Live Flying-Spot Color Scanner

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This new color-television system, the Vitascan, an all-electronic version of the old-style mechanical type, is the simplest and most reliable live-action color system now in existence. It can be regarded as using the reverse of conventional studio methods, as the flying-spot tube is substituted for the image-orthicon camera tube and clusters of phototubes replace regular studio lighting equipment.

COLOR-TELEVISION PICTURES of high quality without the use of expensive and complicated color-television cameras or highly trained and skilled camera and maintenance crews are now produced by the "Vitascan" system, as developed by the Allen B. Du Mont Laboratories, Passaic, N. J. It is, in fact, a modern all-electronic version of the earliest forms of mechanical live television pickup which employed the flying-spot scanning principles.

Although Vitascan cannot displace storage-type color-television cameras, it is expected that its unique advantages will earn it a modest place in color-television programming. This article proposes to explain its virues and shortcomings.

On an historical level, it is interesting to note how the present technical state of the art has allowed this revitalization of the old flying-spot principle. Thus, basic principles are discussed, and evolution of a workable system leading to present commercially available equipment is traced.

HISTORICAL REVIEW

THE ANALYSIS AND SYNTHESIS of a subject by television was first achieved by J. L. Baird, in England, in 1923. He employed a 30-line mechanical scanning system. As late as 1937, the British Broadcasting Company (BBC) in London, England, programmed with a Baird mechanical live-pickup flying-spot scanner operating at 240 lines.

In advancing from 30 to 240 lines, the mechanical scanner system was doomed for two major reasons. First, the extremely acute mechanical problems and, second, the lack of sensitivity of the then available photocells. Since multiplier photocells were not available, the low signal level gave excessive noise when amplified, thus limiting the action to head and shoulder close-ups.

The first nonmechanical live pickup, using a cathode-ray tube, was demonstrated early in 1947 during the first Federal Communications Commission's (FCC) color hearings in connection with the Radio Coporation of America (RCA) simultaneous color-television system.[1] The 18- × 24-inch scanned area limited the device to head and shoulder pickups.[2] Although *931A* multiplier phototubes were used, the light collection was severely restricted by the 5/16- × 15/16-inch pickup area.

The Du Mont color-scanner development program, which began in 1949, took advantage of the newly available 2-inch multiplier phototubes. Although the transmission of slides, film, and opaques was achieved with considerable success, it was not until 1954 that components and techniques had sufficiently improved to allow the contemplation of a satisfactory color scanner for limited live pickup work, which would surmount some of the shortcomings of earlier equipments. The real technical breakthrough came with the commercial availability of the first 5-inch multiplier phototubes, the Du Mont type *6364*.

At first, efforts were directed toward providing a live-action color pickup of a $7^1/_2$- × 10-foot scanned area solely as a signal source for research purposes. However, notwithstanding its inherent limitations, it became apparent that a very definite use could be made of the principle in normal color-broadcasting operations. A commercial version of this device, the Vitascan, was designed and a prototype was demonstrated publicly for the first time at the National Association of Radio and Television Broadcasters (NARTB) Convention in May 1955. This article is not intended as a detailed description of the present commercially available equipment, but rather as a history of its parentage.

BASIC PRINCIPLE OF OPERATION

THE LIGHT from a high-voltage high-beam current flying-spot scanning tube, which emanates from the unmodulated rectangular scanning pattern, is focused onto the subject or scene being televised through a suitable lens system.

As this light spot traverses the scene in its regular pattern, it is reflected from the various objects; the amount and color of reflected light at any given moment varies with the reflection factor and color characteristics of that part of the scene. The scanning light incident on the scene is therefore modified or modulated by the different reflective characteristics of the scene from one part to another. These variations in intensity and color of the reflected light are picked up by groups of multiplier photocells, suitably disposed around the scene, which linearly convert the light energy to varying currents for processing through the normal color-video apparatus for flying-spot scanners.

The phototubes are covered with suitable color filters which, in combination with the spectral emission characteristic of the scanning tube and the response of the phototubes, determine the spectral characteristics of the system.

The major differences between the flying-spot scanning

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operation for the transmission of live pickup and that for transparencies are: (1) the scanned area is many thousand times larger for live pickup than for slide or film operation; (2) the scanning light is reflected from solid objects rather than transmitted through flat material as in the case of a transparency; (3) using a multiplicity of phototubes, lighting effects similar to other live-action television systems are provided; (4) controlled illumination, in addition to the light from the flying-spot, must be provided in the studio; and (5) special television previewing techniques must be employed.

In visualizing how the Vitascan live-action scanner operates, it is helpful to regard the system as being the reverse of conventional studio television operation. Clusters of phototubes replace the studio lighting fixtures and the flying-spot tube is substituted for the image-orthicon camera tube.

Normally, light from the studio fixtures illuminates the scene, and reflected light is gathered by an objective lens onto a light-sensitive electrode, where it is transformed by the scanning process within the camera tube into electric currents. In contrast, the scanning tube and its lens, placed where the camera would normally be, produce the light and perform the scanning operation at the same time. Some of this light reflected from the scene is intercepted by the phototube clusters and converted into electric currents.

The analogous relationship described in the foregoing was recognized by the early pioneers in television; this relationship was described by Lance and Percy in 1935[3]: "In this studio there has been a great deal of work done to produce an artistic effect by correct lighting of the artists; in fact, it was found that, since each photocell could be controlled separately to give the correct balance between top, side, and back lighting, in imitation of the lighting of a floodlight studio, the simplest way of working out the lighting effects was to regard the scanning projector as a camera, and the photocells as light sources, placing them and altering their gain from that point of view."

STUDIO REQUIREMENTS

Inasmuch as the Vitascan system operates by virtue of a scanning light beam, no illumination other than that from the controlled scanning source can be allowed to reach the phototubes during the scanning period because this extraneous light will only produce noise.

The studio, therefore, must be sealed against ambient light. Eliminating all ambient light, however, would leave the studio in relative darkness because the light from the scanner is insufficient to illuminate the studio adequately.

This acute problem was literally a stumbling block in earlier versions of live scanner operation, since lack of light seriously restricted the movement of performers about the studio, made it impossible to read, and produced a staring expression on the faces of the actors.

The difficulty of providing adequate light in the studio without interfering with the Vitascan operation has been resolved by utilizing the 60-cycle vertical-blanking period, during which time the scanning beam is extinguished.

During this blanking period, pulsed or stroboscopic lights synchronized with the television system are flashed on in

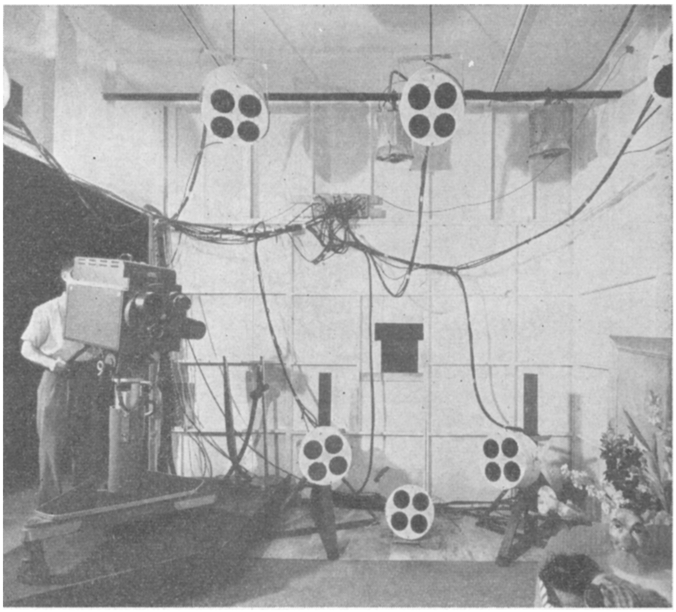


Fig. 1. Television studio, showing Vitascan and phototube clusters.

the studio, providing adequate illumination for studio action without upsetting the scanning operation. During this same period that the lights are pulsed on, the phototubes or associated video amplifiers, or both, are keyed off to prevent overloading. In addition to being lighttight, noise is further reduced by employing reflective materials on the unscanned walls and ceiling, thus increasing the light directed to the phototubes and additionally softening the shadows.

EQUIPMENT COMPLEMENT

In its present form, the Vitascan is operated as a one or two "camera" system. The "cameras" which, in actuality, are flying-spot scanners, may be fixed or mobile. One favorable arrangement, which was used at the initial public demonstration at the 1955 NARTB Convention, includes the Du Mont multiscanner equipment to provide a fixed scanner, augmented by a mobile scanner packaged to resemble a standard image-orthicon camera.

Fig. 1 shows the studio of 200 square feet at the NARTB Convention. The equipment complement included the following items: (1) two scanning light sources, one mobile and one fixed unit, utilizing the Du Mont multiscanner; (2) seven clusters of Du Mont 5-inch multiplier phototubes; (3) six pulsed light fixtures; and (4) processing amplifiers.

The Du Mont multiscanner, as seen in Fig. 2, is a flying-spot scanner system for slide, opaque, and motion-picture film pickup. It utilizes a 7-inch high-voltage cathode-ray tube operating at 40 kv. The tube, which is aluminized, employes a short persistence zinc-oxide phosphor, coated onto a high-quality nonbrowning neutral-density face plate. Use of this gray face plate, rather than a clear face plate, improves the small area contrast by a factor of ten by the reduction of halation flare. Fig. 3 shows how the multiscanner is easily adapted to live pickup work by the removal of the cabinet for 4- × 5-inch opaques and the addi-

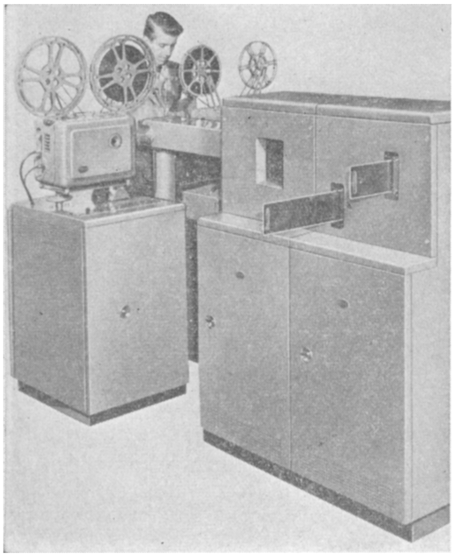


Fig. 2. Multiscanner.

tion of the desired focal-length lens to the flying-spot cabinet.

The mobile light source (Fig. 4) resembles a television camera and includes a lens turret to provide a choice of focal lengths for close-up, medium, or long-shot work. This mobile scanner employs a 5-inch high-voltage cathode-ray tube, operating at 35 kv, in which special precautions have been taken to minimize the phosphor grain size by careful control of the screening process.

The phototube clusters consist of four Du Mont 5-inch diameter 10-stage multiplier phototubes of the type shown in Fig. 5, closely spaced in a compact housing (Fig. 6). Each phototube is covered with an appropriate color filter to analyze the reflected light from the scene into three primary color channels. One cell is allocated to the green (G) channel, and one to the blue (B) channel. Two cells are supplied for the red (R) channel in order to compensate for the lack of sensitivity at the red end of the spectrum. The phototubes identified with each color channel are bridged onto a coaxial line which is terminated at each end, thus allowing the addition of as many clusters as desired.

The pulsed, or stroboscopic, lights are of two types.

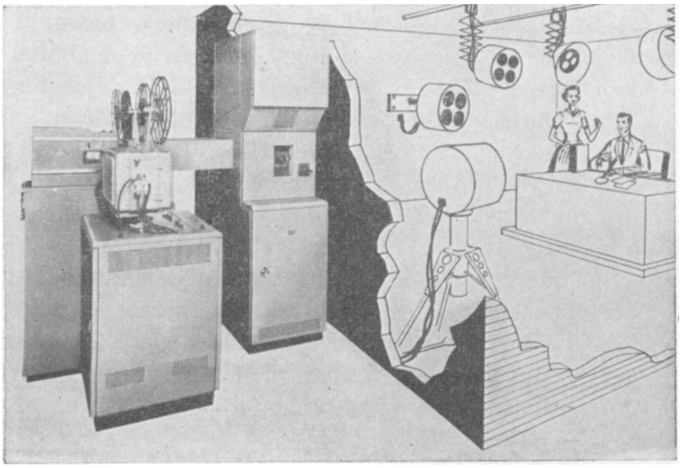


Fig. 3. Multiscanner used as fixed Vitascan.

In one version, small commercially available xenon flash lamps are used, five to a reflective fixture. These lamps are triggered to flash during the vertical-scan blanking interval. In the second developmental version, miniature cathode-ray tubes are employed, three to a reflective fixture. These tubes are operated at 15 kv and are pulsed ON during the vertical blanking interval.

Operation on the R, B, and G signals, developed from the combined outputs of the phototube clusters, is accomplished in conventional video processing amplifiers, providing phosphor correction, gamma correction, and blanking insertion, as normally used in flying-spot scanners.

The foregoing paragraphs have presented a brief general look at the Vitascan system. An expanded explanation of some of the more novel features of the system follows.

VITASCAN PHOTOMETRY

RETURNING to the basic principles of the Vitascan, it is helpful to give a definition of a live-action flying-spot scanner. A live scanner is one which televises an object having depth, and which, consequently, must provide the appearance of "effects lighting." Fig. 7 depicts a schematic top view of a simple monochrome Vitascan. The scene being televised is a square white card suspended some distance from a gray background. When a single phototube pickup is placed at the right of the scanner, the television picture produced looks like one from a storage-type television camera viewing, from the cathode-ray tube position, the scene lit by a single lamp at the phototube position.

Consider what happens at seven equal increments of time, *T1* through *T7*, when the scan is just beginning a new line in the middle of the picture. The tiny spot on the cathode-ray tube is imaged by the objective lens onto the left-hand side of the gray background. A small portion of the light is picked up by the phototube and a signal corresponding to gray is generated and displayed on the screen of the television monitor. Between *T2* and *T3*, no signal is produced by the phototube, which results in a black shadow on the monitor. At *T3* and continuing through *T5*, the phototube transmits a white signal. Finally, from *T5* to *T7*, a gray signal is again displayed.

If only a single phototube is employed, the resultant picture appears to be illuminated by a light at the phototube position. By employing a number of phototubes, any desired lighting effect can be produced such as "key," "fill," and "back" lighting. The apparent intensity of these "lights" are controlled simply by the photomultiplier gain. Thus, the video level and the lighting effects are controlled by only one individual.

With the color Vitascan, the picture is analogous to having red, blue, and green lamps illuminating the scene rather than a single white lamp.

What additional problems are raised when the fixed Vitascan is replaced by a mobile scanner which can be moved around the studio and which employs a turret with a variety of objective lens focal lengths? For instance, if the scanner is dollied very close to the subject, it might be supposed that the signal level would be greatly increased. This supposition is incorrect. If a 6- × 8-foot gray area is scanned, a corresponding gray signal amplitude is produced. If now the scanner dollies in to scan a 3- × 4-foot area, the signal level will remain exactly the same, because the phototube remains at the same distance and still collects the same proportion of the same total light flux leaving the scanner. Also, the small area will be four times as bright as the large area but, since it has only one fourth the area, the total light picked up will be constant.

The same flexibility of movement is allowed, as with any television camera, when the lens turret is changed from narrow to wide lens. In any scene, as long as the effective *f*/numbers of the lenses are the same, the signal level will not vary with focal length.

The color Vitascan also produces a live-action signal source totally devoid of color registration errors for testing of color-television equipment. This absence of color misregistery is readily appreciated by reference again to Fig. 7. Just prior to *T5*, the *R*, *B*, and *G* signals are equal and produce white. When the spot moves to the gray background, all the phototube outputs must change together. There is no way for one color channel to change at a time different from another.

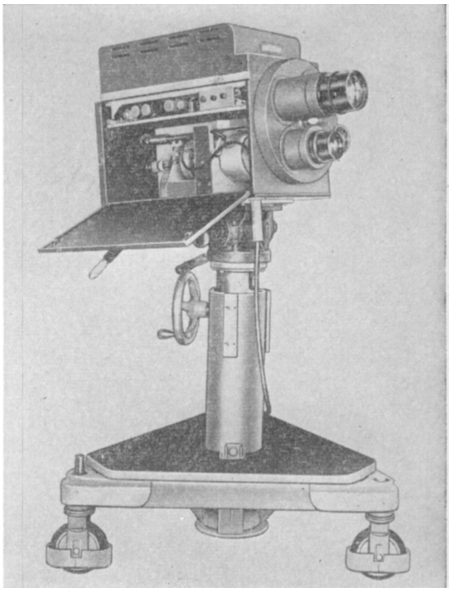


Fig. 4. Mobile light source.

SPECTRAL CHARACTERISTICS

When the Vitascan is used for monochrome television pickup, the over-all spectral characteristic is determined by the product of the phosphor times the phototube spectral responses. This resultant curve is shown in Fig. 8. If appropriate color filters are placed before the phototubes, the resultant *R*, *B*, and *G* sensitivities are shown. Sensitivities relative to monochrome give *R*, 1 per cent; *B*, 17 per cent; and G, 50 per cent. Thus, the red output was doubled to 2 per cent by employing two red phototubes for each blue and green one. To obtain equal *R*, *B*, and *G* signals for white balance, it is necessary to adjust the photomultiplier gains suitably. The spectral characteristics for equal-signal white, with the corresponding gains indicated, are shown in Fig. 9. The poor red sensitivity, requiring increased red photomultiplier gain, results in the red channel noise determining the over-all acceptability of the signal-to-noise ratio in the simultaneous color signal.

With the storage-type color-television cameras, color contamination is present because of the nonlinear transfer characteristic of each camera tube. From the standpoint of color fidelity, the Vitascan is preferred to a slide scanner as a color signal source, because colorimetric failures of the film processes are avoided.

OPTICAL PARAMETERS

Signal-to-noise and depth-of-field considerations have proved to be serious problems. Although theoretically quite independent, the economics of equipment design makes them mutually antagonistic.

In the first experiments, the depth-of-field was only about two feet. To increase the depth-of-field, the lens was stopped down, making the signal-to-noise ratio objectionable. To improve the depth-of-field, it is necessary to use a smaller lens aperture, or smaller scan size, or both. In either case, the amount of light incident on the scene is decreased. Unless the same total amount of light is collected by the phototubes, the signal-to-noise will suffer. Higher collection efficiency can be accomplished by adding simple reflectors to each phototube cluster and by covering the walls with aluminum sheeting. Also, the total of phototube clusters can be increased; this gives interesting modelling effects in the lighting as well as greater light collection.

As a considerable economic problem would exist in larger studios employing mobile cameras, it was necessary to consider the depth-of-field problem purely from the standpoint of the camera design itself. First, a general analysis of depth-of-field as a function of cathode-ray tube raster size and other variables was made. Second, the final optimizing of the camera design for signal-to-noise was determined by practical problems of cathode-ray tube operation.

The present Vitascan units operate at a distinct theoretical disadvantage when compared to image-orthicon cameras in regard to depth-of-field but, in reality, this

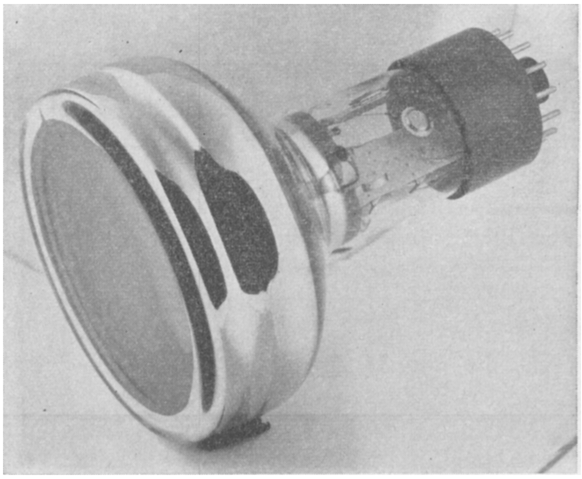


Fig. 5. Multiplier phototube.

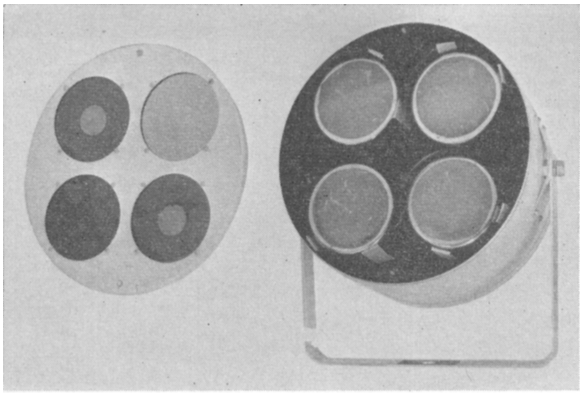


Fig. 6. Phototube cluster.

difference is less than that indicated by the figures since the theoretical depth-of-field advantage is far from being attained in image-orthicon color cameras because of certain effects which reduce the sharpness. This lack of cripsness is caused, first, by optical aberrations introduced by the complicated lens relay system and, second, by misregistery of the red, blue, and green camera scans.

The depth-of-field seriously limits the television programming applications, so that a compromise had to be made in the mobile Vitascan design. A 5-inch cathode-ray tube allows a 3.0- × 4.0-inch scan size or smaller. Experiments indicate the smallest practical scan size to be 2.1- × 2.8-inch, determined primarily by the current saturation, grain size, and life of the phosphor. Typical operating conditions are 35-kv accelerating voltage at 250-microampere beam current. The depth-of-field of the 2.1- × 2.8-inch raster at *f*/2.8 is adequate for many types of television programming; at 10-foot focus, nearly a 4-foot depth-of-field is realized.

STUDIO STROBE LIGHTING

As previously pointed out, two different methods of lighting during the vertical blanking interval have been developed. At present, the first production version of the Vitascan uses a xenon flash lamp, pending quantity manufacture of another light source, a miniature short-persistence cathode-ray tube. Although there are points for and against both methods, the scheme utilizing the cathode-ray tube is ultimately to be preferred.

In the first method, a trigger voltage of several thousand volts is applied to the external electrode of a U-shaped xenon Amglo type *U-35K* lamp. This voltage ionizes the gas and a d-c potential of 350 volts from a charged capacitor applied across the internal electrodes maintains the ionization, producing a blue-white light output for approximately a 100-microsecond duration. Inasmuch as the trigger voltage is synchronized with the vertical drive from a standard sync generator, the flash occcurs during the vertical blanking interval. To provide a suitable light level, five xenon lamps are used in each fixture (Fig. 10).

The second method for strobe lighting utilizes miniature cathode-ray tubes, Du Mont type *K1388*, as light sources. Each tube consists of a $1^1/_2$-inch diameter glass envelope with a special triode gun at one end and a metal phosphor plate, inclined at 45°, welded to the other end. This enables the phosphor to be efficiently air-cooled. The special gun is designed to produce an unfocused flood of electrons over the phosphor surface, typical operating figures being 15-kv accelerating voltage at 200-microamperes average current (Fig. 11). An experimental light fixture utilizes three of these tubes (Fig. 12).

With either of the aforementioned methods, a high-current pulse is generated at the output of the phototubes during the strobe lighting period. It is, of course, essential to prevent this pulse from appearing in the video signal leaving the processing amplifier. There are two convenient ways to accomplish this: first, by keying the phototubes off so as to make them inoperative during the vertical blanking interval; and, second, by clipping and keying out the unwanted pulse in the video processing amplifier.

PREVIEW FACILITIES

The problem of providing preview facilities, where more than one scanner televises the same scene, requires consideration. Suppose that two Vitascan cameras are scanning the same scene from different positions. Because both light sources would be operating at the same time, a mixed signal is generated by the phototubes. On the picture monitor, this would appear as two superimposed images as seen from the respective camera positions. The problem, therefore, is to derive two separate signals, without crosstalk, from the two scanning light sources. Obviously, some multiplexing system must be employed.

There are several possible ways of providing a preview picture for the Vitascan; suggested methods were judged for suitability by the following criteria: (1) economy, governed by the amount of additional nonstandard equipment required; (2) quality of picture, that is, signal-to-noise ratio, resolution, color, or black and white rendition; and (3) complexity of operation. Previewing systems group themselves in two main categories, time and spectral multiplexing. As an example of time multiplexing, the retrace portion of the horizontal scanning cycle for the preview could be utilized. Spectral multiplexing systems can be operated within or outside of the visible spectrum.

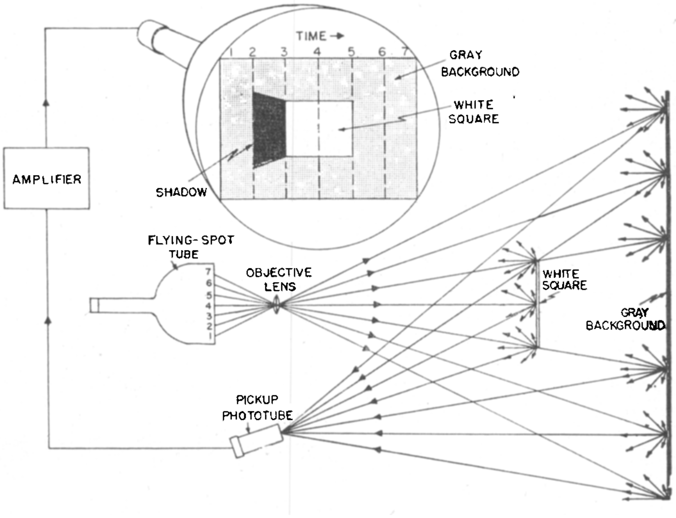


Fig. 7. Principle of Vitascan "lighting."

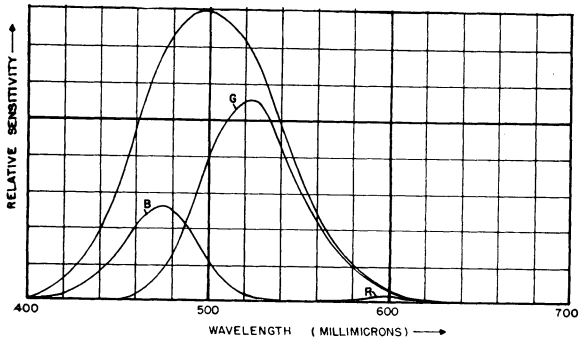


Fig. 8. Color Vitascan filter shaping.

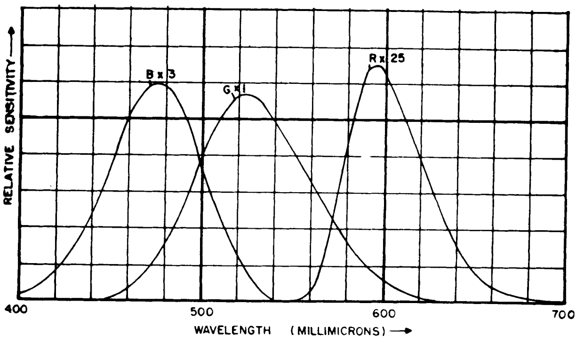
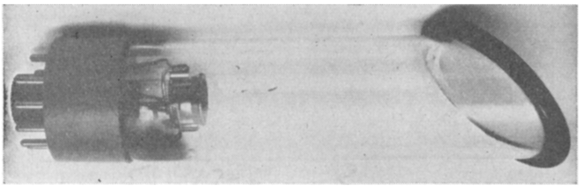


Fig. 9. Color Vitascan spectral characteristic.



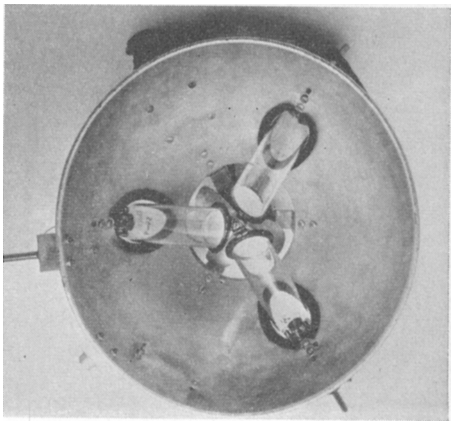


Fig. 11 (top). Miniature cathode-ray-tube strobe light. Fig. 12 (right). Cathode-ray-tube fixture.

The preview may utilize the existing phototubes or an auxiliary-storage camera associated with the scanning source. A number of other methods have been investigated and discarded; however, others hold considerable promise of ultimate success.

CONCLUSIONS

There appear to be three major fields wherein the Vitascan should find application. These are: (1) industry, (2) color-television research, and (3) color-television broadcasting.

Experience with the color Vitascan leads to enthusiasm concerning its place as a research tool. It has definite advantages over a transparency scanner. It provides excellent color-television signals, especially in respect to resolution, color rendition, and lack-of-color misregistery. From an operational standpoint, it is the simplest and most reliable live-action color-television pickup system in existence. Its initial cost is relatively low because of the inexpensive components employed. Operating costs are also low because of the long life and smaller number of components.

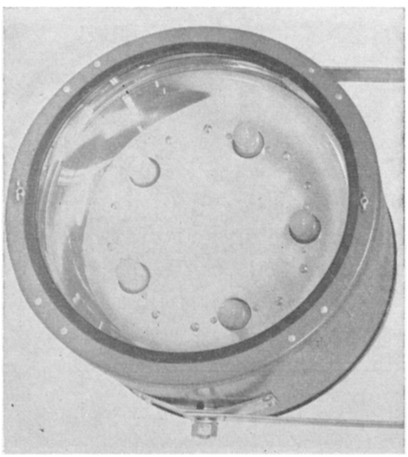


Fig. 10. Xenon flash lamp fixture.

In the field of color-television broadcasting, the Vitascan has both advantages and disadvantages. The major disadvantages are rather obvious. It cannot be operated outdoors or where extraneous illumination exists. Multiple camera use will be limited until suitable previewing facilities are developed.

However, certain of its advantages are not obvious until comparison is made with image-orthicon camera operation. For example, typical color studio operation requires illumination levels of at least 100 watts per square foot. In addition, the heat generated presents a formidable air-conditioning problem. The Vitascan, therefore, represents a very significant reduction in operating power costs.

Perfect colorimetric camera match is obtained at all times, since the pickup tubes are common to all scanners. Because of its excellent color reproduction, no special make-up is required with the Vitascan system.

There is no image burn-in, so that a scanner may be left undisturbed on a scene at fixed focus for any length of time. Also, the warm-up and adjustment time required is only a few minutes compared to the hour or longer needed for the image-orthicon color camera.

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