TELEVISION SIGNAL PROCESSING - RESTORING THE D.C. COMPONENT

For practical reasons it is necessary to use a.c. coupling throughout the television signal chain. At many points in the chain however it is essential that the d.c. component of the signal is correct in order that some other process, e.g. gamma correction, can be applied, or to facilitate the correct matching of the picture component to the characteristics of a display tube. This information sheet describes the techniques that are available to enable the d.c. component to be recovered in an a.c. coupled signal chain.

1. A.C. COUPLING

Figure 1 shows a typical a.c. coupling network. To avoid distortion of the signal the time constant is made very long compared to the period of the input waveform.

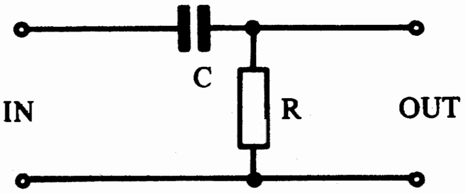

Figure 1: A.C. Coupling Network

The simple square wave shown in figure 2 will be used to demonstrate the effect that the a.c. coupling network has on a signal.

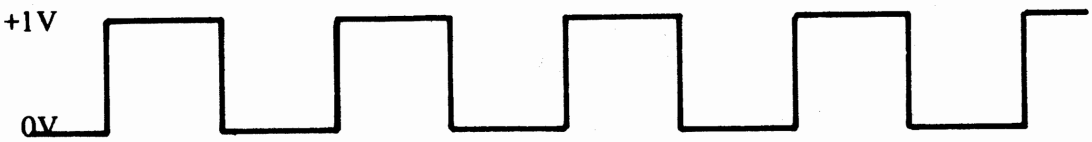

Figure 2: Simple Square Wave Signal

When the signal is first applied to the coupling network C will be uncharged and the initial input transition to +1V will appear across R. The capacitor will now start to charge up through the resistor in a conventional exponential fashion, aiming to the level of 1V. This is shown in figure 3.

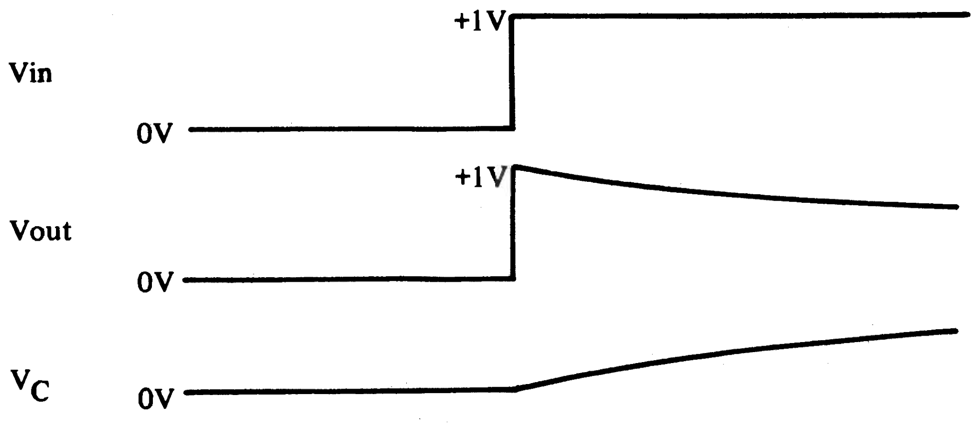

Figure 3: Initial State of the a.c. Coupling Network

At the end of the first half cycle the input signal returns to 0V. The capacitor is a short circuit to instantaneous changes of voltage so the whole 1V transition appears across R. The capacitor will now discharge slowly, aiming this time to 0V as shown in figure 4.

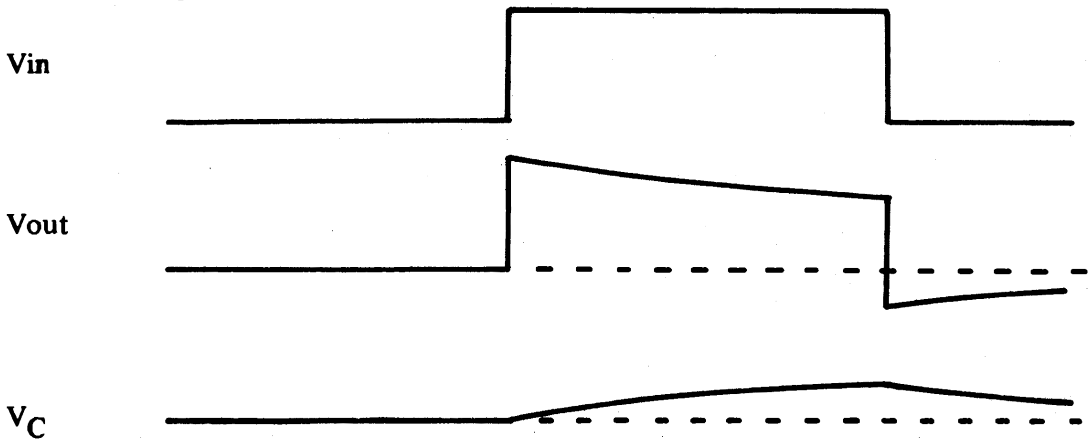

Figure 4: A.C. Coupling Network after 1 Input Cycle

At the end of the first input cycle it will be seen that the capacitor has acquired a small charge. When the second input cycle commences the capacitor will start charging from this point, and at the end of the second cycle the residual charge on the capacitor will have increased slightly. This is shown in figure 5.

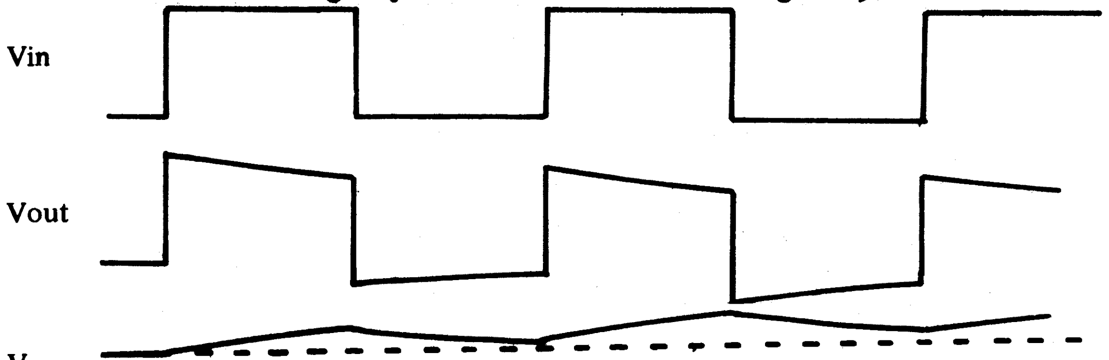

Figure 5: A.C. Coupling Network after 2 Input Cycles

After each cycle therefore the capacitor acquires slightly more charge until the point is reached when the rate of charge is the same as the rate of discharge. Any charge thus gained by the capacitor during one half-cycle of the signal is exactly cancelled by the loss during the second half cycle. This state of affairs exists when the capacitor has charged to the mean level of the input signal, which in the case of the simple square wave is +0.5V. After several cycles of the signal the network settles down to the steady state shown in figure 6.

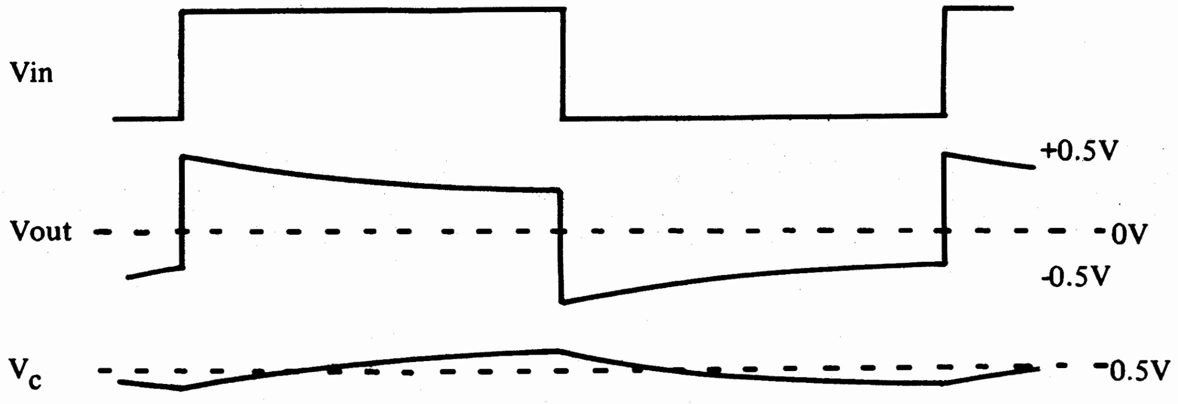

Figure 6: A.C. Coupling Network - Steady State Condition

When used as an a.c. coupling network the time constant is made long compared to the period of the input waveform, consequently the small amount of sag that occurs may be ignored. If square wave signals having different mark-space ratios are applied to the network the output waveforms will have different d.c. levels, in all cases the capacitor will charge to the mean level of the input. Some different examples are shown in figure 7.

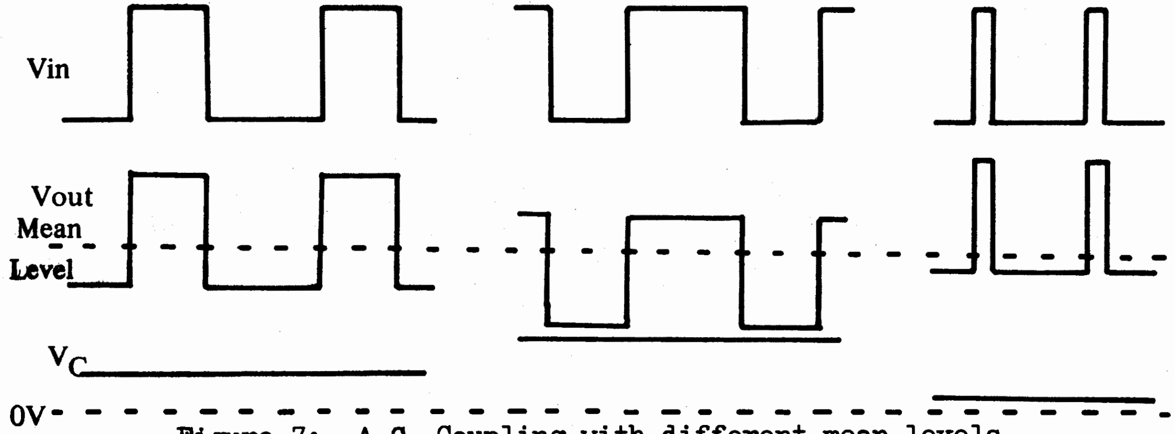

Figure 7: A.C. Coupling with different mean levels

It should now be obvious that the output waveform always sits with its mean level corresponding to the common signal rail (e.g. earth).

If the input signal were a television waveform the mean level would continuously vary as the picture content changed, this would mean that the output d.c. level would also vary. This is illustrated in figure 8 where signals at black, white and 50% average picture level (A.P.L.) are shown.

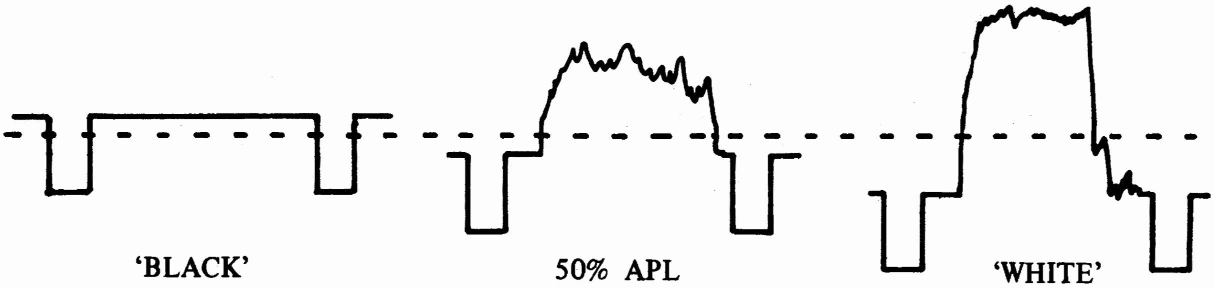

Figure 8: A.C. Coupling with Television Signals

The significance of this can be seen if the output of the a.c. coupling network was applied to a display tube. If the brightness was correctly set for the average scene then the black scene would be displayed as mid-grey and the white scene as light-grey! Additionally any detail in the dark areas of a 'white' scene would be lost as it is "blacker than black" when referred to the average picture.

All these factors point to the need for a means of re-establishing the d.c. level of the signal black level. This may be achieved in a number of ways as outlined in the following sections.

2. THE D.C. RESTORER

The simplest method for recovering the d.c. component is the d.c. restorer, (sometimes called a sync-tip restorer). In its basic form the d.c. restorer is an a.c. coupling network with the resistor replaced by a diode, as shown in figure 9.

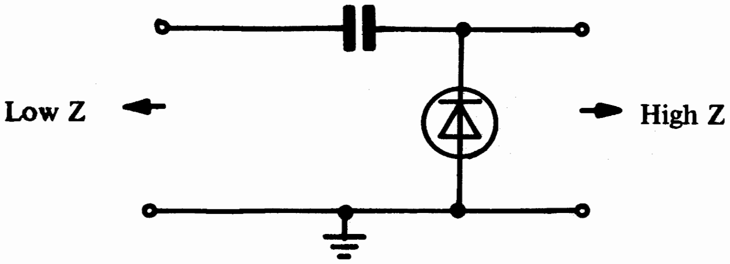

Figure 9: Basic d.c. Restorer

The basic operating principle of the d.c. restorer is that the diode will conduct when any part of the signal across it goes negative with respect to earth, (or the common rail potential). This will normally occur on sync pulses, and as the diode, when conducting, presents a low impedance charging path, the capacitor will rapidly charge to the difference between the sync and mean levels. When the sync pulse is over the signal goes more positive and the diode will cut off. The capacitor will hold its charge as it can only discharge very slowly through the high impedance load, thus the d.c. level of the waveform is re-established. This is a simplified account of the operation of the d.c. restorer. The next section describes its operation in detail.

2.1 Operation of the d.c. Restorer

To observe precisely the operation of the d.c. restorer an 'equivalent circuit is needed. Such a circuit is shown in figure 10 where the source amplifier is represented by a perfect voltage amplifier (R_{out} = 0Ω) together with its effective output resistance, R_{out}.

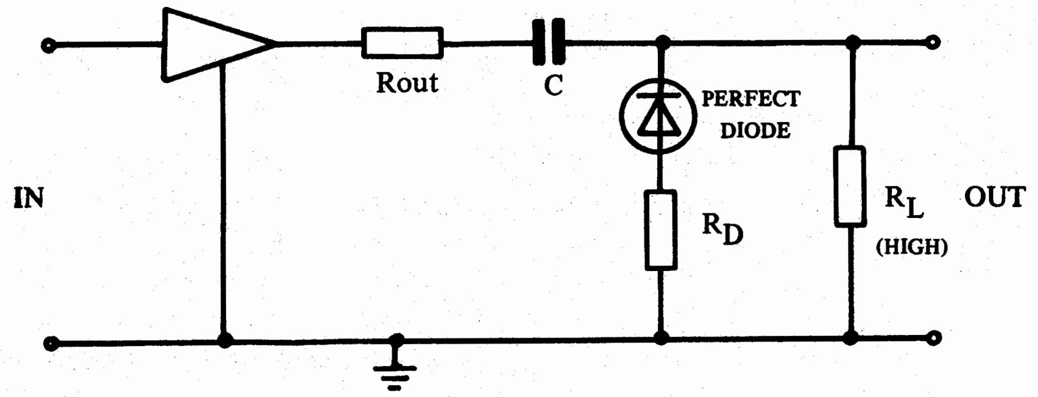

Figure 10: Equivalent Circuit of the d.c. Restorer

First consider the state of the circuit with no input signal. The amplifier output will be at some potential V, and on switch-on C will be uncharged. To simplify matters the diode resistance will be ignored.

On switch-on the capacitor will charge up to V through R_{out} and R_1. At the end of this initial charging period the voltage across the capacitor is V and across R_1 is 0. This is shown in figure 11.

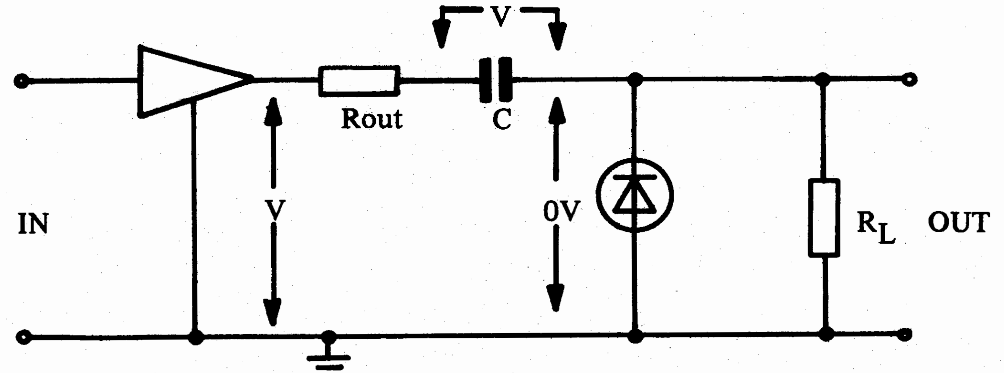

Figure 11: D.C. Restorer with no Signal

If a video signal is now connected to the circuit it will sit at the amplifier output with its mean level corresponding to V. If there were no diode it would sit across R_1 with its mean level at 0V. The tips of the sync pulses would be negative with respect to the mean level by some small amount and would therefore be negative with respect to 0V. This difference between the mean level and sync tip level will be called Vs as shown in figure 12.

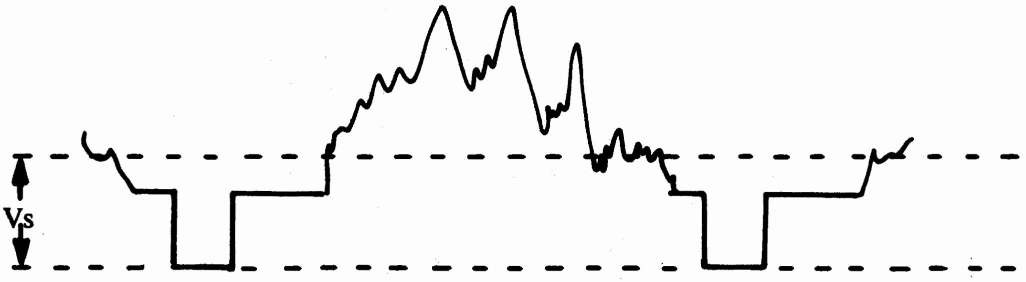

Figure 12: The Significance of Vs

With the diode in circuit however the output cannot go negative as the diode will conduct. When the video signal is applied the sync tips will be at -Vs w.r.t. the mean level, and at the amplifier output will be at V - Vs. The sync tips will also attempt to take the output to -Vs, but will be prevented from doing so by the diode. At the instant the diode conducts the following conditions exist:

a) The amplifier output is at V - Vs

b) C is charged to V

c) The output is clamped to 0V by the diode.

These points are illustrated graphically in figure 13.

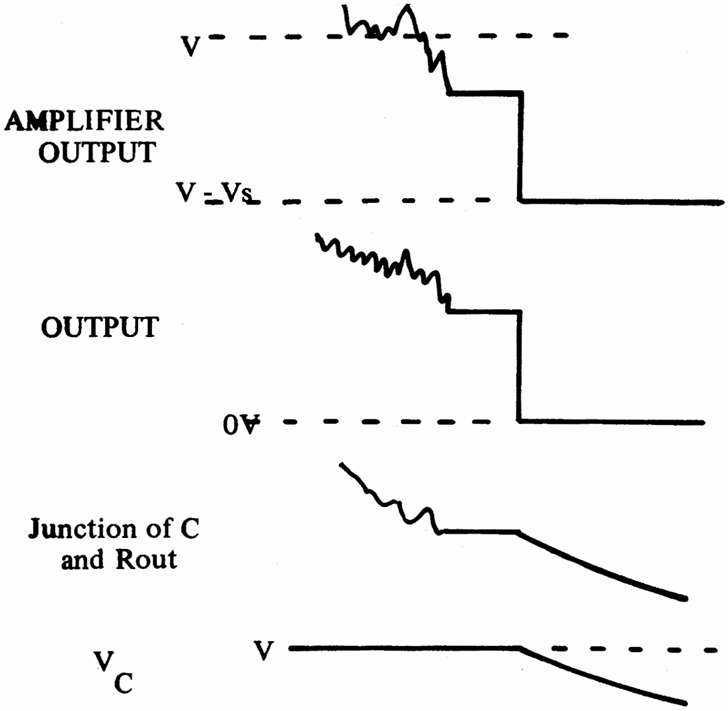

Figure 13: The d.c. Restorer when the Diode Conducts

The result of this is a voltage equal to Vs appearing across R_{out}. This will cause a discharge current to flow which is trying to discharge the capacitor to V - Vs, at which point the circuit will again reach a steady state value. The time constant for this is C.R_{out} (R_D is assumed to be 0), and if this is of the order of 1µs the capacitor will have discharged to its new value by the end of the sync pulse, as shown in figure 14.

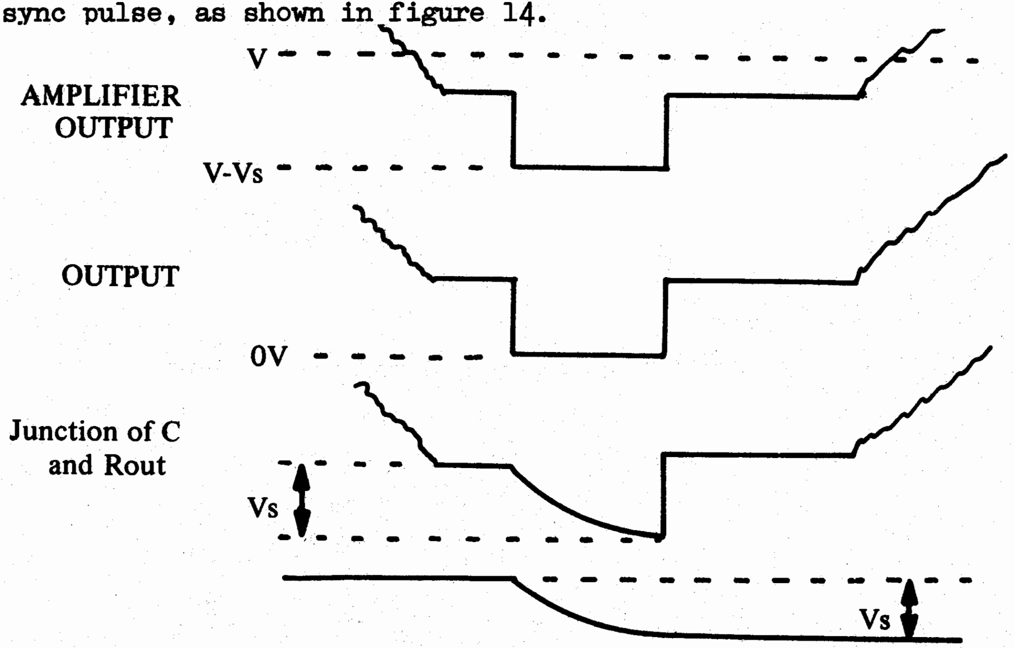

Figure 14: The d.c. Restorer at the end of the Sync Pulse

At this point there is no further change in the charge on the capacitor and the diode could be removed from circuit without any change in the d.c. conditions. This effectively happens at the end of the sync pulse when the signal returns to blanking level. As the discharge time constant for the capacitor is now very long (C.R_1) the capacitor will maintain its charge and hold the d.c. level of the signal constant for the remainder of the line.

At the end of the line a new sync pulse arrives, this will once more cause the diode to conduct and re-establish the charge on the capacitor to take account of any change in mean level that may have occurred. In this way the output is held with the sync tips at 0V, and provided the sync amplitude remains constant the black level will also be maintained at a steady value.

2.2 Limitations of the Basic d.c. Restorer

In its basic form the d.c. restorer will only function correctly on signals of constant mean level, or if a signal transition from a low to a high mean level occurs. If the mean level suddenly increases then Vs will increase, consequently the diode will conduct again and cause the capacitor to discharge further to take the new mean level into account.

If a transition from high to low mean level occurred the d.c. restorer would not function correctly. To re-establish the black level of a low mean level signal the capacitor has to recharge, as Vs is now much smaller than it was. As the only way the capacitor can charge is via the long time constant path of R_1 the output signal remains for a long time at some level positive with respect to 0V. This is shown in figure 15.

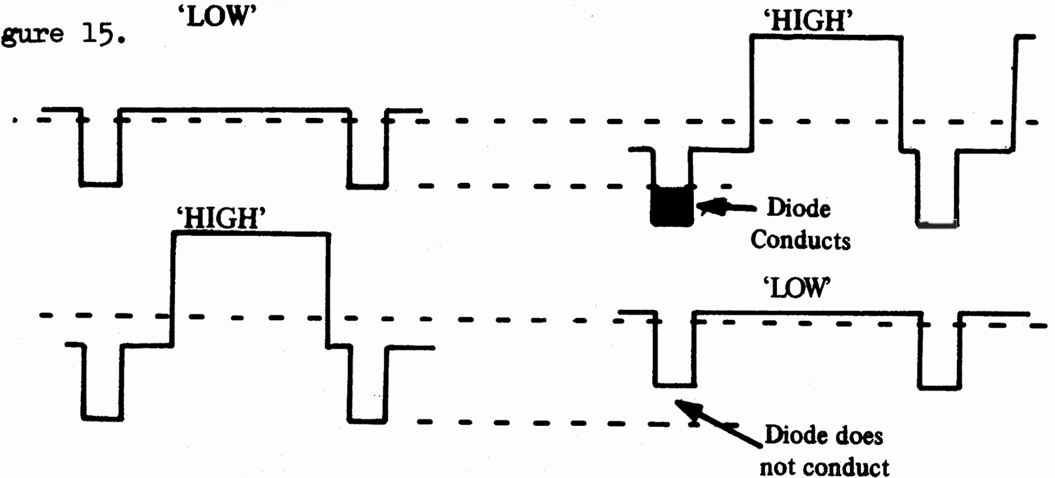

Figure 15: D.C. Restorer Performance with Mean Level Changes

A similar problem would occur if the input signal were distorted, due to hum for example. In this case the hum would tend to raise the d.c. level of the signal and again prevent the diode from conducting. In fact as the diode only conducts on the most negative parts of the waveform the negative peaks of the hum would be held at earth, as shown in figure 16.

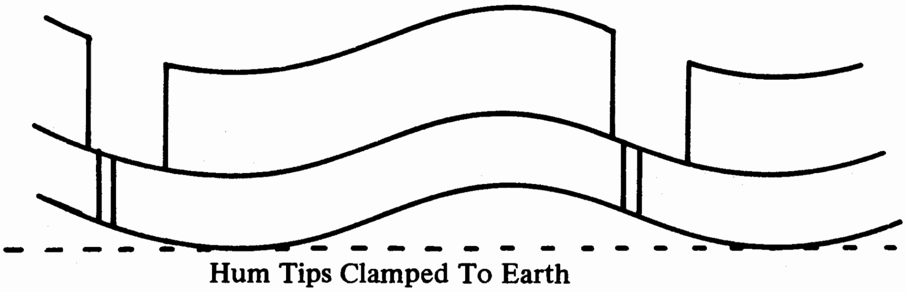

Figure 16: Hum and the d.c. Restorer

The failure of the d.c. restorer in both cases is due to the same reason. The capacitor can only change its charge very slowly when the diode is not conducting, consequently any effect which causes the d.c. level of the signal to go more positive prevents the diode from conducting and d.c. restoration fails.

The solution is to provide a faster charging path for the capacitor. The only way in which this can be achieved is to connect a resistor in parallel with the diode. The resistor is chosen so that over one line a small amount of sag is introduced. A high to low mean level change is now compensated by the capacitor re-charging through the resistor until the diode once more conducts. The process of recharging will take several lines and is shown in figure 17.

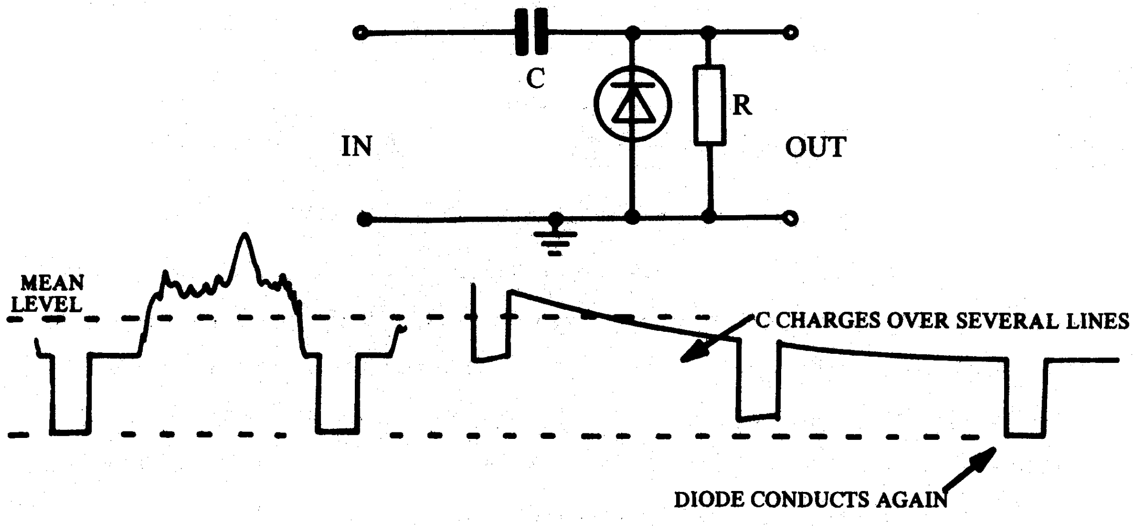

Figure 17: The Improved d.c. Restorer

The time constant chosen for the circuit has to be a compromise between speed of operation and minimum distortion of the video signal. Often it will be calculated on the maximum level of hum to be expected on the video signal. The resistor must introduce as much sag on the video over one half-cycle of hum to displace the signal negative as the hum has tended to displace the signal positive. A time constant of about 2ms is usually found to be the best compromise.

Despite its obvious advantage of simplicity the d.c. restorer is rarely encountered as it is not as effective as a black level clamp. The technique is essential to sync separator circuits however.

3. THE BLACK LEVEL CLAMP

The main limitation of the d.c. restorer is its inability to cope with high to low mean level transitions quickly without seriously distorting the video signal. In an ideal situation the capacitor should be able to charge and discharge quickly whenever a change in mean level occurs, and then have a very long discharge time constant so that no distortion of the signal occurs. This function is achieved by the black level clamp, which basically is a long time constant circuit into which a much shorter time constant may be switched to enable rapid corrections to be made. A basic black level clamp is shown in figure 18.

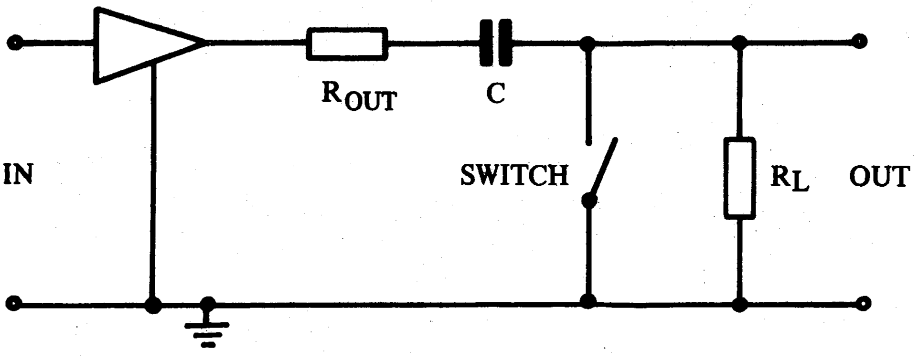

Figure 18: The Basic Black Level Clamp

The switch is timed to operate during the back porch of the video signal, when the picture is at black level, rather than during the sync bottoms. As in the d.c. restorer the capacitor will charge to V in the absence of any signal. When a signal is applied to the circuit it will sit at the output of the amplifier with its mean level at V and across the output with its meal level at OV. If the switch closes during the back porch the output is immediately clamped to OV, however the amplifier output will be at some level slightly negative with respect to V, due to the difference between the black level and the mean level of the signal. As in the d.c. restorer this small difference appears effectively across R_{out}, consequently a discharge current flows to regain a balanced condition.

When the capacitor has discharged by the difference between the black and mean levels of the signal no further current will flow. If the switch is now opened the d.c. conditions will be maintained as the circuit time constant is now very long, and the charge on the capacitor will be retained. These points are illustrated in figure 19.

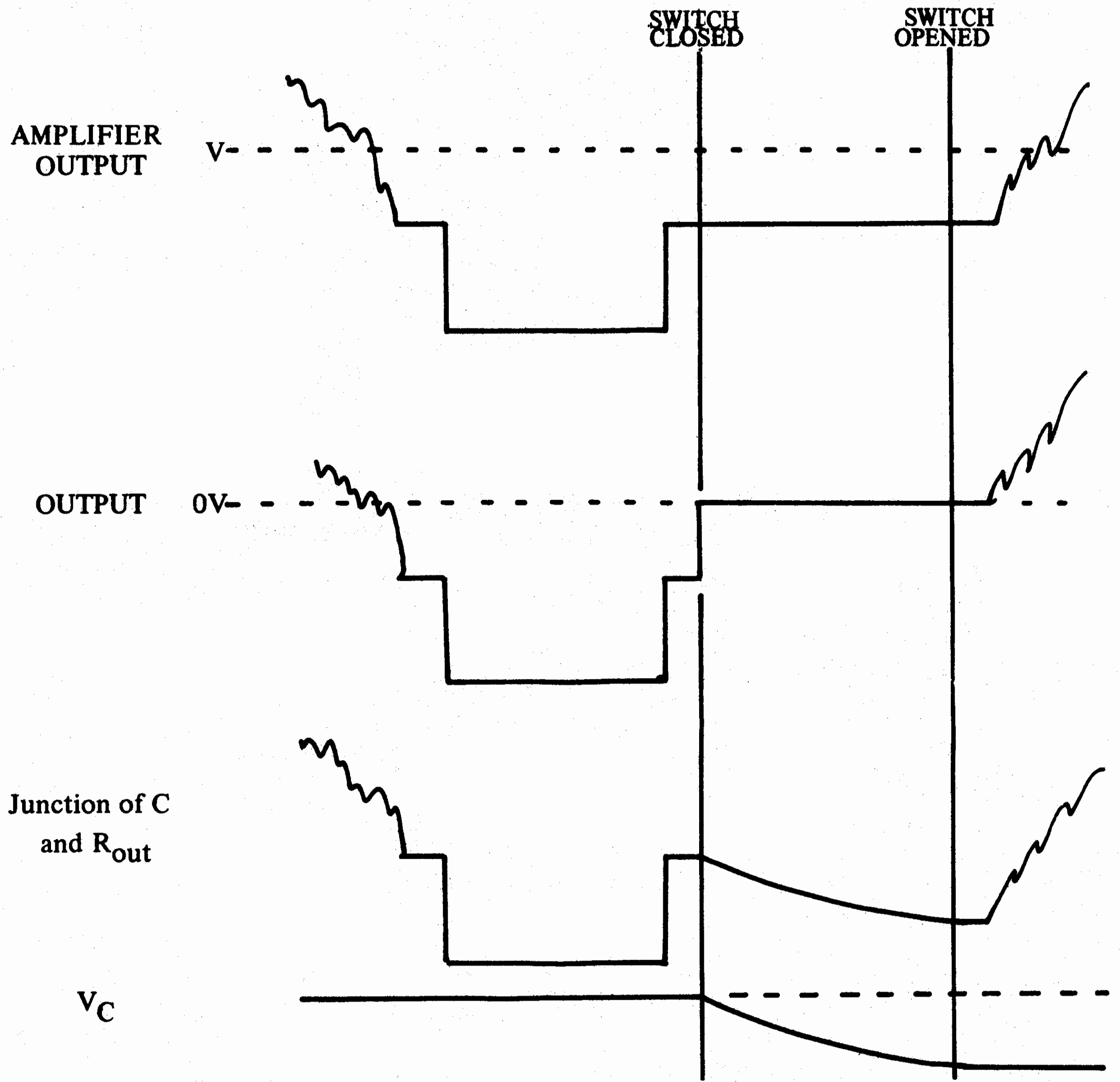

Figure 19: Operation of the Black Level Clamp

If any change in mean level now occurs the capacitor will recharge to take account of it during the next clamping period. As the clamping circuit is via a switch the capacitor is just as easily able to charge as discharge, consequently any change in mean level can be corrected.

3.1 Choice of Clamping Time Constant

In the clamp circuit just considered the time constant was sufficiently short to enable the capacitor to charge fully to the new mean level in the duration of one clamp period. At first this would appear to be an ideal situation, changes in mean level being corrected immediately they arose. A fast acting circuit such as this does have its drawbacks however. If the back porch interval was in some way distorted, due to the presence of noise for example, the capacitor would not charge to the correct level. In fact noise on the back porch can lead to random clamping levels, which show up as random horizontal banding on the picture.

To overcome these difficulties the clamping time constant is lengthened so that a change in mean level is only corrected over several lines. As noise and most impulsive interference is random in nature the effects of the noise cancel out over the longer clamping period. The time constant is generally increased by including a resistor in series with the switch, as shown in figure 20.

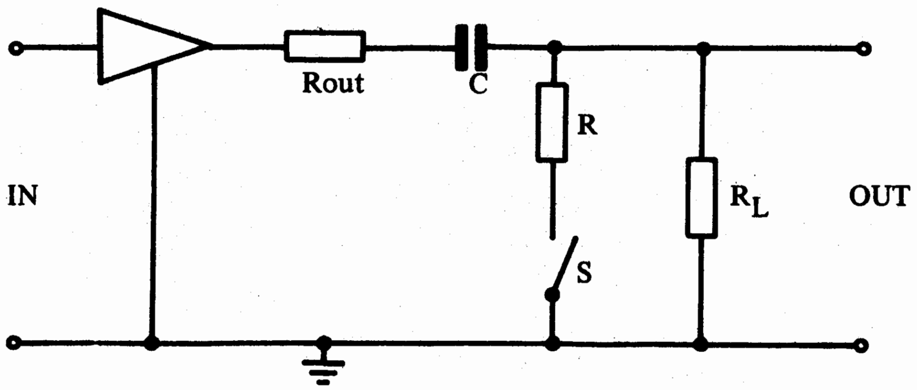

Figure 20: Clamp Circuit with Long Time Constant

Clamp circuits with short time constant are known as "Hard" clamps, and are usually found only in the earlier stages of a signal chain. Longer time constant clamps are known as "Soft" clamps and are used in potentially noisy situations.

3.2 Practical Clamp Circuits

The essential element of any clamp circuit is the switch. This has taken a number of forms over the years; diodes, valves and bipolar transistors have all been used. The device most often favoured in current equipment however is the field effect transistor, (FET). The FET is ideal as a clamp switch as it is basically a voltage controlled resistor, with low 'on' (about 300Ω) and high 'off' (greater than 100kΩ) resistances. To turn the switch on during the back porch a clamp pulse is used. This is a short duration pulse (about 3µs) timed to occur in the back porch. Usually the pulse will be derived from the syncs on the video signal.

One other problem encountered with colour signals is the presence in the back porch of the colour burst. To avoid disturbance to the clamping circuits by the burst, and vice versa, a filter is included in series with the switch. This makes the switch present a high impedance at the subcarrier frequency, consequently the clamping action and the colour burst are not affected.

A typical clamp circuit is shown in figure 21.

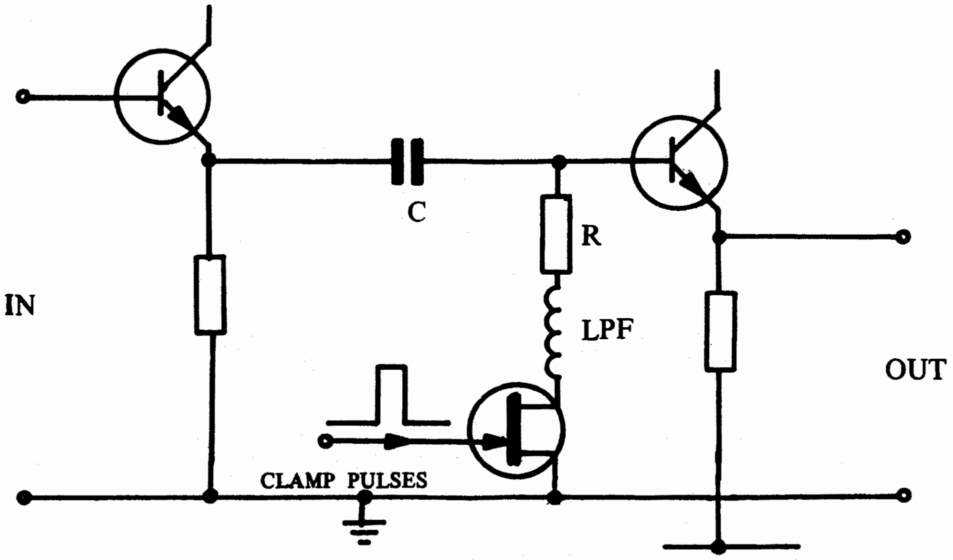

Figure 21: A Typical Black Level Clamp

4. FURTHER CONSIDERATIONS

The explanations contained within this information sheet are only intended as an introduction to the theory of clamping and d.c. restoration, and do not represent an exhaustive study of all the techniques available. Many other types of clamp circuits may be encountered, some of which will be discussed in subsequent lecture periods. Whatever type of black level correcting circuit is employed, however, its operation will depend upon black level dependant information being stored on a capacitor.

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22nd January 1979