# CAMERA TUBES FOR STUDIO USE - A SEMI-TECHNICAL APPRAISAL FOR EDUCATORS

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# Camera Tubes for Studio Use—A Semi-Technical Appraisal for Educators

**A TUTORIAL PAPER**

By JOHN W. WENTWORTH

**The relative merits of vidicon and image-orthicon tubes are discussed with a minimum of technical jargon. Brief descriptions of the tubes are provided, but major attention is directed to picture quality, ease of operation, and economic factors. Either type of tube can be used successfully in educational TV studios, but the two types require significant differences in operating practices.**

### 1. Introduction

As educational television "comes of age," it frequently becomes necessary for educators with relatively little television experience to make decisions about the basic *type* of camera equipment to be employed in an instructional TV studio. The *vidicon* and the *image orthicon* (the two basic types of camera tubes readily available in the U.S.A.) are sufficiently different from each other that equipment designed for one type cannot be used for the other. Because a television camera represents a significant investment, a decision in favor of one type of tube or the other is likely to influence the capability and operating practices used in an ETV studio for many years to come, and it is important that the decision be based on reasonable understanding of the major technical and economic issues involved. This paper provides no new technical data not already available in the literature, but is offered as an *interpretation* of the major factors that deserve consideration in the selection of camera tubes for educational television applications.

The problem of choosing a basic type of television camera has been made even more difficult by the fact that image-orthicon tubes are now available in two basic sizes, commonly designated "3-inch" and "4½-inch" (the dimensions refer to the maximum diameter in each case). The physical differences between the two sizes are great enough for them not to be readily interchangeable in the same camera equipment. Thus, the educational telecaster really has three basic choices: 1-in. vidicons, 3-in. image orthicons, and 4½-in. image orthicons. While this paper is devoted primarily to discussions of the relative merits of the two basic tube *types*, it provides some comments on the significant differences between the two sizes of image orthicons. It should be noted that a 1½-in. vidicon has also become available, but at the time of this writing, the consensus of informed opinion is that this tube is not yet sensitive enough to warrant serious consideration for live pickup service; hence the 1½-in. vidicon is not considered in the following discussion.

### 2. Basic Physical Characteristics

An educator desiring to make an intelligent choice between the vidicon and image orthicon should have at least a superficial understanding of the basic principles involved in the two types. In both cases, the major objective is, of course, the conversion of an optical image to a television signal through a scanning process. The television signal is simply a voltage which varies with time in accordance with the brightness encountered by a scanning spot as it moves rapidly over the image area in a regular pattern of lines. In virtually all modern TV picture tubes and camera tubes (including both the vidicon and the image orthicon), the scanning spot is formed by an electron beam, which is made to move over the image area by precisely controlled magnetic fields.

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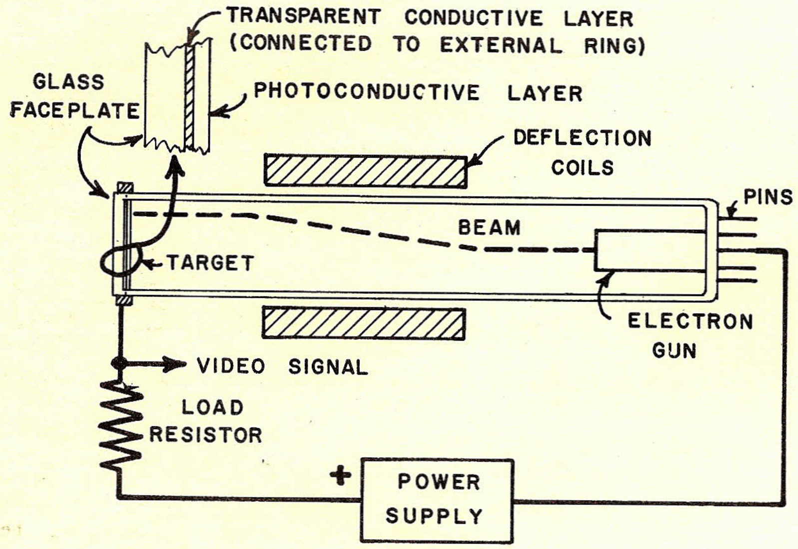


**Fig. 1. Simplified sketch of vidicon camera tube (many electron-optical components omitted for clarity). The basic signal circuit includes the electron beam and photoconductive layer.**

The vidicon is a relatively small tube, about one inch in diameter and 6.5 in. long. It operates on a *photoconductive* principle; an optical image projected on the *faceplate* at one end of the tube causes the electrical *conductivity* of a layer of special material deposited on the *inside* of the faceplate to vary in proportion to the brightness of the various areas of the image. The electron beam formed by an *electron gun* at the distant end of the tube, is able to pass more freely through the photoconductive layer in the bright image areas where the conductivity is high than through the dark or shadow areas where the conductivity remains low. After passing through this light-sensitive layer, the beam current is passed through an external circuit where it is converted into a variable *voltage* and amplified many times to form the television picture signal. A simplified sketch illustrating the basic principle of the vidicon is shown in Fig. 1.

Compared to the vidicon, the image orthicon is a relatively large, complex tube. Even the bulb is more complex than the simple glass cylinder used for the vidicon, in that the large-diameter section of the image orthicon (3 in. or 4½ in., as the case may be) extends for only a few inches behind the faceplate. Throughout most of its length, an image orthicon is about one inch smaller in diameter than the faceplate end. The 3-in. tube has an overall length of 15.5 in., while the 4½-in. tube has an overall length of 19.5 inches.

The image orthicon is basically a *photoemissive* tube, in that the optical image focused on the faceplate causes electrons to be *emitted* from a light-sensitive coating on its inner surface. The number of electrons emitted from each small section of the sensitive surface is proportional to the brightness of that section of the image. Under the influence of both electric and magnetic fields, these electrons are all moved parallel to each other for a few inches within the tube until they encounter a very thin glass membrane known as the *target*. Here the electrons strike with such force that they "jar loose" other electrons from the glass material, leaving a pattern of positive charges on the target proportional to the brightness values of the original optical image. Meanwhile, an electron beam approaches the thin glass target from the opposite side, and deposits just enough electrons to neutralize the charge in each small image area as it sweeps by. (The beam passes any specific point in the picture area only once in every 1/30th of a second, since complete TV pictures are transmitted at the rate of 30 per second.) The part of the electron beam which does *not* land on the glass target is then collected and amplified many, many times by a built-in amplifying device known as an *electron multiplier*, which is mounted near the socket end of the tube surrounding the electron gun which forms the beam. (Most of the length of the tube is needed to accommodate the external *deflection coils*, which form the magnetic fields needed to make the beam trace out the desired line pattern.) Thanks largely to this built-in amplification, plus further amplification which occurs at the glass target, the image orthicon has very high sensitivity, in some cases superior to that of the human eye. Figure 2 is a greatly simplified sketch illustrating the basic operation of the image orthicon.

The 4½-in. image orthicon operates on the same basic principles as its smaller "relative," but has a target of approximately three times the effective area, which yields superior performance in several important respects. The optical image size, however, is identical in the two sizes of image-orthicon tubes. The larger tube provides electronic magnification between the light-sensitive surface and the glass target.

Both vidicons and image orthicons are normally mounted within relatively long coils which provide the uniform magnetic fields needed to keep the scanning beams in sharp focus.

### 3. A Preliminary Evaluation

The major factors deserving consideration in comparisons of camera tubes are (1) picture quality, (2) ease of operation, (3) equipment investment required and (4) operating costs.

Superficially, there appear to be many strong reasons for educators to favor the vidicon over the image orthicon. It is a much cheaper tube (typically $205 as compared to $1,200 or more), it lasts much longer (typically 5,000 hours as compared to perhaps 800 to 1600 hours). On an hourly basis, the 4¢ required to keep a vidicon in operation is so low as to be negligible in a normal operating budget, while the $1.00 to $1.50 typically required for the image orthicon represents a cost factor comparable to the wages of a student operator for the camera. The vidicon is a lot less subject to accidental damage by careless or unskilled operators. A vidicon may be left unattended for hours on a stationary scene without damage, while an image orthicon left for even a few minutes on a bright scene may become unusable for an hour or two until the "burned in" image is removed. Furthermore, the investment required for vidicon camera equipment is well below that required for image-orthicon equipment. Industrial-grade vidicon cameras can be purchased in the $1,000 to $5,000 price range, and the professional-type studio cameras are typically priced at approximately $10,000. By contrast, image-orthicon cameras based on 3-in. image-orthicon tubes are priced in the vicinity of $18,000, and the new designs based on the 4½-in. image orthicon are priced at about $20,000.

The picture quality obtainable from a vidicon camera under favorable conditions requires no apology. In fact, many characteristics of vidicon pictures, notably the uniform gray scale and the relative freedom from "noise" or graininess, are theoretically *superior* to image orthicon pictures. Strong evidence to support the technical excellence of vidicon pictures is the almost universal use of the vidicon for film pickup in commercial broadcasting stations throughout the United States. Until quite recently, there was a very substantial difference in sensitivity between the vidicon and the image orthicon, but one of the latest vidicons (Type 7735A) can be adjusted to permit operation at essentially the same light levels commonly used for some types of image orthicons.

In spite of the strong arguments cited above, the vidicon has not made obsolete the historically older image orthicon, nor is it likely to do so in the foreseeable future. Commercial broadcasters continue to rely almost entirely on the image orthicon for live pickup service, as do a great many educational broadcasters. Telecasters who begin operations with vidicon equipment frequently convert to image orthicons when they upgrade their facilities, while conversions in the opposite direction are very rare. These facts suggest that image orthicons may offer advantages which more than offset the higher price tags.

The experience of commercial broadcasters should not be dismissed casually with the simple assumption that the economic problems of broadcasting are totally different from those of education. Actually, most commercial broadcasters are in business to make money, and are prompt to adopt any technique that offers significant savings. If such broadcasters felt that vidicon cameras were substantially equal in performance to image-orthicon cameras, they would be prompt to adopt them, especially in the highly competitive market areas, in order to benefit from the apparently lower costs. The fact is that the two types of cameras are not truly "equal" in performance, and the economic factors involved are too complex to permit analysis solely in terms of equipment investments and hourly tube costs. An educator desiring to evaluate the relative merits of vidicons and image orthicons on more than a superficial basis must develop further understanding of the major evaluation factors.

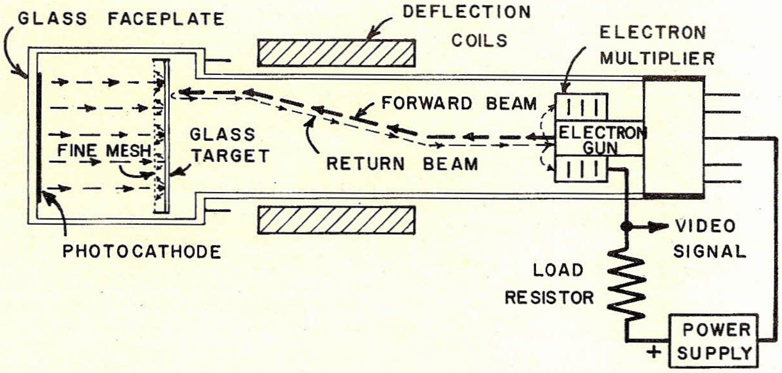


**Fig. 2. Simplified sketch of image orthicon tube (many electron-optical parts omitted for clarity). The basic signal circuit includes the forward beam, return beam, and electron multiplier.**

**4. How to Evaluate Picture Quality**

Television engineers generally recognize six basic factors in the evaluation of picture quality in either television or photographic processes. While different terms may be employed in some cases, the six basic factors are:

(*1*) *Sharpness*, which refers to the ability of the system to show sharp transitions between areas of different brightness and to show fine detail with clarity: While sharpness is sometimes equated to "resolution," it should be noted that the "limiting resolution" of a TV camera (usually somewhere in the order of 500 to 600 lines) is an almost meaningless specification, since an overall system with either a broadcast transmitter or a television tape recorder included cannot have more than about 320 lines of limiting resolution. The psychological sensation of *sharpness* is most closely correlated to what engineers call *aperture response* or *detail contrast*.

(*2*) *Graininess*, which refers to random fluctuations in what should be uniform gray areas, resulting in a "mottled" appearance in the picture: In photographic processes, this effect results from the actual grains of silver used to form the image. In television systems, the effect results from random signal fluctuations or "noise," frequently referred to as "snow." Ideally, pictures should be completely free of "grain," "noise" or "snow," but no TV camera tube or transmission system is perfect in this respect.

(*3*) *Sensitivity*, which refers to the amount of light required on a scene to produce an acceptable picture: While the overall sensitivity of any camera system is determined by the optical system as well as by the characteristics of the pickup tube (or film, in the case of photographic cameras), it is *not* reasonable to rely on "fast" lenses with wide apertures to compensate for inadequate sensitivity in the light conversion device. Wide-aperture lenses have severely limited depth of focus, making it impossible to keep both a foreground performer and a background display in focus at the same time. When evaluating the relative sensitivities of cameras with entirely different tubes and optical systems, it is important that the comparison be made with lens settings which give equivalent depth of field. Tests which show how little light is required to produce a picture from a flat, stationary object (such as a test pattern) are almost meaningless except for simple observational applications.

(*4*) *Gray scale*, which refers to the accuracy of relative reproduction over a wide range of gray values from black to white: The ideal gray scale for a television system is not easy to define because there are a great many variables involved. As a general rule, TV picture tubes tend to compress the shadow region of the gray scale and stretch out the highlights, so some degree of curvature in the *opposite* direction is desirable in camera tubes or equipment to compensate for the picture tube characteristic. Also, the *contrast range* (or the ratio of the brightest highlight to the deepest black) is severely limited in most practical viewing situations (including those in classrooms), making it impossible to reproduce with true fidelity the full contrast range to which most camera tubes can respond. Subjective judgment is often the best guide in determining "good" gray scale response.

(*5*) *Image Geometry:* This refers to distortions which may change the shape of image areas, resulting in such objectionable effects as egg-shaped circles, or curved lines that should obviously be straight.

(*6*) *Portrayal of Motion:* In television, as in motion pictures, the illusion of smooth motion is conveyed by the transmission of a series of still pictures which are presented so rapidly that the "persistence of vision" effect serves to fuse them together. An ideal television system should be free of effects which tend to blur or smear the images of objects in motion.

**5. Basic Picture Quality in Vidicons and Image Orthicons**

For the benefit of nontechnical readers, a simplified "good-better-best" rating scale is used below to compare the three types of camera tubes with respect to the six basic picture-quality factors. Technically minded readers who wish more definitive information are invited to study the several references listed at the end of this paper. Since there are several tubes with rather different characteristics available in each basic category, the specific types assumed for this comparison are identified in the following table.

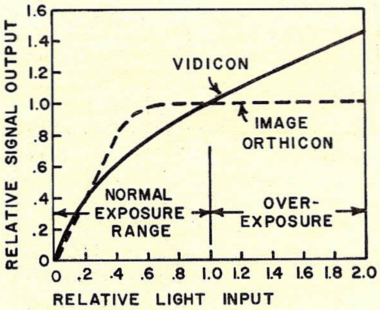


**Fig. 3. Gray-scale characteristics of typical vidicons and image orthicons.**

| Quality Factor | Vidicon Type 7735A | 3-In. Image Orthicon Type 5820A | 4½-In. Image Orthicon Type 7295A |
|---|---|---|---|
| (*1*) *Sharpness* | good | better | best |
| (*2*) *Graininess* | best | good | better |
| (*3*) *Sensitivity* | Poor to good | best | better |
| (*4*) *Gray Scale* (theoretical rating) | best | good | better |
| *Gray Scale* (practical rating) | good | better | best |
| (*5*) *Image Geometry* | No significant difference, assuming equipment of comparable quality | | |
| (*6*) *Portrayal of Motion* | Poor to good | best | better |

Interpretive Comments for each quality factor are presented below:

(1) The relative differences in sharpness result primarily from the size differences in the areas actually scanned by the electron beams. Just as a photograph taken directly on a 4 by 5-in. plate is sharper than one taken on 16mm film and enlarged to the same size, so is the picture picked up from the large target of the 4½-in. image orthicon sharper than those picked up from the smaller image orthicon or the much smaller vidicon. The apparent sharpness of image-orthicon pictures is also improved by a "transition enhancement" effect which occurs at the glass target. To be considered "good" with respect to sharpness, a vidicon camera requires a special correction circuit (aperture correction) external to the tube itself; this correction circuit is frequently omitted from industrial-grade cameras.

(2) The graininess of image-orthicon pictures is determined almost entirely by pickup tube characteristics alone, while the graininess of vidicon pictures is determined primarily by the characteristics of the first stage in the camera amplifier. The vidicon deserves the "best" rating (that is, minimum grain or noise) only when it is operated in a high-quality camera under reasonably high light levels. Relative freedom from noise or grain is one of the significant advantages of the 4½-in. image orthicon over the smaller size, and results from the larger target area.

(3) It is unrealistic to quote a single number to specify the sensitivity of any type of camera tube because of significant variations between individual samples and wide possible ranges in operating conditions. The vidicon, in particular, can be operated as a high-sensitivity tube by raising its target voltage, but such operation results in serious sacrifices in stability, motion portrayal, sharpness, and possibly in graininess. A realistic impression of *relative* sensitivity is conveyed, however, by the following summary of the studio light levels required for *broadcast quality* pictures with reasonable depth of field.

| | *Minimum Level* | *Preferred Level* |
|---|---|---|
| 7735A Vidicon...... | 40 ft-c | 160 ft-c |
| 5820A Image Orthicon (3-in.)... | 10 ft-c | 40 ft-c |
| 7295A Image Orthicon (4½-in.).. | 30 ft-c | 120 ft-c |

Note that the 7735A vidicon is comparable in sensitivity to the 7295A Image Orthicon, which is somewhat less sensitive than the 3-in. size because of the need to distribute the electrons from the photosensitive surface over a larger target area.

(4) Two ratings are offered for gray-scale performance because the performance indicated by theory and scientific tests with test patterns does not correlate well with subjective impressions gained from actual studio practice. In theory, the vidicon offers superior performance, providing a gray scale which is gently curved in the proper direction to compensate for normal picture tubes (the performance can be made even better by so-called gamma correction circuits found in high-quality cameras). The image orthicon, on the other hand, is normally operated in a manner which "flattens out" the white portion of the gray scale, and is essentially linear in the shadows. Typical gray-scale characteristics for image orthicons and vidicons are shown in Fig. 3. A moderate degree of gray-scale correction may be applied to 4½-in. image-orthicon signals, but not to signals from the 3-in. tubes (because of excessive graininess or noise). In practice, the subjective impression of the gray scale from image-orthicon pictures is often superior to the vidicon because of an "electron redistribution" effect in the glass target which causes bright objects to be outlined by areas that are slightly darker than normal (the same "transition enhancement" effect which also improves subjective sharpness). While this effect represents a *distortion* in the strict technical sense, it happens to be a type of distortion shared by the human eye. While "purists" and technicians with photographic training often find fault with the "artificial" quality of image-orthicon pictures, there is substantial evidence that the edge enhancement effect helps to create a desirable illusion of greater contrast than is actually present, especially under poor viewing conditions.

(5) The fidelity of image geometry is determined almost entirely by equipment design, not by the pickup tube. Industrial-grade equipment may be compromised in this respect, but broadcast-quality equipment is normally designed so that geometric errors do not exceed 1 or 2% of the picture height.

(6) The vidicon can be considered "good" in the portrayal of motion only when it is operated at high light levels (roughly 60 ft-c or above in the case of the 7735A). At low light levels, a pronounced "lag" effect results in serious smearing and loss of sharpness in the portrayal of objects in motion. The lag effect is detectable in image orthicons, but is usually of no practical significance except at abnormally low light levels.

### 6. Comments on Ease of Operation

The "ease of operation" factor should be separated into two parts: (a) ease of setup, and (b) ease of routine operation.

The ease of setup depends greatly upon equipment design characteristics. High-quality equipment with thoroughly stabilized circuits, automatic adjustments wherever possible, and built-in test facilities is much easier to bring to optimum adjustment than low-cost minimum-design equipment, and can be expected to stay in good adjustment for much longer operating periods. For equipment of a given quality level, however, the vidicon enjoys a clear advantage over the image orthicon because of its relative simplicity — there are fewer adjustments to make.

With respect to the ease of routine operation, the image orthicon enjoys a major advantage over the vidicon. Exposure control for the image orthicon is not at all critical, thanks to the intrinsic "automatic level setting" action resulting from the pronounced "knee" in its gray-scale characteristic. The camera may be pointed at a variety of scenes with highlight brightnesses which vary over a wide range, and will continue to deliver a signal of standard voltage level without readjustment by the operator. The "flattening" of the highlight areas which makes this possible is compensated for by the "transition enhancement" effect mentioned earlier, so the picture quality is not seriously affected, as it would be in a typical photographic process under conditions of serious over-exposure. An image-orthicon camera makes possible almost ideal adaptation of the gray scale of an actual scene to fit the limited contrast range of the television system; by proper choice of exposure, an operator can emphasize highlight areas, shadow areas, or the middle ranges. Similarly, the image orthicon is highly tolerant of the highlight "glints" which result from shiny jewelry and other bright objects in the scene; such "glints" do not result in abnormally high signal levels. The vidicon, on the other hand, responds with perhaps unfortunate fidelity to changes in the peak brightness of the scene placed before it, requiring a great deal of attention on the part of an operator to make compensating changes in either exposure (lens setting) or signal level. It is also necessary to give considerably greater attention to lighting and to the reflectances of objects in the studios when using vidicons, and there are some scene conditions which simply cannot be tolerated. When operated under low light level conditions, the vidicon is subject to a black level instability effect which also requires frequent attention by an operator.

### 7. Economic Factors

From a superficial point of view, it appears that the vidicon offers major advantages in economy over the image orthicon. The advantage of minimum investment in equipment is undeniably real; because of the relative simplicity of the vidicon, camera equipment for this tube costs only about half as much as equipment of comparable quality for the image orthicon. It should be noted, however, that live camera chains represent only a fraction of the total investment in a television studio, and the *requirements* for film chains, sync generators, monitors, switching equipment, and audio facilities are not significantly affected by the type of camera selected. Purchase of low-cost terminal facilities to support low-cost vidicon cameras may involve further compromises in picture quality, flexibility and reliability.

With respect to *operating costs*, the advantages are not nearly so one-sided, in spite of the apparent 20-to-1 differential in the hourly costs of the tubes themselves. Actually, *all* technical operating costs are normally a relatively small fraction of the total cost of producing a series of ETV programs (and an even smaller fraction of *commercial* TV programs, where substantial talent fees may be involved). The major item of operating expense in any television studio consists of the wages or salaries of "talent," production personnel and technicians, and the chief economic justification for the image orthicon is the *time* it saves in achieving picture quality of an acceptable level. While it is relatively easy to compute the hourly cost of a vidicon or image orthicon *tube*, it is difficult to compute accurately the "hidden costs" of vidicon operation — greater operator attention, greater attention to lighting, and reduced flexibility in what is placed before the cameras. A major factor in the continued popularity of the image orthicon in commercial broadcasting is the fact that the camera can be pointed at almost anything, and can produce from it an *acceptable* picture (not necessarily an ideal one) with a minimum of fuss and bother. This is definitely not the case with the vidicon, which tends to produce a more "faithful" picture, but one that remains poor if the scene conditions are poor.

### 8. Conclusions

Since both vidicons and image orthicons offer significant advantages, it is unrealistic to make a flat statement that one tube or the other is more suitable for use in ETV studios. The widespread use of image orthicons in commercial broadcasting supports a conclusion that these tubes are somewhat superior to vidicons for live pickup service, but it has been amply demonstrated that the vidicon can be used successfully if due allowances are made for its limitations. In situations where the accumulation of capital is a major obstacle in launching an ETV project, the vidicon may be a wise choice because of the lower investment required. (It might be unwise, however, to invest in vidicon camera equipment of less than true "professional" quality, since the tube must be operated with highly refined circuits to minimize its limitations. In general, low-cost vidicon cameras designed for observational or industrial monitoring applications are poorly suited to studio operations.) In situations where adequate financial resources are available, image-orthicon equipment can usually be justified as a sound investment in production tools of maximum effectiveness.

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