Image Orthicons Camera Tubes: Operating Techniques and Economies

by
R. G. Neuhauser

The image orthicon tube is manufactured in two sizes and in a variety of ways for specific performance characteristics. It is helpful to understand the effect that the various construction features have on performance and picture characteristics so that the best tube can be selected for any specific use.

The major variations in construction are:

- Spectral Response of the Photocathode
- Target-to-Mesh, i.e., Target Capacitance
- 3" or 4-1/2" Diameter Tubes
- Inclusion or Omission of Field Mesh

Spectral Response

Two different photocathodes are available in the RCA 3" Image Orthicons, the S-10 and the bialkali. **Figure 1** shows the two spectral response curves.

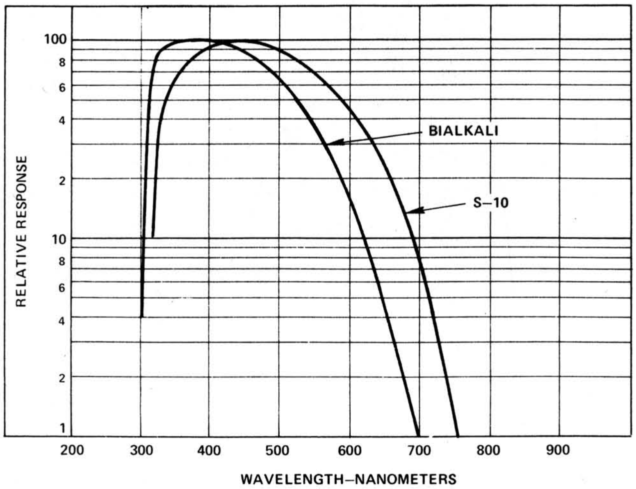

Figure 1 — Spectral Response of Image Orthicon Photocathodes

In black and white TV service, the S-10 and the bialkali photocathode have about the same sensitivity to tungsten-lamp illumination.

The higher red response of the S-10 photosurface will produce more natural facial tones, particularly with persons having darker complexions.

The red response of the bialkali photocathode is closer to the response of the eye and produces pictures that are more accurate for true brightness values.

The most decided advantage of the bialkali photocathode in black and white service is in outdoor broadcasting, with no artificial illumination available on overcast days or near dawn or twilight. At these conditions, the natural illumination is primarily blue in color and the higher blue sensitivity of the bialkali photocathode is a distinct advantage.

In color broadcasting where 3-tube image orthicon cameras are used, the bialkali camera tube has a distinct advantage in sensitivity over the S-10 photocathode, particularly in the blue channel. The blue channel is usually the limiting factor for camera sensitivity because the tungsten bulb studio illumination is very low in blue energy. Image orthicon tubes with the bialkali photocathode in the blue channel can increase the camera sensitivity by a factor of 2:1 over the S-10 photocathode tubes. The red response of the bialkali photocathode is more than adequate for the red channel of these three-tube cameras.

Target Structure and Tube Performance

The heart of the image orthicon tube is the target assembly. This portion of the tube determines many of the performance and picture characteristics. The function of this assembly is to store the electrical charges that define the television image, amplify this charge, limit the charge build-up of highlights, and to provide a means for the scanning beam to read out the stored charges.

Indirectly, this assembly controls such important characteristics as the signal-to-noise ratio, the sensitivity, the lag and the ability to handle highlight overload.

Target Structure

The target assembly structure is shown in **Figure 2**. The target mesh is a very fine mesh-type screen having 87,000 holes/cm^2. The wires of the screen are so fine that 70% of the electrons from the photocathode can go through the mesh holes to strike the target. The target is spaced from 0.001" to 0.002" (20 μm – 40 μm) from the mesh.

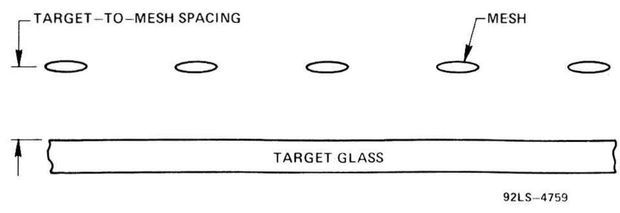

Figure 2 – Image Orthicon Target-Mesh Assembly

Target Operations

Electrons from the photocathode are focused on the target; these strike the glass target and produce many secondary electrons. Most of these secondary electrons are collected by the mesh which is operated a few volts more positive than the target. The loss of these electrons from the target produces a positive charge on the glass. (See **Figure 3**.) This action amplifies the charge by the secondary emission process.

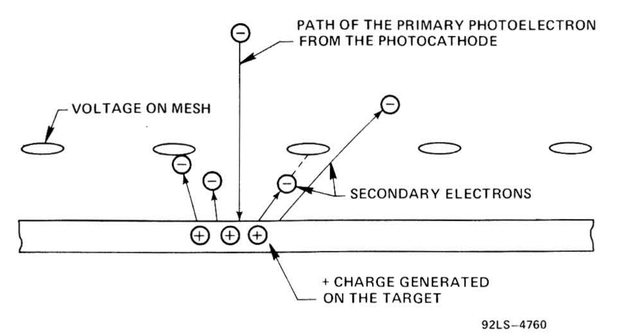

Figure 3 – Image Orthicon Target Charging Process

When the positive charges on the target increase to the same voltage as the mesh, the secondary electrons are no longer attracted to the mesh but fall back onto the target from where they were released and limit the positive charge build-up to no more than the mesh voltage.

This action produces a knee which is characteristic of the image orthicon tube. In the image orthicon, the signal builds up with increasing light to the point where it is limited by the target charging action that was described. (See **Figure 4**.)

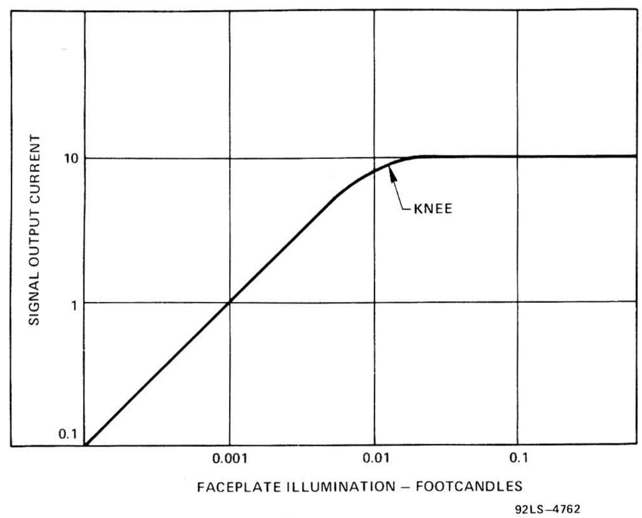

Figure 4 – Typical Image Orthicon Light vs Signal Characteristic

The target produces another image orthicon picture characteristic known as edge enhancement. This improves the contrast of an object and makes the picture appear to be sharper and of higher contrast. Some of the secondary electrons that travel toward the mesh go through the mesh. These electrons fall back through the mesh to the target and land alongside the place from which they were emitted. Since they have low velocity, they do not produce secondary electrons but tend to discharge any positive charges already on these areas. (See **Figure 5**.) As a result, the signal from

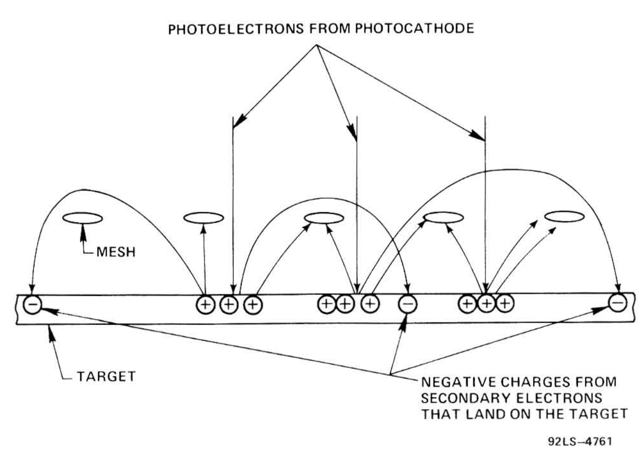

Figure 5 – Illustration of the Process that Produces the Enhanced Boundry Around Illuminated Areas

an object is enhanced as is shown in the photograph, **Figure 6**, and in the waveform oscilloscope, **Figure 7**. These electron redistribution effects are responsible for the sharp, high-contrast picture that is developed by the image orthicon. The high contrast of the edges between areas of different contrast is maintained and is actually enhanced. This is clearly shown in **Figure 7**.

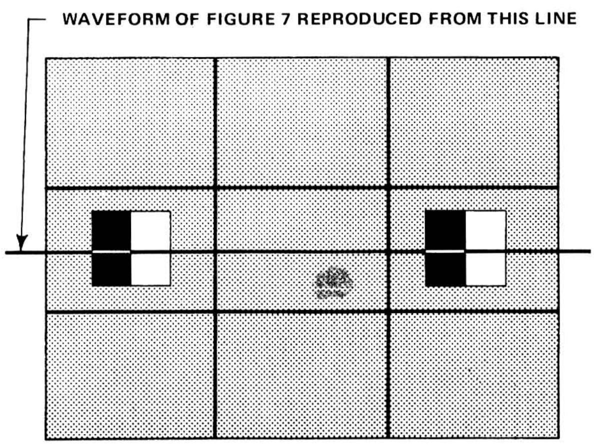

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Figure 6 — Photograph of a Test Pattern Reproduced by an Image Orthicon

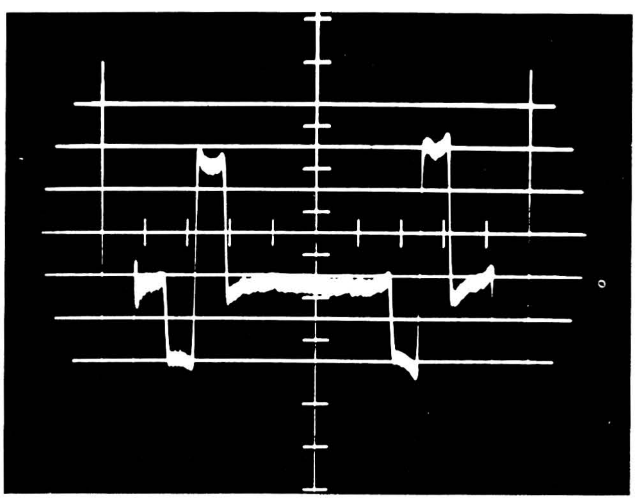

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Figure 7 — Video Waveform From Figure 6

Target-to-Mesh Spacing and Size

The amount of charge that an image orthicon target can store is controlled by three factros: the target-to-mesh voltage, the target-to-mesh spacing, and the target size. The first is an operational choice and the second two are determined by the choice of the target-to-mesh spacing and the size of the image orthicon being used.

The target size and spacing determine the electrical capacitance of the target. The target-to-mesh voltage determines the voltage to which this target capacitance can be charged. The total or maximum charge that can be stored on the target determines several performances and picture characteristics of the image orthicon. The most important being signal-to-noise ratio and the camera sensitivity.

An image orthicon with a very small target-to-mesh spacing will have a high capacitance independent of target voltage. Those with wide target-to-mesh spacing have low capacitance targets. Assuming the same target voltage, say 2 volts in both cases, the stored charge can be larger on the higher capacitance target and the signal-to-noise ratio of the output signal will, therefore, be higher and better. Also, for a given target-to-mesh spacing and target voltage, the larger-diameter target in the 4-1/2" image orthicon can have an even higher capacitance than that of the 3" tube and, as a result, a still higher signal-to-noise ratio in the output signal.

The higher target capacitance requires more photoelectrons to charge to the knee and therefore, more light must be used. The camera will be less sensitive than if a low capacitance target tube is used.

The Influence of Target Voltage

Signal-to-noise ratio can be improved by increasing the target voltage which will allow the target to store more charge. There is a limit to how high this voltage can be. At higher target voltage, the scanning beam will be bent toward high charge areas of the target, causing distortion of the image and some loss of resolution. (See section on **Field Mesh.**) High target voltages will also tend to eliminate or minimize the electron redistribution effects which maintain detail in highlights that produce added sharpness and contrast in the picture. At high target voltages, the knee characteristic becomes very abrupt and appears to be a signal clipping action rather than a smooth limiting action, and more detail is lost in the highlights. Exposure control and scene lighting uniformity must be more accurately controlled and care taken to avoid over-exposure.

Figures 8, 9 and **10** illustrate the performance characteristics that have been described. These are photographs of the video waveform generated by an image orthicon camera "looking" at a logarithmic gray scale at various target voltages and exposures.

Figure 8 is developed by a type 5820A/L, 3" image orthicon.

It was operated with the highlights at the knee and 1-1/2 stops above the knee at a target voltage of 2 volts. Note the tilt on the steps and the high contrast step that is maintained between adjacent step levels. At 1-1/2 stops above the knee these transition steps are still maintained, which preserves the detail in the highlights. **Figure 9** shows the same comparison for a 4-1/2" image orthicon with the same target voltage and exposure. Note the lower noise and better contrast in the low lights on these waveforms and the good preservation of highlight detail.

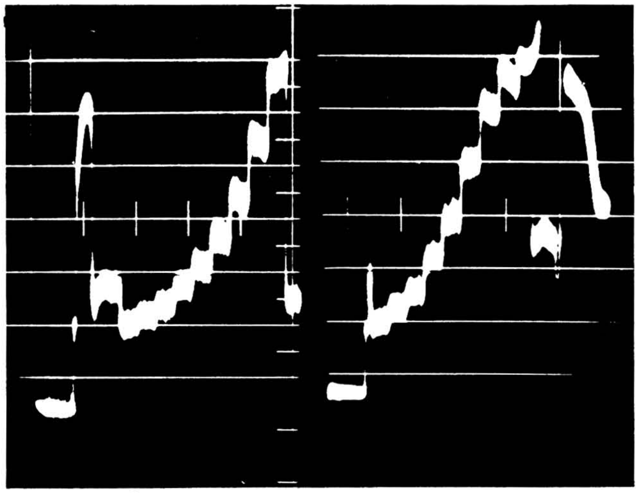

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Figure 8 — 5820A/L 3-Inch Image-Orthicon Characteristic. Operation is at 2 volts target setup. Left waveform-highlights at knee. Right waveform-highlights lights 1-1/2 stops above the knee.

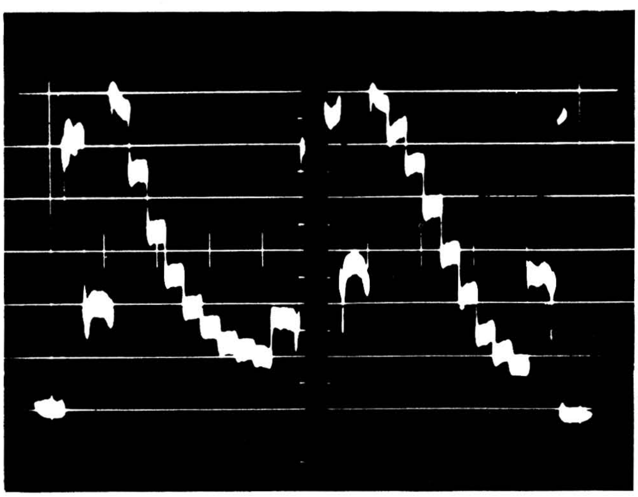

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Figure 9 — 7295C 4-1/2-inch image orthicon operated with a target voltage setup of 2 volts. Left waveform-highlights at knee. Right waveform-highlights 1-1/2 stops above the knee. EIA logarithmic gray scale chart.

Figure 10 illustrates the use of higher target voltages. The steps are more precise with less tilt and less enhancement of the transitions from one step to another. Also with exposure over the knee, the highlight transitions are reduced, some highlight detail is lost.

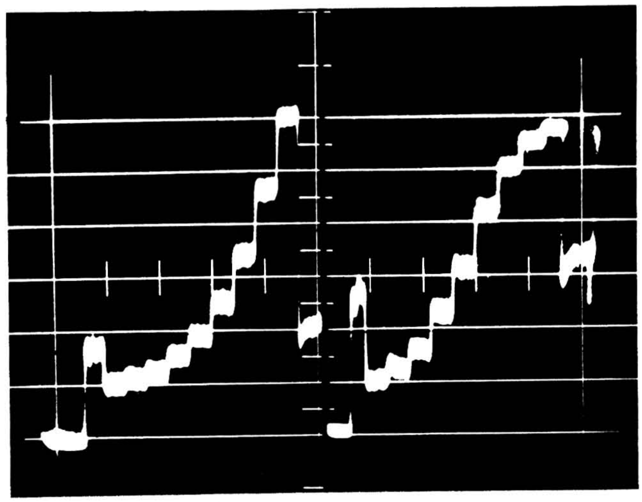

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Figure 10 — 7295C 4-1/2-inch image orthicon operated with a target voltage setup of 3 volts. Left waveform-highlights at knee. Right waveform-highlights 1-1/2 stops above the knee. EIA logarithmic gray scale chart.

Image Orthicon Target Characteristics

Tube Size	Target-Mesh Spacing Wide Spaced (0.002")	Close Spaced (0.001")
3"	Type 5820A/L Type 8775 Type 8674	Type 8673
4-1/2"	Type 7295C	Type 4536*

*Type 4536 is specially designed and manufactured to meet the specific requirements of the RCA TK42 and TK43 Color Cameras.

The following are the tabulated performance characteristics to be expected with high target voltages or high target capacitance tubes, compared to low target voltage and low target capacitance tubes.

High-Target Voltage	High-Target Capacitance
Better S/N	Better S/N
More light required	More light required
More critical exposure control	More critical exposure control
Loss of picture contrast	Requires lower contrast scene lighting
Beam-bending and distortion	More accurate gray scale
Slightly lower resolution	More lag

4-1/2" Compared to 3" Image Orthicon

The 4-1/2" image orthicon is designed to have a larger target structure than the 3" tube. The larger target area produces better resolution and has higher capacitance. The highest target capacitance in an image orthicon is available in the type 7398C which has a target-to-mesh spacing of 0.001" (20 μ). It is impractical to make targets with closer spacing than 20 μ.

The high-capacitance target tubes have a tendency to show some lag or smear of moving objects or picture-smear during fast motion of the camera from scene to scene. This is caused by the RC time constant of higher target capacitance which is effectively in series with the beam which has a finite "resistance".

Field-Mesh Construction

A field mesh is incorporated in the scanning section of some image orthicon types. This mesh is spaced relatively close to the target. It is intended to help bring the beam to the target in a perpendicular trajectory. It also strengthens the electric field near the target so that beam is not bent away from its proper path by electrical image charges on the target.

The picture from a field-mesh tube is more uniform in amplitude over the scanned area and has less geometric distortion and "bending" in the outlines of bright objects. A non-field-mesh tube will have a tendency to produce exaggerated edges on bright objects and some geometric distortion of the image due to "beam-bending". This effect is particularly noticeable in a color camera because different beam-bending in the different color channels will produce false-colored edges in the picture.

The field mesh intercepts some of the return beam of the image orthicon and causes some loss in signal and signal-to-noise ratio. On the other hand, field mesh tubes have less beam-bending at higher target voltages. These tubes can be operated at higher target voltages to achieve a higher signal-to-noise ratio before the beam-bending effects and loss of resolution become noticeable.

Operating Techniques

Camera Adjustments

The most critical adjustments of the image orthicon are the adjustment of the target voltage, the beam, and the alignment.

The target voltage should be established at a pre-determined voltage above the target cut-off voltage after the tube is properly aligned. On most cameras, this is established by a switch that adds a fixed voltage to the target after the target control has been set to the cut-off condition. These circuits should be checked periodically for proper operation. If a fixed setup switch is not used, a calibrated dial on the control panel can be used to establish the desired target voltage above cut-off. It is very difficult to match the pictures from different cameras if the targets of the image orthicons in each camera is not set to the same voltage above cut-off. The cut-off voltage is the target voltage where the highlights of the image just begin to appear at normal camera exposure. As indicated in the previous description of the tube operation, a change in the target voltage will produce distinct changes in the characteristics of the picture. The practical lower limit of target setup voltage is 1.5-volts and the higher limit is 3.5 volts.

The **beam control** is important because improper adjustment can produce a poor signal-to-noise ratio or a non-uniform background. Proper adjustment is achieved when the beam is set to just discharge the highlights of the picture. The knee produced by the target action of the image orthicon limits the amplitude of highlight signals and therefore the beam does not have to be set higher than normal to handle unexpected highlights.

Alignment of the beam is performed to cause the beam to approach the target in a perpendicular manner at all points. Alignment is achieved when there is rotation about the exact center of the picture as the **beam** focus is varied. In a non-field-mesh tube, the alignment can be achieved by capping the camera and adjusting alignment currents until the white spot (which is the beam aperture hole) does not move as the beam focus is varied. Failure to achieve proper alignment will produce poor signal-to-noise ratio, lag, poor resolution and non-uniform signal output.

Target voltage and beam setting should be rechecked after the alignment procedure is completed.

Camera Sensitivity

Sensitivity of the camera is defined as the amount of light necessary to operate the camera. The image orthicon requires a very small amount of light. As an example, the 3" wide target-to-mesh spaced tubes (5820A/L and 8775) require a faceplate illumination of only 0.01 footcandle (0.1 lx) to charge the target up to the "knee". Normal black and white practice is to operate the tube between one and two lens stops above the "knee". If a lens opening of f/8 is used to produce an adequate depth of focus, the scene illumination will be:

$$\text{Scene Illumination } E_S = \frac{4f^2 E_{pc}}{TR}$$

$$= \frac{4 \times (8)^2 \times 0.04}{0.8 \times 0.6}$$

$$= 21.3 \text{ footcandles (213 lux)}$$

$E_{pc} = 0.04$ = faceplate illumination at 2 stops above the knee (4x) in footcandles

$T = 0.8$ = lens transmission (typical)

$R = 0.6$ = highlight reflection (average white paper, cloth, etc.)

A common fault in studio lighting for image orthicon cameras is to use entirely too much light, causing the image orthicon tube to be over-exposed.

The Multiplier Section

The image orthicon has an electron multiplier built into the tube. This multiplier increases the image orthicon output signal to a level well above the noise level of the first video amplifier stage in the camera preamplifier.

This electron multiplier has much more than adequate gain and for this reason, cameras are equipped with a **multiplier gain** control or multiplier voltage control to reduce the signal level to where it will not overload the video amplifier. The variation in electron multiplier gain from tube to tube may be as much as 20 or 30 to one. This variation can be easily accomodated by the multiplier gain control or video control in the camera. A low output tube will still have more than adequate gain to maintain good signal-to-noise ratio in the signal. Variations in signal output from tube to tube are in no way related to tube sensitivity (which is determined by the amount of light needed to charge up the target) or on the signal-to-noise ratio of the output signal. Care must be taken to not set the multiplier gain too high; if signal level is set too high amplifier or multiplier overload will occur.

In the process of adjusting the tube, the **multiplier focus** must always be adjusted to produce maximum signal level consistent with uniform background shading. If this control is not adjusted to produce maximum signal level, the signal-to-noise ration **will** be degraded. Subsequent adjustment of the **multiplier gain** control will not alter the signal-to-noise ratio.

Temperature

If the image orthicon is operated at a high temperature, the tube will suffer from poor resolution and will have shorter life. High temperatures will lower the resistance of the special semiconductive glass target and when the target resistance is too low, the leakage will diminish the details in the charge pattern and the resolution is degraded.

If the target resistance is too high due to low temperature, the tube will have a "sticking" or retained image because the charges cannot be easily transferred through the target as it is scanned by the beam.

The recommended temperature at the target end of the tube is 35 to 40 degrees C. This temperature is difficult to measure but there is a handy comparison method that works very adequately. Remove the tube from the camera and immediately place the enlarged front end on your bare forearm to compare it with body temperature (37 C). It is easy to tell from this comparison if it is above 35 C. At the upper end of the range, 45 C is uncomfortable to touch for more than a few seconds. This system is usually adequate to tell if the camera tube is operating at the proper temperature range or if the target temperature control mechanisms in the camera are not operating.

Exposure and Operating Techniques

The knee of the image orthicon exposure characteristic is a very useful characteristic. The knee is the point where the peak signal level tends to compress with further increase in light level. The reason this knee occurs is explained in the section on the **Target Structure.**

The operational advantages of this knee are several:

1. Automatic gamma correction
2. Automatic limitation of specular highlights
3. Automatic compensation for non-uniform lighting
4. Good handling of high contrast scenes

Automatic Gamma Correction

Every camera system must have a method of compressing the highlights of the scene to match the non-linear characteristics of cathode ray picture tubes. This is called gamma correction. Operating the image orthicon about one lens (f) stop above the knee produces a signal where the highlights are compressed adequately to produce a picture on the picture tube that has proper gray scale brightness values and a pleasing picture to the eye. If there is inadequate compensation, the picture will appear to be predominately dark and human face tones will appear too dark compared to white areas of the screen.

Proper exposure is obtained by adjusting the lens iris with the camera focused on the studio and observing video signal on the scene waveform oscilloscope. As the lens iris is opened, the entire signal level will increase in amplitude to a point where the highlights will begin to compress while the low-light signals continue to increase. This point is the knee. The lens iris should then be opened between one and two lens stop openings above this point.

Automatic Limitation of Specular Highlights

Specular highlights are those reflecting from highly polished surfaces such as jewelry, musical instruments, or glass.

The brightness of these can be thousands of times brighter than the normal scene highlights since they are images of the light sources. The image orthicon knee limits the amplitude of these highlights automatically and also produces a dark area surrounding the highlight. The dark surrounding area actually makes the specular highlight appear of very high contrast when viewed on the picture tube. However, the highlight signal itself is limited in amplitude by the knee so that the peak signal will not overload the amplifiers or the transmitter.

Automatic Compensation for Non-Uniform Scene Illumination

When the highlights of the scene are operated between 1 and 2 lens stop above the knee, the image orthicon tube can tolerate wide variations in scene lighting. Variations of 2 or 3 to 1 in scene lighting will not affect the signal output levels as the camera pans over the studio scene. The low-lights will change in contrast, but the signal amplitude will remain relatively constant. This characteristic usually eliminates the necessity for continuous control of the lens iris during a television program. When high capacitance target tubes are used, however, or when the target voltage is operated at a high value, it will be necessary to more accurately control the lighting uniformity or the lens iris opening. If this is not done, detail in the highlights will be lost and the highlights of the signal will appear to be "washed out" like an over-exposed photograph.

Handling High-Contrast Scenes

Many scenes such as those encountered outdoors in direct sunlight have very high contrast ranges in the 1000 to one range. This contrast range cannot be handled very easily by the television system which has a contrast on the picture tube that rarely exceeds 50 to one. If the system is linear, many portions of the low lights of the scene will be lost. The image orthicon tube can be operated in such a way that it will compress this high-contrast scene content into a low-contrast TV system without losing detail and information in either the highlights or the low-lights of the scene.

This can best be handled by using low-capacitance-target image orthicons such as the 5820A/L, 8775, or the 7295C, and operating them at low target voltages. Under these conditions, the highlights are exposed more than two lens stops above the knee. The low-target voltage and the low-target capacitance retains detail in the highlights and the over-exposure allows the low-lights of the scene to be raised well above the noise level in the tube signal.

Operating Economies

The image orthicon tube may first appear to be an expensive tube. However, modern image orthicons have an electronically conducting glass target and achieve exceptionally long life. Life averages of 4000 hours to 7000 hours are reported by many TV stations. The cost per operating hour for the image orthicon tube, is therefore, very small.

Additional economies are directly attributable to the higher sensitivity of image orthicons, when compared to vidicon or Plumbicon* and vistacon cameras. These operating economies are produced by much lower studio lighting power required for the image orthicon cameras.

The studio light level for a B&W image orthicon camera system will be as little as 25 footcandles (250 lx) with a lens opening of f/8, or 50 footcandles (500 lx) at f/11. In contrast, the lighting level for a vidicon camera will have to be 400 footcandles (4000 lx) with a lens opening of f/4, and a Plumbicon or vistacon camera will require a studio lighting level of 130 footcandles (1300 lx) with a lens opening of f/5.6 for an equivalent depth of focus for the lens.

In most countries, it has been calculated that the 3 to 8 times additional lighting power costs alone for a typical TV studio set using vidicons or Plumbicons will be higher than the operation costs of the image orthicon tubes.

The comfortably low studio lighting levels possible with the image orthicon cameras means that the air conditioning load is considerably reduced. Thus, in addition to a smaller investment in lighting and air conditioning facilities, there is a significant reduction in air conditioning power costs as well.

New image orthicon cameras are not being made, but reliable and well designed image orthicon cameras are readily available at modest cost from broadcasters throughout the world who have switched to color broadcasting.

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