transfer from shot to manual but not *vice versa* was made 'bumpless' by the use of a follow-up servo. Many variations of this basic system were custom built. One in particular was designed to provide an operator with control access as required, to any one of four cameras, from a single desk.

Later on, more controls were added to enable the operator to control the transition of the functions in a gradual manner when going from shot to shot, rather than having all the servos running at the respective maximum speeds. These controls varied the amount of tacho feedback and consequently the speeds of the functions. Thus, by adjusting these controls it was possible to arrange for the functions to arrive at the next shot position simultaneously. To obtain a good result with each shot change led to considerable complication and this method was soon dropped in favour of the fader control. Its use required two shots to be available for selection at the same time, one to start from and one to go to, and this was generally achieved by arranging the shots available in two rows. The fader could be moved to and fro between rows by hand, in a positional mode or alternatively driven by a variable-speed motor in a rate mode, the shot selected in the row that the fader was at or nearest to taking relative preference over the shot selected in the other row.

Development continued, especially at the man-machine interface, to provide controls with a more natural 'feel'. Bumpless on-air trim controls were introduced and the control of the lens iris was provided for in a number of systems as an alternative to the CCU local control. Later, pedestal height was added to the list of controllable functions. More shots were incorporated to allow greater flexibility and as these are stored by the setting of a potentiometer, one per function per shot, an acceptably sized panel for six functions could only accommodate some ten shots if adequate accessibility was to be maintained. This is the limitation of this type of system if the camera control area is not to be saturated with shot-setting potentiometers.

Clearly a more sophisticated form of shot storage was needed and such a system forms the subject matter of this article. It may be useful to define at this stage some of the terms that have evolved and which are summarized below.

Fade

Rate or positional — a controlled change which produces the same proportional rate of change between one set of conditions at one end, i.e the start of the fade, and another set at the other end.

Shot

The combined positions of all the controlled functions which provide the desired picture.

Shot Cut/Jump

Once initiated this causes the controlled functions to run at their respective maximum speeds to establish the new shot either in the same row (cut) or in the other row (jump).

On-air Trim

This is a bumpless rate or positional control which enables a shot to be modified at will, but with the capability of being cancelled upon selection of the same shot or other action(s) dependent upon the type of system.

Manual Hand Controls

Rate and/or positional hand controls may be employed. Rate controls are bumpless whilst positional controls are not, except in the special circumstances of being faded from or to, or in systems employing follow-up servos. They are sometimes provided as an alternative to, but not

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necessarily instead of, on-air trim controls. These controls tend to be more sophisticated than the on-air trims to provide 'feel' and usually incorporate control access for two or more functions.

INSTALLATION

A plan view of the News Studios, BBC Television Centre, is shown in figure 1. The remotely controlled camera installation, a schematic of which is shown in figure 2, comprises in addition to the interconnecting cables:

i. Main data processing console
ii. Patch panel
iii. Ten control panels
iv. Eight lens units (two types)
v. Eight heavy duty pan and tilt units
vi. Eight pedestals (four servo controlled)
vii. Eight camera channels
viii. Two multi-function hand controls

This complement of equipment to serve the two main studios referred to as N1 and N2, each with separate control rooms, the conference room and the central news room having a common control room. The main console, patch panel and CCU's are situated in the vision apparatus room.

Console

This duplex cubicle accommodates standard 19in racks which comprise power supply units, ferrite core store, timer and store interface card rack and for each controlled camera, one analogue/digital convertor (ADC) card rack. Although only eight channels are used at present, the console is wired to accept a further four channels. Connectors to the panels and camera pedestals are accessible at the base of the console and are routed via the patch panel.

Patch Panel

The patch panel, figure 3, enables the ADC's to be patched in any order to eight of the available fifteen studio outlets and to two of the four control panels in N1, N2, or to the conference control room's panels. Two of the control panels in N1 and N2 are permanently wired to ADC's. The BBC has standard facilities for patching CCU's to the required studio outlets and, since the master black level is routed via this panel, it is imperative that the patching of both panels is compatible.

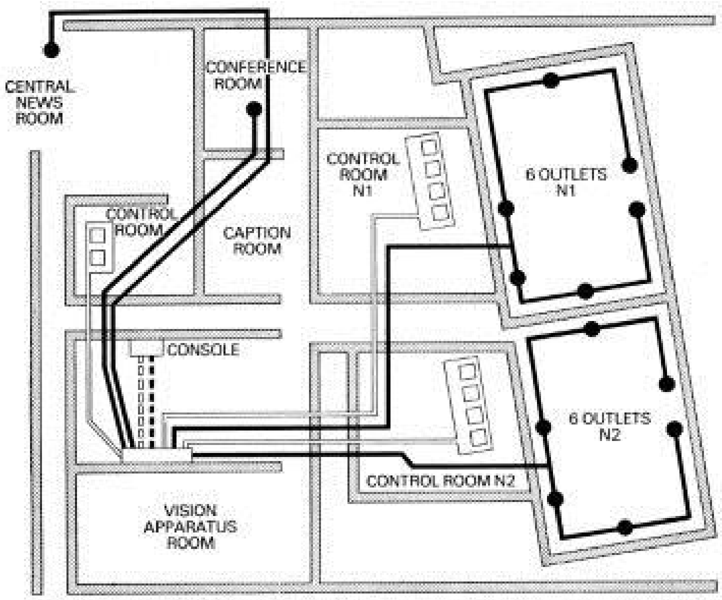

Fig.1 New studios, BBC Television Centre.

Camera Mounting

One of the remotely controlled cameras, complete with lens unit and mounted on a servo operated pedestal with the heavy duty pan and tilt, is shown in figure 4. It will be seen that conventional pan bars with zoom shotbox and focus control are fitted. The BBC considered these facilities should be retained and incorporated in such a way that a cameraman can take control, having switched from remote to local control at the pedestal. This feature increased the complexity of the system somewhat but ensured three things; first a reversionary means of control in the event of a system failure broadly excepting power supplies, second the same means of control should the system prove inflexible enough for special presentations, and thirdly that the camera and lens could be used in other studios without remote control. In addition the facility is used during camera line-up. With control switched to local the pedestal height is adjusted by means of the steering ring and tacho damping is applied to the pan and tilt servos to provide the cameraman with 'feel'. An important aspect of the pedestal is that it was designed specifically for both remote control and manual operation and is extremely simple to service.

CONTROL PANELS AND OPERATION

Two control panels are used for each camera, a larger one described as the 'Main Control Panel' and a smaller one, the 'Camera Control Panel'. This division is preferred since it keeps as far as possible the vision controls, normally associated with the Camera Control Unit, separate from the camera attitude controls, (Fig.5). It is worthwhile noting at this point that relay logic had to be employed throughout the panels.

Main Control Panel

This panel mounts the following controls

(a) *'Available On' Illuminated Push Switch.*
A push-push type switch enabling power supplies to be switched on or off the camera servos which the panel controls. A significant interruption of power to the system or switch-off causes this facility to fail safe such that when supplies are restored the camera servos are off.

(b) *Remote Control Off Annunciator.*
This annunciator is illuminated red when local control at the camera is assumed. The local/remote switch is located at the camera pedestal and may be operated to prevent remote control whilst the camera is being serviced or for other reasons already discussed.

(c) *On Air/Camera Number Annunciator.*
This annunciator, engraved with the camera

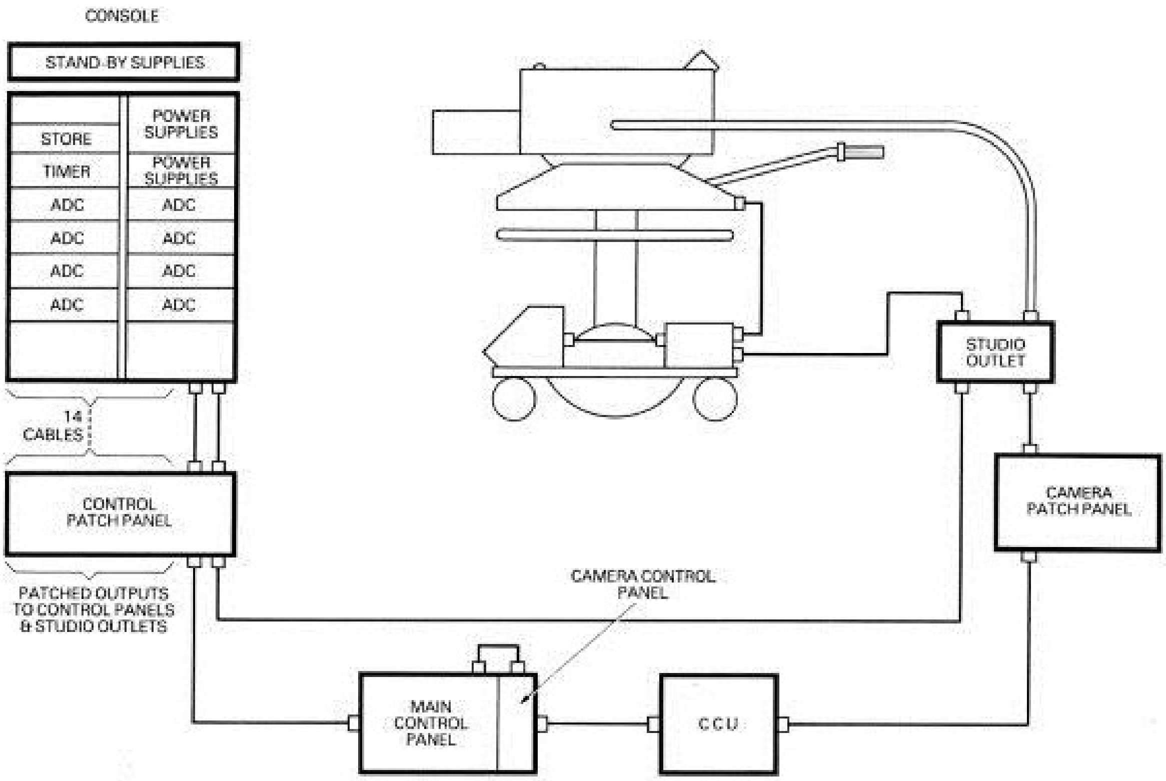

Fig.2 Camera control system.

number is normally illuminated white, changing to red whilst the camera is 'on air'.

(d) *Shot Selection Illuminated Push Switches and Writing Strips*

Two rows, each of ten illuminated push switches provide the means for shot selection and setting up. The upper row 'A' is numbered 1 through 10 and the lower row 'B' is numbered 11 through 20. Shot selection is accomplished by momentarily depressing the required button when the system acknowledges receipt of this selection by illuminating that button white. Only one button in each row is operative at any one time and when the camera is 'on air' one or other or both of the shots selected changes to red depending upon the fader control position. Two writing strips, situated adjacent with the rows, are illuminated white when the panel is 'available on'. They are intended to help the operator remember the shots set up.

(e) *Manual Selection Illuminated Push Switch*

Momentary depression of this switch overrides a shot selected in row 'A' and *vice versa*. Selection of this facility provides access to camera control via the multi-function hand controller provided that it is connected. The system acknowledges receipt of this selection by illuminating the push switch white.

(f) *Fader Control*

This control determines the relative contributions of the shots selected at each end of the fader. A lamp at the top of the fader is illuminated when the fader control is at the top and one at the bottom is illuminated when the fader control is at the bottom. Both lamps are lit when the fader control is away from these positions.

(g) *'On Air Trim Controls and Trace Annunciators'.*

Five 'on-air' trim controls are provided, one each for the Pan (coarse, fine) Tilt, Zoom, Focus and Pedestal Height functions. These controls may be used to trim a shot at any time. Trim so introduced is added to the shot in the row which the fader control is at or was last at. Any trim introduced may be cancelled by reselecting the same shot or selecting any other shot in the same row, or at completion of a fade to the other row. This action automatically cancels the shot selected in the other row.

The pan control is equipped to provide a coarse trim when the knob is depressed whilst it is turned. In every case it is possible to trim a function through its extremes of range. The controls are clutch operated spring return-to-centre potentiometers suitably geared to the control knob.

Trace annunciators associated with the trim controls, and appropriately engraved, light when there is continuity of connection through the system to the respective servo units.

(h) *Store Push Switch.*

Momentary depression of this switch is used to update a trimmed shot and is operative provided that the camera is not in mid-fade. It may also be used for the purpose of transferring a given camera position from one shot number to another, either in the same or the other row. Although it is not possible to store into the manual selection, the store push button may be used to transfer a shot set up on the hand controller to any required shot location.

Camera Control Panel

This panel mounts two 'On Air Trim' controls and trace annunciators, one each for Iris and Master Black Level, which work in a manner similar to those previously described, together with colour gain and lift controls plus camera talkback facilities. The R, G, B, lift and gain controls are simply potentiometers connected directly to the CCU remote inputs.

DATA AND SIGNAL PROCESSING UNIT

Timer

The timer provides for the system all the necessary time slots to control the analogue/digital conversions, and for time division multiplexing digital information to or from the store. The electronics comprise an asynchronous divider chain driven by a 8MHz crystal clock. The thirty or so necessary time slots are decoded by simple logic gating, from the divider chain, which is best considered as being grouped as follows:

i. Divide by eight
ii. Divide by sixteen — decoded to provide store and a/d counter strobes
iii. Divide by twelve — decoded to provide twelve camera slots
iv. Divide by sixteen — decoded to provide a/d conversion control slots
v. Divide by two — top row slots/bottom row slot
vi. Divide by ten — decoded to provide ten function slots

Store and Interface

The ferrite core store used has a capacity of 2,048 words and is operated in its full cycle modes; read — restore, when running from stored data, or clear-write, when storing a shot. Every function in the system has 14 bit resolution. The number of words used is determined by the product of the number of functions (7), the number of shots (20) and the number of cameras (8), to produce a total of 1,120 words.

The store address input of eleven lines is logically derived at the interface from the binary representation of shot numbers (5 lines), binary representation of function (3 lines) and binary representation of camera number (4 lines).

Security of stored data in the system is of the utmost importance. The store is equipped with a retention circuit such that, in the event of a.c mains and/or its internal supplies exceeding preset limits, it shuts down in a logical manner so as to retrieve all stored data. Operation of the store is inhibited thereafter until supplies are again in tolerance.

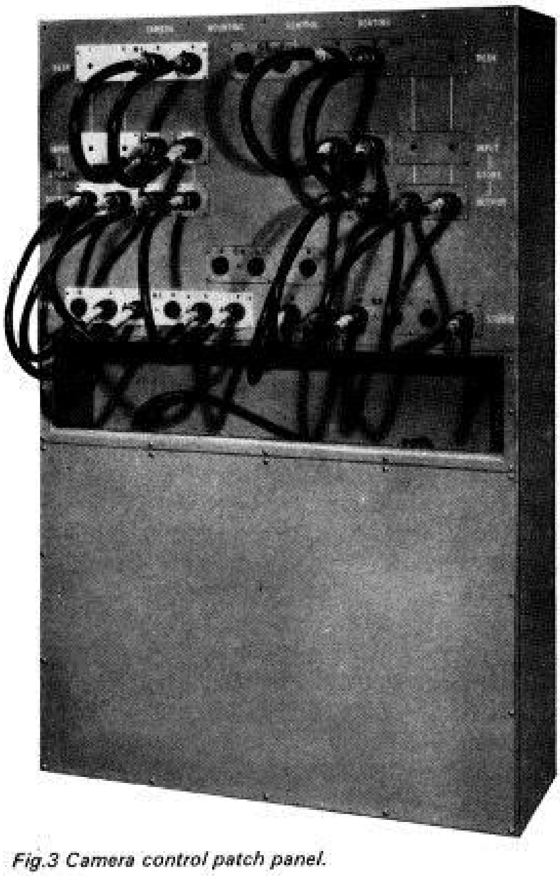

Fig.3 Camera control patch panel.

Analogue Digital Convertor (ADC)

One of these units is required for each controlled camera.

Signal Multiplexing

The seven functions together with a spare channel and two test functions are time division multiplexed by equal increments in the order: Pan, Tilt, Zoom, Focus, Pedestal Height, Iris, Black level, Spare, Test low, Test high. Every time slot is divided into two equal parts, the first relevant to the top row of shots, A, and the second relevant to the bottom row of shots, B. The updating of the test functions, whose relevance will become apparent later, is carried out during the first half periods only. Every function is updated nominally 16 times a second. Each half of every function time slot is divided into three important parts, namely, Read slot, D/A — A/D conversion period and Write slot. Both read and write slots are divided into twelve equal parts, each being referred to as a camera time slot. It is these slots that time division multiplex digital information (shot number and positional data), between the ADC's and store interface. The read slot precedes the conversion period, data from the store being required for the conversion. Similarly the write slot follows the conversion period, the data for the store being available only after the conversion.

Analogue Digital Convertor

A single ramp reversible AD convertor is employed to convert positive d.c potentials. Five basic elements are employed, Voltage ramp, Voltage comparator, 14-bit binary counter, Clock and Analogue clamp, and in the following sections only the broad principles are discussed.

Analogue to Digital Conversion

Reference should be made to figure 6 where these elements are shown connected to illustrate the principal of A to D conversion. The positive going ramp is connected to one input of the voltage comparator. The other input to the comparator is the

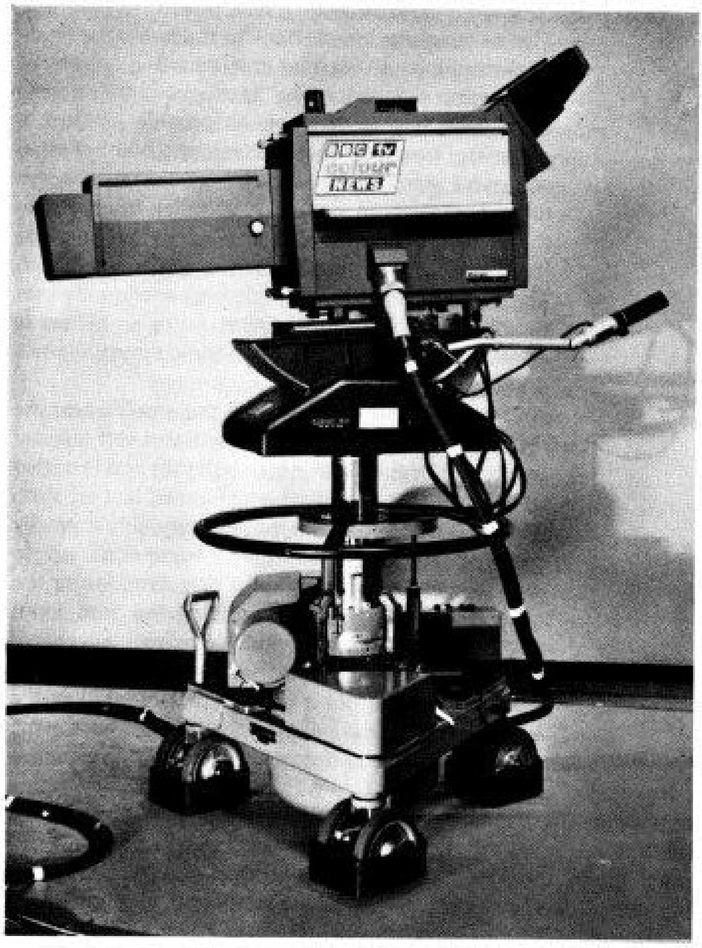

Fig.4 Remotely controlled Marconi colour camera with Angenieux lens and Evershed pan and tilt and pressurized pedestal.

positive analogue clamp output voltage to be digitized; the differential inputs to the comparator are such that its output is initially a logical '1'. The allow conversion signal is connected so as to allow the ramp and the counter, which is initially set to zero, to run, the rate of count being determined by the clock frequency. The instant the ramp potential just equals the analogue input, the comparator output switches to a logical '0' to inhibit the counter. This switching of the comparator is referred to as the 'analogue edge' and occurs after a time duration proportional to the analogue voltage input. The number held in the counter is also proportional to the time duration and hence to the analogue voltage. This count at the end of the conversion period is made available as a parallel word for transfer to the core store. In the event of the analogue input exceeding the ramp voltage, a constant count will be obtained proportional to the allow conversion period. Should the analogue input be zero or negative, then a count of zero is established. A necessary condition, to ensure that there is no ambiguity of count, is that the counter should not over-fill during the allow conversion period. This is determined by selecting an appropriate clock rate taking into account the number of bits in the counter and the allow conversion period. The number of bits in the counter was determined by the resolution required to produce the specified system repeatability, which for pan and tilt is 4' of arc, nominally 1 part in 5000.

Digital to Analogue Conversion

Referring again to figure 6, the same elements are connected to illustrate the principle of D to A conversion. The comparator inputs are connected as before but it would be well to define the signal path between it and the clamps as the 'feedback path'. Before conversion starts the counter is preset with the 1's complement of the digital number to be converted. Provided that this is not all 1's the output of the fourteen input nand gate will be a logical '1'. As before, the allow conversion signal enables the ramp and counter, the rate of count again being determined by the clock frequency. The instant the counter fills, that is when all its outputs are at logical '1', the output of the 14-input gate switches to inhibit any further count. This switching is referred to as the 'digital edge' and occurs after a time proportional to the true binary value of the number to be converted. This edge defines the time that the analogue edge should occur. Coincidence will only happen if the analogue voltage is equivalent to the number counted. If the analogue edge occurs before the digital edge, then the clamp voltage is too high, by an amount proportional to the time difference between the two edges, the converse being true if the analogue edge occurs after the digital edge. A simple arrangement of logic gates and inverters are connected to derive these drive-up and drive-down proportional error pulses. The analogue clamp, effectively a capacitor connected to a very high-impedance field-effect device, includes two normally reverse-biased pump diodes. The drive-down error pulse is suitably interfaced to remove charge from the capacitor via one of the diodes whilst the drive-up error pulse is interfaced to supply charge via the other. The charge transfer is accomplished by means of a constant current which ensures a linear voltage-time relationship. The magnitude of current is established taking into account the value of capacitors and ramp slope to produce a somewhat over damped system response. To achieve the required accuracy of repeatability, a ramp checking technique is necessary.

Ramp Checking

This method requires the use of two additional analogue clamps, shown connected in figure 7 (British Patent No. 1232857). One is referred to as 'test low', used to establish the ramp starting voltage, and the other, referred to as 'test high', is used to control the ramp slope. Control of these clamps is carried out during the two test time slots allocated for the purpose during each multiplex cycle. Two fixed analogue potentials are multiplexed to the voltage comparator, the first zero volts for convenience and the other the system full-scale volts. During the corresponding time slots the test low and test high digital edges generated by the timer are applied instead of the counter output to

Fig.5 Main and camera control panel with multi-function hand controller.

the error pulse logic, the timing of these two edges being related to the two test potentials. Because zero volts is used for test low, it is necessary to start the ramp from a slightly negative potential in advance of the edge in order that proportional error control may be effected. Such control is also necessary at full scale and for this reason the ramp runs on for a short time after the high test digital edge. During the test low timeslot, unless the ramp passes through zero volts as determined by the voltage comparator at the occurrence of the test low digital edge, an up or down-error pulse will result. The test low clamp output changes in response to the error to re-establish the ramp starting point for minimum error.

During the test high slot, unless the ramp equals the full scale reference at the occurrence of the high test digital edge, an up or down-error pulse will result. The test high clamp output changes in response to the error to modify the ramp slope for minimum error. This periodical checking of the ramp using the one voltage comparator results in an extremely stable convertor. Absolute ramp linearity is not necessary in such a system since repeatability, not absolute accuracy, is the primary requirement.

Output Filters

To provide smooth controllability, especially during fades, 'L' section filters are employed at the output of the clamp cards to attenuate the fundamental updating frequency component and higher frequency components produced, especially during fades to levels below which the servos and black level will respond. It is the output of these filters that provide the positional command signals and, in the case of the master black function, a d.c to d.c isolator circuit is incorporated to eliminate earth loops via the camera channel.

'On Air' Trim Input

The clamp output feeds back to the analogue feedback multiplexer via the non-inverting inputs of summation amplifiers (the 'feedback path' referred to earlier). It was desirable to provide as large a command signal as possible from the point of view of servo control to maintain a high signal-to-noise ratio. However, in order to multiplex comfortably these analogue signals, it was necessary to scale them down for a dynamic range of nominally 5V. The overall gain of this path is consequently one quarter. The inverting input of these amplifiers is connected to the appropriate trim control signals via electronic switches.

These switches allow trim to the amplifier during the appropriate half of every multiplex slot and are controlled by the fader logic such that trim is added to the row that the fader is at or was last at. With no trim applied, the trim input potential is normally zero and positive or negative excursions up to ±5V d.c occur for full trim in one direction or the other. The overall gain factor of the trim input through the summation amplifier is nominally unity; thus it is possible to add to or subtract from the scaled clamp output a voltage proportional to the trim input up to a maximum of plus or minus the full scale output. The effect of applied trim is to cause the appropriate clamp to be driven to a new value such that the summed output with trim is exactly the same as it was before trim was applied. When storing a shot it is necessary to convert the scaled clamp output voltage irrespective of any trim input. The clamps are 'frozen' i.e up and down-error pulses inhibited from driving the clamps. At the same time the trim signals are reset to zero and the electronic switches operate to ground the amplifier input and disconnect the trim signal. Thus when the store operation ceases, the camera remains in the set position.

Fader

The fader operates as a pulse width modulator to produce a variable mark-space output proportional to the fader control voltage derived from the panel. The true and complement mark-space outputs are gated with the halves of each function multiplex slot and the outputs combine to chop the drive-up and drive-down error pulses. The connections are such that, with the fader at the top row of shots 'A', 100% of the up or down-error pulses are allowed during the first half multiplex slot, whilst 0% of the up or down-error pulses are allowed during the second half multiplex slot. The converse is true for the fader at row 'B'. In mid-fade, the error pulses are chopped by the mark-space signals to produce the correct relative proportions of error correction as dictated by the fader control position. The problem encountered with this fade technique, because the chopping frequency although high (nominally 250kHz) has a period comparable with a few minutes of arc of pan or tilt, was to produce an observable staircase effect when fading diagonally over small angles. The problem was considerably improved by employing a segmented fader, that is, one in which there are eight different phase relationships of the chopping signal with respect to the conversion period. These are established in a non-sequential pattern at the start of each complete multiplex cycle, the effect being to enable a better average value of the error pulse durations to be obtained and consequently a smoother fade.

Manual Control

The positional mode of control via the multi-function hand controller is available as an alternative to a shot in row 'A'. D.C signal voltages for each function are time-division multiplexed via the manual multiplexer to a second ramp comparator. Pulse durations proportional to the inputs are obtained and gated during the first halves of the function multiplex slots to the error pulse logic instead of the digital edge produced by the binary counter. Bumpless transfer between store shots and manual is not possible unless fading to or from a shot in row 'B' as is always the case with 'on air trim', since the camera must align itself in a position corresponding with the relative settings on the hand controller.

'Store Freeze' and Shot Number Logic

Simple logic is included to freeze the clamps upon receipt of a store command provided that the fader is at one end or the other. This logic also ensures that the clamps are frozen for at least one complete multiplex cycle, sets the convertor in reverse and initiates store write commands. The binary equivalents of the shot numbers selected are gated during every function slot and strobed by the camera time slot to leave for the store interface.

Servo Units

Conventional 50Hz servo motor-drive units are employed for all mechanical functions except pedestal height where the power requirements demanded the use of a d.c motor drive. The ADC

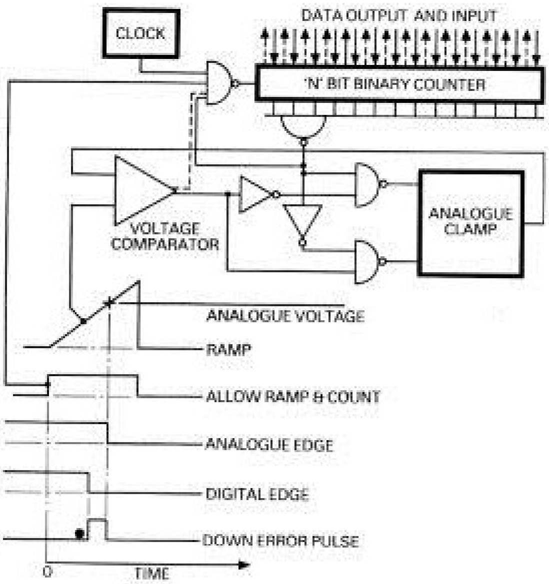

Fig.6 Digital to analogue conversion – with analogue to digital conversion shown dotted.

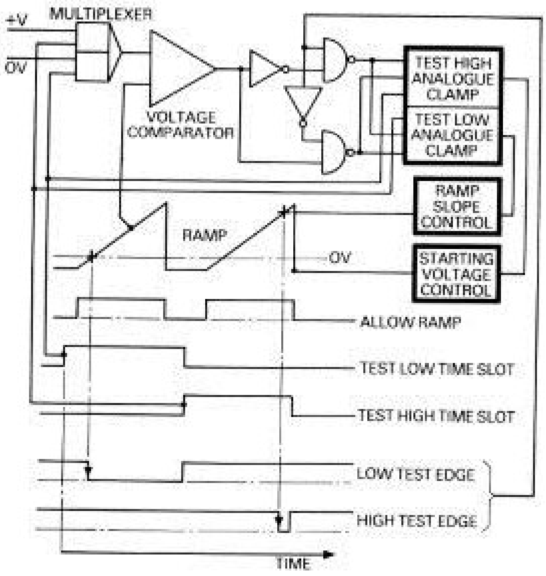

Fig.7 Ramp stabilization.

outputs (d.c voltages having a dynamic range of some 20V) are electrically limited to prevent the functions from driving into the mechanical end stops. In the case of pedestal height the output is compared with the d.c resetter voltage to produce a d.c error signal to drive the servo. The word 'resetter' in this context is used to describe the positional feedback potentiometer. In the case of pan and tilt, error signals are derived in a similar way but are then chopped to produce a.c signals for the servos.

The lens units had to be compatible for use with the zoom shotbox, focus and iris controls, not only in the News area, but other studios as well. This required that the resetters be excited from an a.c reference signal. The ADC outputs are first converted to proportional amplitude a.c signals and then compared with the resetter a.c volts. The resetters reference voltage is converted in a similar way to ensure the phase, waveform and amplitude stability necessary to maintain the system repeatability.

The electronics associated with the servos are accommodated in the various units; lens, pan and tilt head, pedestal amplifier unit and junction box, which in addition provides a convenient interface for the main control cable.

CONCLUSION

The development and capital cost of such a system is justified by the savings in operating costs. The News Spur is a new installation and new and more comprehensive facilities were required,[1, 2] — although remote control was not new to BBC News. It is, however, a matter for speculation whether such a complex system would have been introduced were it not for the general availability of low cost analogue and digital integrated circuits. The system now has been in operation on air since September 1969. Since that time, three further studio camera control systems have been realized, utilizing to a greater extent electronics in place of relays in the control panels, and are installed in other broadcasting networks.[3] Two of these systems are equipped for the computer initiation of jump and fade, one system allowing the pre-programming of shots into sequences.

The ramp convertor principle has been employed with every success in a remotely controlled colour camera system over a telephone line.[4] The second generation of equipment includes optical encoders as on air trim controls, and the third generation will incorporate digital computation of trim and fade, thereby eliminating the cog-in-fade and a great deal of analogue circuitry.

ACKNOWLEDGEMENT

The author wishes to thank the BBC for permission to use photographs and sketches of their equipment.

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