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VARIABLE MAGNIFICATION - A MEANS OF INCREASING THE RESOLUTION OF TELEVISION TRANSMITTED DATA

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ABSTRACT

Some of the problems arising in the military application of television are discussed, as are the resolution limitations of currently available techniques and equipment. It is shown that improved resolution is possible, justified, and desirable. Three methods are proposed for partially solving these problems; the capabilities and limitations of each are pointed out and experimental evidence given. It is concluded that, no matter what the resolution of the initial television link, several-fold improvement can be had on a lesser portion of the object by the techniques described.

PROBLEM STATUS

This report completes this phase of the problem.

AUTHORIZATION

NRL Problem R10-40R
NR 510-400

VARIABLE MAGNIFICATION - A MEANS OF INCREASING THE RESOLUTION OF TELEVISION TRANSMITTED DATA

THE PROBLEM

Teaching

The use of television in mass teaching is becoming more widespread, since by this medium top-quality instructors with the best visual teaching aids can be brought before a large audience. The studio and camera techniques for this service were recently studied at the Navy Special Devices Center, Sands Point, Long Island, New York, where television is being evaluated as a means for military training. Thus far, the limited size and/or resolution of the reproduced picture has introduced peculiar limitations on the charts, mockups, and cutaway types of visual aids used by the instructor, but some distinct advantages are apparent nevertheless.

In demonstrating a piece of equipment, for example, an over-all picture of the device is usually shown first. Then the camera is "dollied in" for a close-up, or another camera must be switched in for a close-up view. Because the dollying technique requires smooth coordination between dollyman and cameraman, as well as unobstructed floor space, it is difficult to use effectively. Switching to another camera for a close-up shot causes the audience to lose orientation on all but the simplest devices. For this reason commercial television studio techniques are not entirely adequate for this application. Enlarging the viewing screen, for a given size audience, produces rapidly diminishing returns beyond the point where the eye dissects the line structure of the television picture.

At this point it is the resolution of the television system which limits ability to read, for example, the numbers on a slide rule or the letters on printed material. To increase the inherent resolution, each element in the chain must be capable of functioning better. This can be accomplished in most cases by the expenditure of sufficient effort in redesign of each component to higher standards. However, for the plan to succeed, all components must be capable of this higher standard of resolution.

The image orthicon camera tube, the most successful device for general service to date, has inherent features making it difficult to obtain much beyond the 400-line resolution of commercial equipment. As a result, the camera is the chief obstacle in the way of increased resolution for military applications. Commercial television is, of course, limited by the scanning standards, channel width, etc. adopted by the FCC, and these standards have been reasonably adequate for commercial use.

Data Relay

Television is also being used in military service to transmit radar data, plotting-table calculations, and map information rapidly from point to point to enhance its tactical value by reducing transmission time. Here again the resolution of the television link restricts the amount of information which can be transmitted in one picture successfully. These applications do not readily lend themselves to the "dolly" and lens-switching techniques used in the studio.

Guided Missiles

Television cameras and transmitters have been installed in guided missiles to provide the remote pilot with information for steering the missile on a collision course with its target. Marshall and Katz[1] pointed out the difficulties encountered with a fixed camera fitted for this service with a single lens. The pilot often lost his bearings due to sudden winds, cloud formations, etc. and, because of his inability to "look around," was unable to rediscover the target soon enough for a hit. The complexity of adding a lens turret with a choice of lenses, together with its radio control mechanism, and the unnatural effect gained were sufficient to leave this an unsolved problem in their work.

ANALYSIS OF THE PROBLEM

Thus, the requirements of a satisfactory television link for military applications are often quite different from those of commercial or entertainment equipment. High resolution, flexible operation, remote control, and bandwidth conservation are a few of the incompatibles involved. A system designed to give the maximum obtainable resolution is wasteful of radio-frequency spectrum unless, as is seldom the case, that resolution is required at all times. The techniques used in commercial telecasting, and justified on their esthetic value, are not suitable for military use unless they make the interpretation of the picture information more natural.

Perhaps the most natural and widely used technique for achieving greater resolution of an object of interest is to bring it as close as the eye can comfortably focus. Thus each minute detail subtends the greatest angle and excites the greatest number of optical nerves. The wide-angle view is used first to locate the object, then the field is narrowed as it is brought closer for inspection. This being a natural phenomenon, it should be preserved whenever possible in the use of intermediate devices for seeing, such as microscopes, telescopes, and television. The practice of switching lenses on television cameras can be justified on one or more of three bases: (1) to maintain interest and provide different points of view, (2) to provide enlargement of the reproduced image, (3) to provide greater resolution as in the above example. The first of these has little military value except perhaps in teaching applications; the second has little value if the viewing conditions are correct. It is the third factor which has greatest military application, since by restricting the field of vision the greatest possible magnification and detail can be had. Discrete steps in this enlargement, however, are unnatural to the eye, and for this reason the possibilities of accomplishing magnification by a continuously variable method have been investigated.

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[1] *Marshall, Charles J., Leonhard Katz, "Television Equipment for Guided-Missiles," Proc. I.R.E. 34:375-401, June 1946*

The "ZOOMAR" lens is an optical device capable of providing continuously variable magnification with constant light output. Except for its size, cost, limited change of magnification, and difficulty of remote control, it might be considered the ideal solution. On the other hand, it has been shown that an image orthicon type camera is capable of working satisfactorily with light intensities varying several hundred to one.[2] Only minor variations in picture quality occur. It is not necessary, then, to maintain constant light output (constant f stop in photographic parlance) when a lens is used with a television camera. A change of magnification of 10:1, obtained by cascading two lens systems before the camera, causes a variation of 100:1 in light output, or the equivalent of 6.7 f stops. This range can be handled without readjustment of the image orthicon and could be expected to provide slightly less than ten times better resolution of a particular part of the information being transmitted. The masking effect of noise at the lower light levels, attendant with greater magnification, prevents the realization of the full 10:1 increase of resolution. Nevertheless, much is to be gained if a workable system can be devised.

Three principles appear capable of providing continuously variable magnification in the television camera, whereby maximum resolution is gained by eliminating the portions of the picture momentarily unused and the radio-frequency spectrum is used economically at all times. Furthermore, the resolution obtainable on any part of the picture is comparable to that achieved by the use of a telephoto lens providing the same magnification. Two of the systems are entirely electronic and adaptable to remote control. Unfortunately, either system requires the development of a specially designed vacuum tube to exploit its advantages fully.

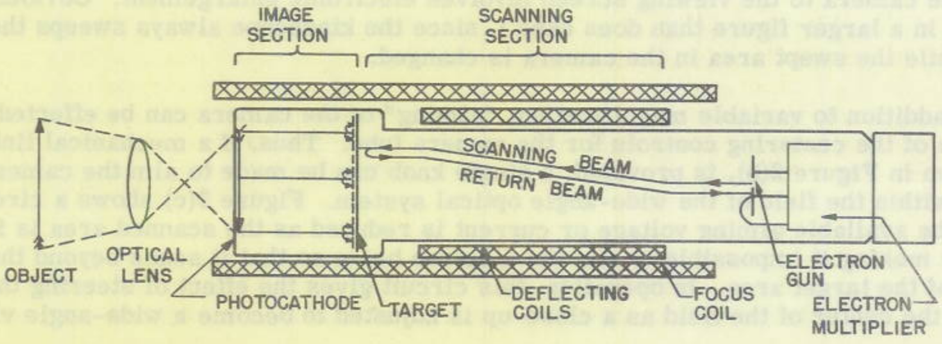

Figure 1 - Typical image orthicon

Figure 1 shows a schematic arrangement of a typical image orthicon. The information to be televised is focused on the photocathode by an optical lens, and the electrons released by the light energy are in turn focused on the target structure, forming a charge pattern corresponding to the original information. The electron gun on the opposite end of the tube emits an electron beam which is made to scan the charge pattern on the target. Those electrons not required to neutralize the charge return to the electron gun and excite the electron multiplier which delivers video signal.

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[2] *Janes, R. B., Johnson, R. E., and Moore, R. S., "Development and Performance of Television Camera Tubes," RCA Review, Vol. X No. 2, p. 191-223, June 1949*

Rose, Weimer, and Law[3] state that the resolution of the image orthicon is limited by three transformation factors: "optical image to electron image, electron image to charge pattern on the target, and charge pattern to modulated stream of electrons in the scanning beam." Therefore, any technique intended to extend the capabilities and usefulness of the image orthicon must be weighed in the light of these three factors.

SOLUTIONS

Variscan Principle

The Variscan (variable scanning) Principle[4] offers interesting possibilities for continuously variable magnification, improved resolution, and conservation of bandwidth requirements.

In the conventional camera, the optical system necessarily selects the area to be viewed, and this area is focused onto the camera tube and scanned by the electron beam. If, however, the optical system is made to view the entire area to be televised, and to focus that area on the camera tube, any or all portions of that area can be scanned by the electron beam and converted into a video signal. Hence, by providing a means for expanding and contracting the area scanned by the electron beam in the camera tube, a close-up shot may be obtained by scanning only a small portion of the scene; and an over-all view can be had by advancing the sweep amplitudes to sweep the maximum usable area. This phenomenon is illustrated in Figure 2(a), where the term "electronic enlargement" is introduced and derived. Whatever the size of the kinescope screen, the transfer of a picture from the camera to the viewing screen involves electronic enlargement. Obviously, case II results in a larger figure than does case I, since the kinescope always sweeps the same area while the swept area in the camera is changed.

In addition to variable magnification, "aiming" of the camera can be effected by manipulation of the centering controls for the camera tube. Thus, if a mechanical linkage, such as shown in Figure 2(b), is provided, a single knob can be made to aim the camera at any object within the field of the wide-angle optical system. Figure 2(c) shows a circuit in which the available aiming voltage or current is reduced as the scanned area is increased, thereby making it impossible to aim the electron beam so that it scans beyond the normal limits of the target area. In operation, this circuit gives the effect of steering the camera toward the center of the field as a close-up is adjusted to become a wide-angle view.

The effect of variable scan on the definition of the camera was investigated on an RCA Field Camera Chain, using a type 5655 image orthicon.[5] Figure 3 is a photograph[6] of the image appearing on the monitor kinescope with the camera trained on a standard

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[3] *Rose, Albert, Weimer, Paul K., and Law, Harold B., "The Image Orthicon - A Sensitive Television Pickup Tube," Proc. I.R.E. 34:424-432, July 1946*

[4] *First proposed by Iams, U. S. Patent No. 2,098,390; see also Collup, Dayle O., "The Variscan Principle: etc," p. 1, Report of NRL Progress, August 1949.*

[5] *This work was carried out in the Communications Branch of Radio Division II of NRL. For his cooperation thanks are extended to Mr. H. L. Wuerffel of that Branch.*

[6] *Some loss of detail and tone quality must be attributed to the photographic and reproducing processes.*

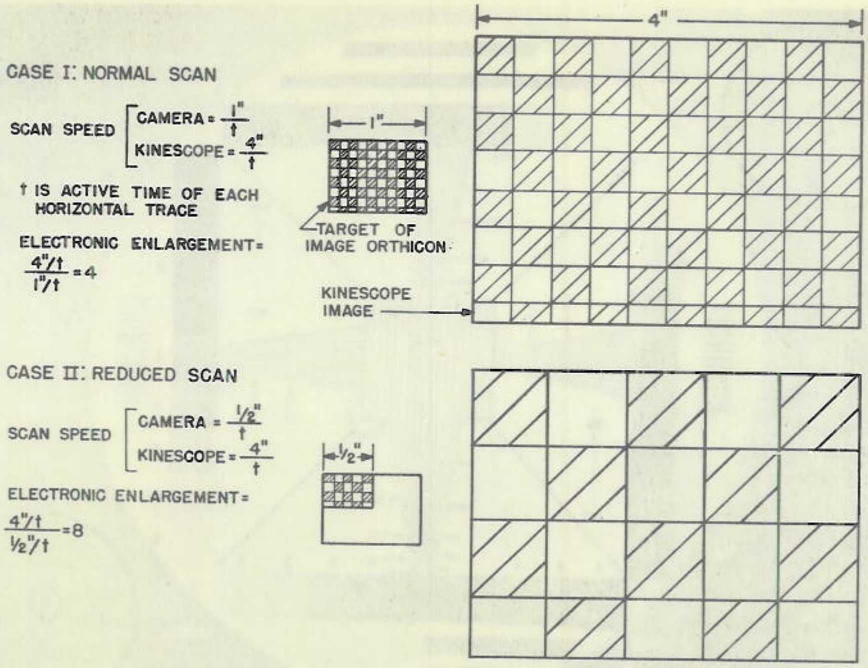

Figure 2(a) - Electronic enlargement of television image

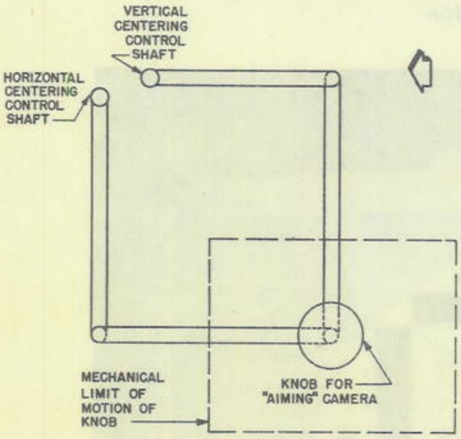

Figure 2(b) - Electronic and mechanical device for aiming Variscan camera

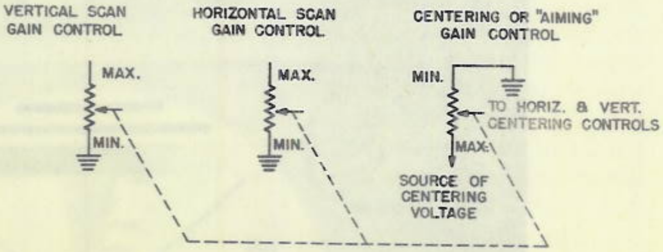

Figure 2(c) - Ganged scan and aiming gain controls

resolution chart and adjusted for normal operation. Figure 4 shows the resolution obtained when the scanning gain controls were set for maximum scan. Besides the reduction of object size, the increased field of view and decreased vertical and horizontal resolution can be noted. The scanning gain controls were then set to minimum scan position (Figure 5). Reduced field and increased object size and resolution are obtained.

With the electrical controls unchanged, the television camera was then backed away from the chart until the same field of view was obtained as in Figure 4. Under these conditions the same information as in Figure 4 was presented to the camera, with the exception that in the second case only about 0.3 of the target area was being used. Figure 6 shows the resulting performance. It can be seen that the use of the reduced target area has

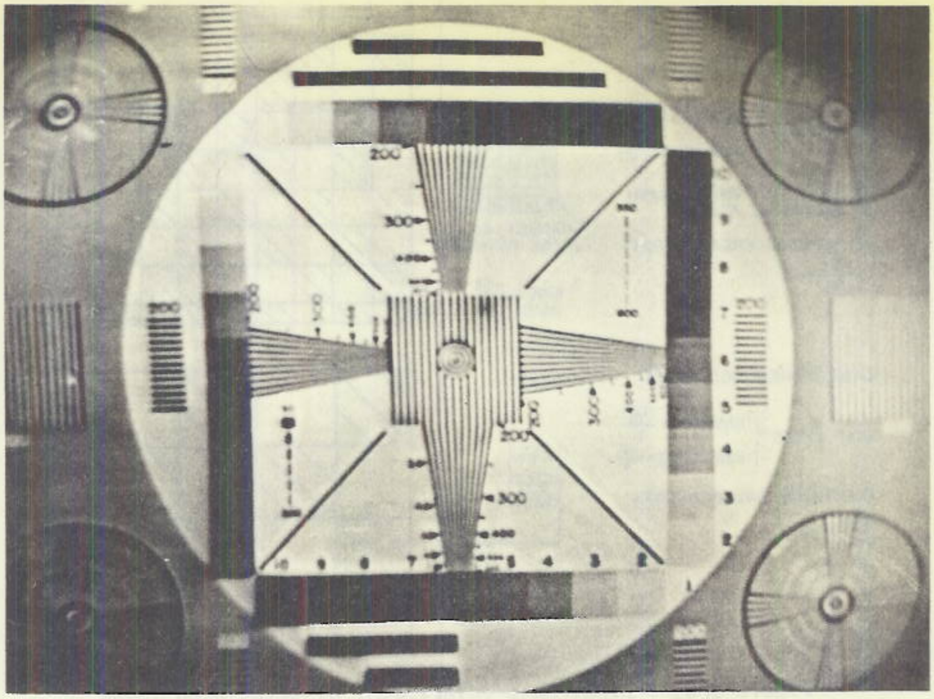

Figure 3 - Resolution of a test chart with the camera adjusted for normal operation

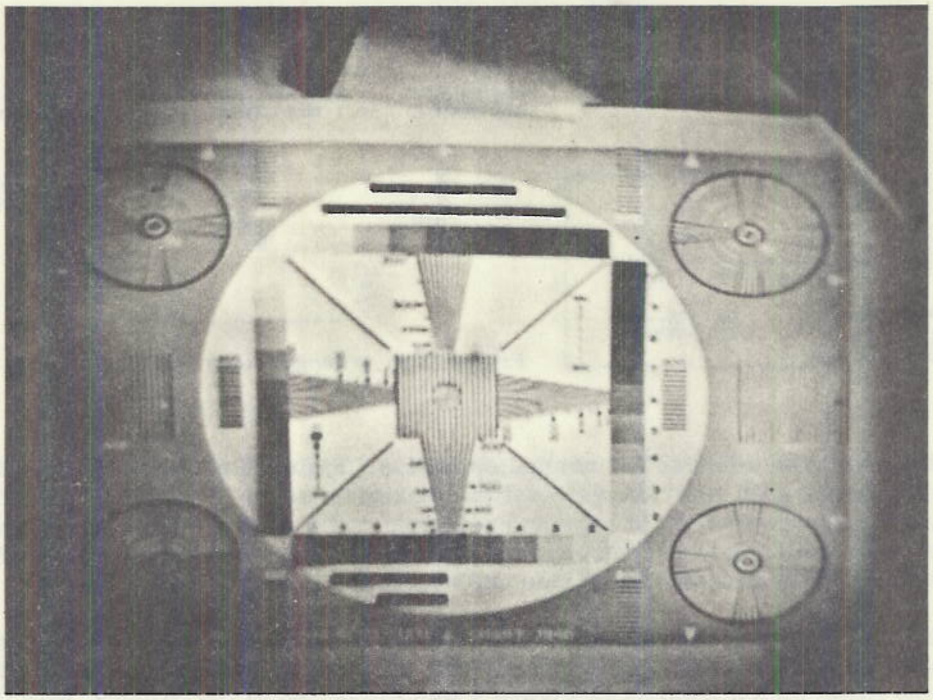

Figure 4 - Resolution of a test chart with vertical and horizontal sweep controls of camera adjusted to sweep beyond the useful target area

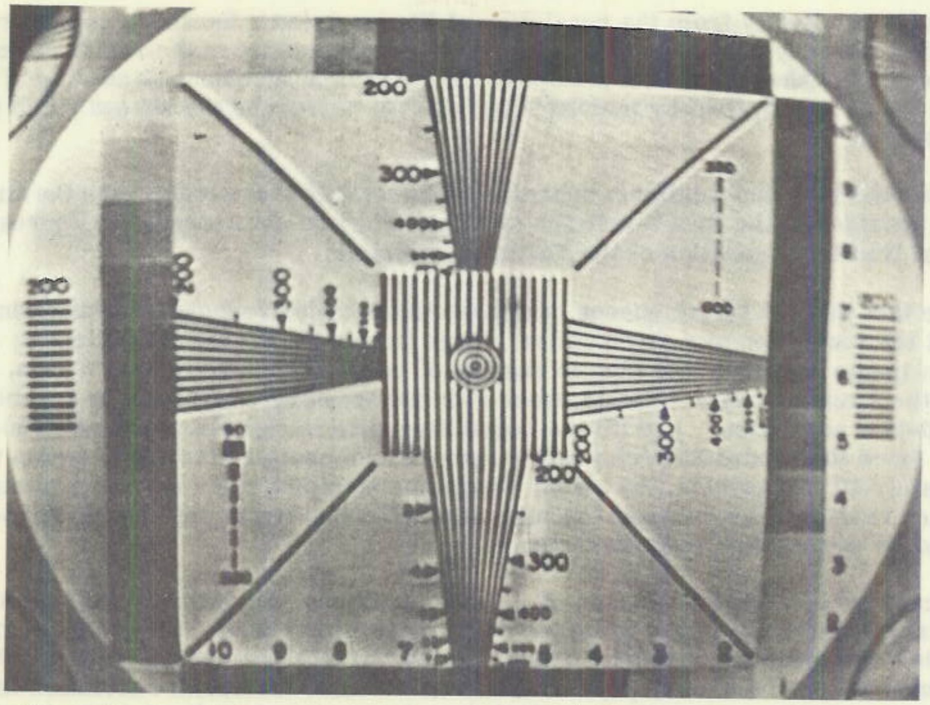

Figure 5 - Resolution of a test chart with sweep controls adjusted for minimum scanning consistent with correct aspect ratio

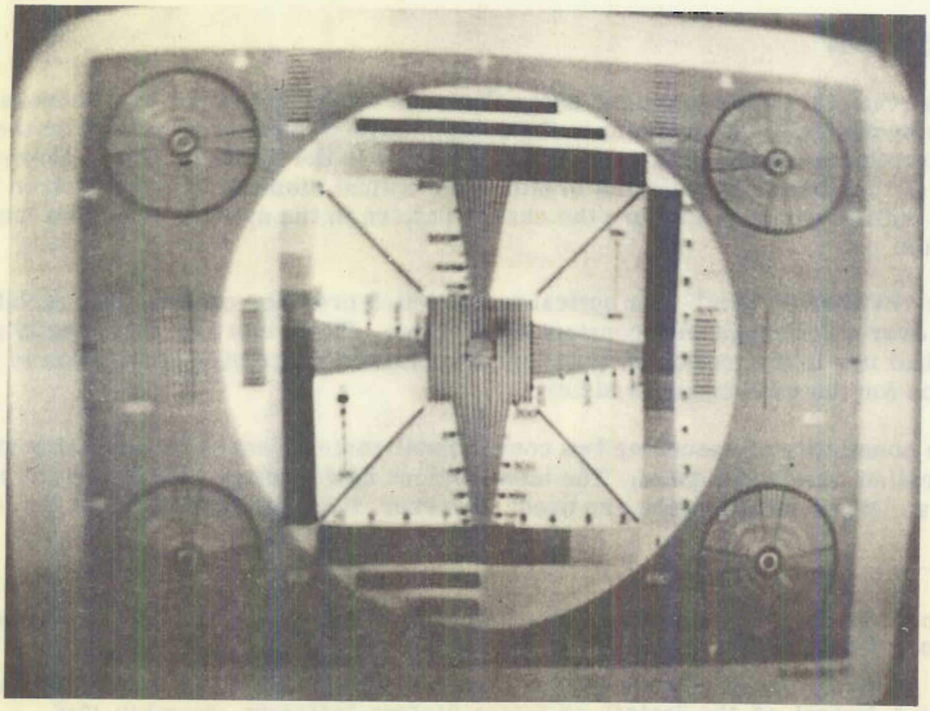

Figure 6 - Resolution with sweep controls as in Figure 5; camera-to-chart distance increased to include same area as in Figure 4.

detracted only slightly from the resolution of Figure 4, but a herringbone pattern can be detected in the grey portions of the picture. The latter effect is the result of scanning the active portion of the target with almost twice the normal number of lines and at only one-half the linear speed, thereby making it possible to reproduce the screen mesh in the target structure.

The maximum and minimum scanning areas used in these tests were the limits of control provided in the RCA television camera. They do not necessarily represent the practical limits of operation of the Variscan principle.

The fact that the target screen becomes visible under reduced scanning conditions and that the resolution of a given optical image improves (Figure 5), indicates: (1) the electron image portion of the tube is capable of better than 600-line resolution, (2) the spot size of the scanning beam, at least under reduced scanning conditions, is capable of better than 600-line resolution,[7] and (3) the target structure is capable of at least 600-line resolution. Since the bandwidth of the entire camera and monitor circuits is known to be approximately 10 megacycles, the lesser resolution obtained under normal scanning must be attributed to interaction between the magnetic deflection fields and the image focusing field and/or some other unknown factors.

It can now be seen that the use of an image orthicon with either finer target mesh, or with a larger diameter target using the same mesh size, would make possible greater resolution with fixed bandwidth by employing the Variscan principle. Conversely, the use of the present type tube could provide the same 600-line maximum resolution in a system normally designed for much less resolution, and requiring less bandwidth, provided only portions of the picture need be examined with this resolution at any one time.

Optical Methods

Experimental evidence gained using Variscan confirms the fact that increased resolution is unobtainable at any point in the system beyond the charge pattern on the target of a conventional image orthicon when that element is the limiting factor. However, magnification of the picture information in either the optical elements or the electron image section, both of which are before the charge pattern in the system, may give increased resolution.

The "ZOOMAR" lens[8] is an optical device which provides continuously variable magnification over a 3:1 range with constant light output. While more or less ideally suited to its original use in the motion picture field, its limited range of magnification is a severe limitation for the uses considered here.

The possibility of cascading two conventional camera lenses for obtaining variable magnification was investigated. The most obvious disadvantage of this scheme is the loss of light as longer focal lengths are used. However, it has been shown[9] that the image

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[7] *It should be understood that 600-line resolution here refers to 1/600 of the vertical dimension of the optical image, or of that of Figure 3*

[8] *Back, Frank G., "Zoom Lens for Motion Picture Cameras with Single-Barrel Linear Movement," Journal of the Society of Motion Picture Engineers, December 1946*

[9] *Janes, Johnson, and Moore, Op. Cit.*

orthicon is capable of operating, with only minor changes in picture quality, over light ranges of several hundred to one. The recent announcement of the image isocon camera tube[10] may provide additional freedom in this respect.

Because of the unavailability of the RCA Camera Chain used in the Variscan work, experimental evaluation of this principle was carried out using a type PH-548/AXT-2A camera, equipped with a 2P21 image orthicon, and using the monitor portion of a type CRV-46ACD receiver. The performance of this early military equipment is inferior to that of the RCA Chain, but the relative resolutions under the various conditions of the test, rather than the absolute values, are the significant factors.

Figures 7(a), (b), and (c) show the ability of the television equipment to resolve portions of a resolution chart horizontally at three different positions of the cascaded lenses. It will be noted that the smaller the area viewed, the better the resolution, as predicted. Over-all change in magnification is about ten. Figures 7(a), (d), and (e) show the same characteristics on vertical resolution, with a change of magnification of four. To illustrate the import of these phenomena in a different way, Figure 8 presents a series of pictures with the two lenses adjusted for increasing magnification. Five discrete values of magnification are shown, although the lenses could be made to show a continuous transition throughout the range. The object is the Supply and Fiscal building of this Laboratory. The first picture in the sequence shows the general structural features of the building, its number (21), and a sign. The sign is not truly legible, and the observer might have reason to want to read it. The sequence progresses until the sign fills the width of the last picture where it can be interpreted unmistakably, yet only a four-to-one magnification was needed.

During these sequences no adjustments were made on the television camera or lenses, except in lens position. The same exposure, development, and printing treatment was given all films in the photographic recording of the performance. The bright spot appearing in all pictures is due to a burned area on the target on the image orthicon and cannot be eliminated except by use of another tube. When it is realized that the enlargement figure of ten (Figures 7(a), (b), (c)) represents a light ratio of 100 (or almost 7 f-stops), it is seen that the image orthicon can indeed handle a wide range of light intensities. Of course, for successful operation, the minimum light available (during maximum magnification) must provide adequate signal/noise operation.

Aiming of such a camera can be materially simplified by providing a small mirror immediately before it, the mirror being mounted with a sufficient degree of freedom to allow it to reflect any part of the scene into the camera lens.

Vareo Lens

From the preceding discussion it can be seen that the mesh structure of the target limits the resolution when the Variscan principle is employed. The Vareo (variable electron optical) lens, on the other hand, does not have this limitation and hence suggests greater possibilities for continuously variable magnification.

Figure 9 shows the essentials of a Vareo lens setup. An image tube, similar to the type 1P25 used in the infrared sniperscope, is introduced between the object and the television camera. In operation, this tube is similar to the image section of the image

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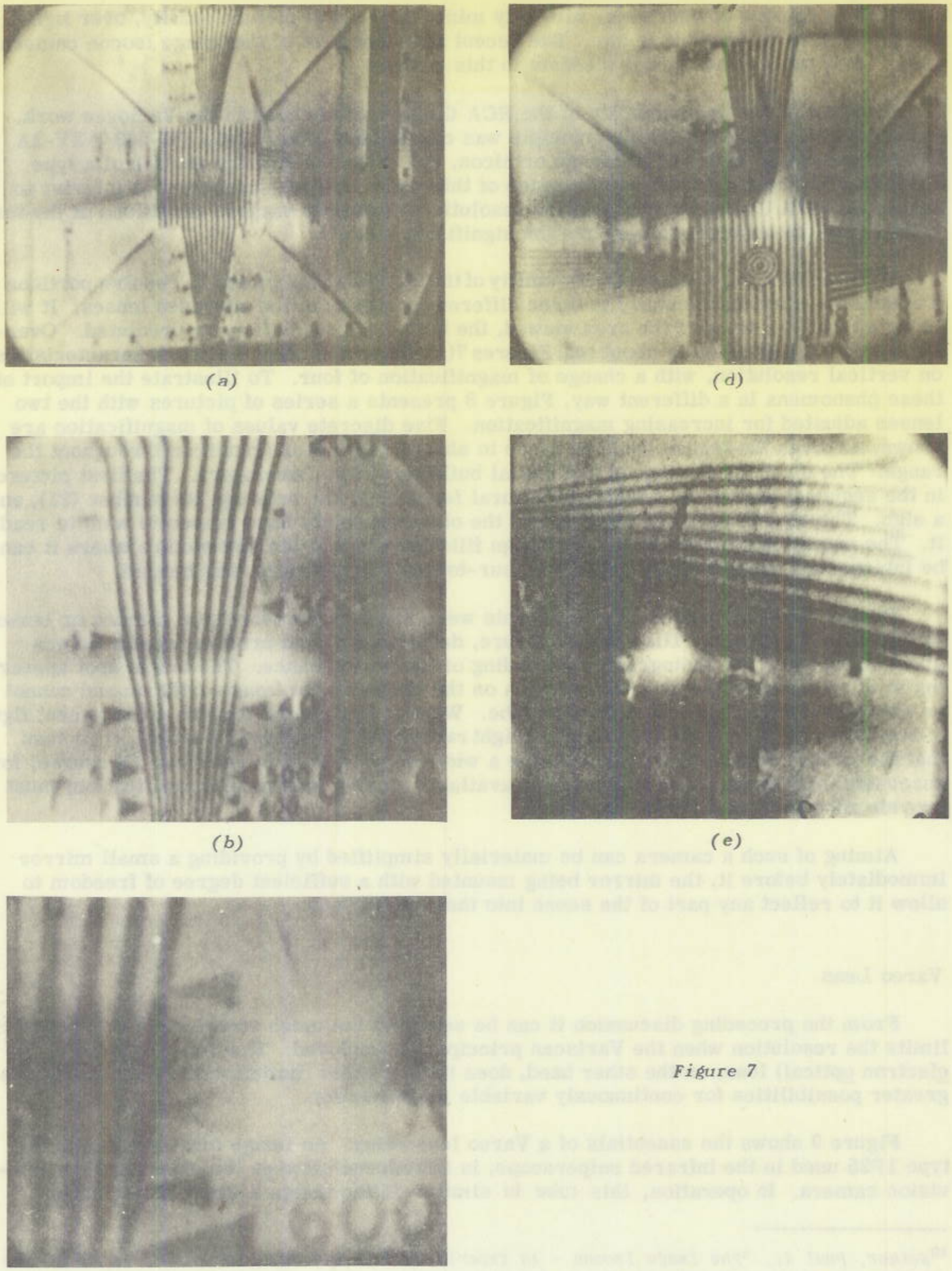
[10] *Weimer, Paul K., "The Image Isocon - An Experimental Television Pickup Tube Based on the Scattering of Low Velocity Electrons," RCA Review, Vol. X No. 3, p. 366-386, September 1946*



(a) (d)

(b) (e)

(c)

Figure 7

orthicon, except that it contains four deflecting plates and a more complicated electron lens system. If the first optical lens is made to focus the entire area to be televised onto the photocathode of the image tube, then by means of suitable deflecting potentials and electron lens adjustment all or any small part of the scene can be made to fill the fluorescent screen at the right end of the image tube. This image is then projected onto the image orthicon by a suitable optical system. Thus the image orthicon is operated under normal conditions, and the special image tube may be thought of as an element providing continuously variable magnification and having the ability to aim anywhere within the field of its optical system.

An alternate method of providing the same performance is illustrated in Figure 10. Here the image tube is surrounded by a solenoid providing an axial magnetic field of sufficient strength to restrict the diameter of the orbital path followed by the electrons to a value less than the element size in the target of the image orthicon. Thus the image tube is always "in focus" and is not critical as to magnetic or electric field strength. Variable magnification is obtained by means of the tapered field produced by the auxiliary coil; aiming must again be accomplished by a movable mirror or by motion of the entire camera. Obviously, were it not for the difficulties introduced in the scanning section by the strong magnetic field, this tapered field technique could be applied to the image section of the image orthicon itself.

General

It is difficult to put a quantitative value on the bandwidth required to transmit a picture of given resolution. Fink,[11] discussing this problem, shows that the video signal lends itself to the usual Fourier analysis and, theoretically at least, would require an infinite frequency spectrum to reproduce a sharp transition from black to white or vice versa. Reduced to practice, the greater the bandpass allowed the more nearly a television system comes to reproducing such a transition.

In a television system restricted to a finite bandwidth, the highest frequency component of the video signal is limited by this bandwidth; hence the highest order term of significance in the Fourier analysis is set. Higher order terms may be transmitted, however, by lowering the fundamental frequency. The absolute frequencies

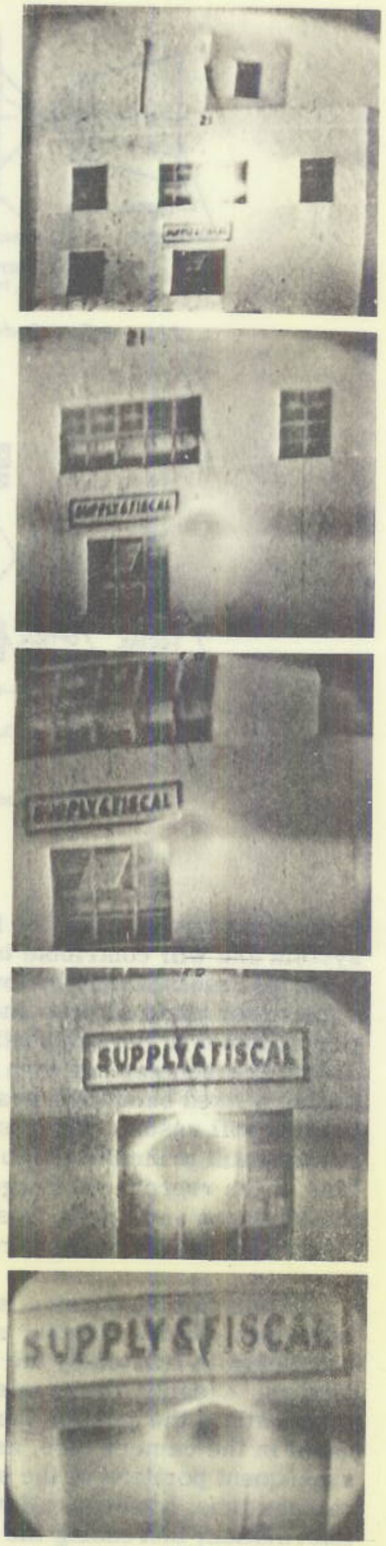


Figure 8

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[11] *Fink, Donald G., "Principles of Television Engineering," p. 184-196, McGraw-Hill, New York, 1940*

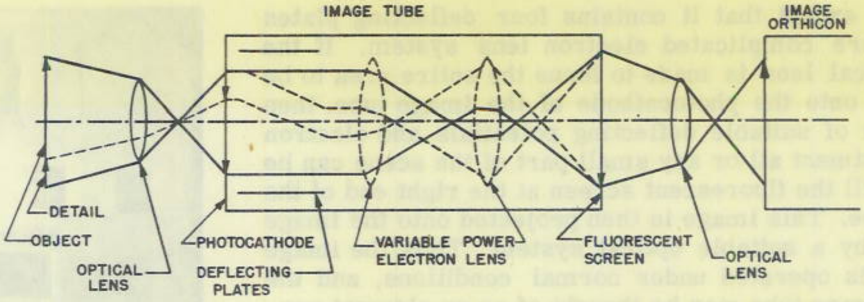

Figure 9 - Special image tube providing variable magnification and aiming

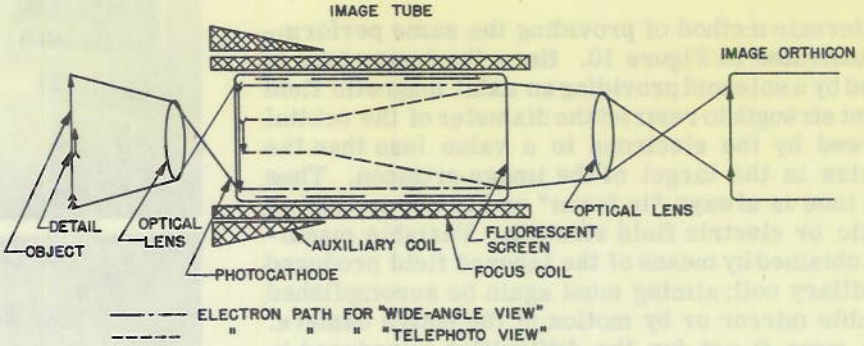

Figure 10 - Special image tube providing variable magnification

represented by some of the higher order terms will then be less than the bandwidth of the system and will contribute to the fidelity of reproduction. The absolute values of the frequencies involved may be lowered, for example, by changing the optical lens to one giving a narrower angle of view and greater magnification. The result is that a black-white transition occupies a "larger portion" of the picture and is scanned more slowly than before. Lower frequencies can then reproduce this transition with the same detail as before, or, having a fixed bandwidth available, higher relative frequencies will be available and higher fidelity will result. The restricted field of view is the price paid for the added resolution—a fundamental principle not to be confused with the gain obtained merely by increasing the size of the reproduced image on a kinescope or by closer viewing of a given image. Both the Variscan and Vareo lens techniques described here are the exact equivalent, so far as bandwidth considerations are concerned, of the variable optical lens.

While this discussion is applicable only to the horizontal resolution of a reproduced television picture, similar analysis of the vertical resolution may be made. Here the resolution is limited by the number and position of horizontal lines which compose the picture. Clearly, the greater the number of lines devoted to a given object or piece of information, the greater the detail which can be reproduced. The horizontal lines are originated in the camera tube, and again little can be done to improve the vertical resolution in subsequent portions of the equipment. Magnifying the picture before it is presented to the camera tube, however, allows more scanning lines to be devoted to a smaller amount of information, increasing the vertical resolution. As a result, both horizontal and vertical resolutions are improved simultaneously.

CONCLUSIONS

The limitations of the camera tube prevent the design of a television system capable of the higher resolution demanded by military applications. Pending the development of camera tubes with higher resolution, several methods for achieving higher resolution on selected portions of the information have been investigated as an interim measure. However, it is shown that the compromise of restricted field-of-view for greater resolution may be made, no matter what the resolution of the original system. The Variscan system is a theoretical exception to this theorem, since its ultimate resolution is limited by the size of the picture elements on the target structure. Three methods have been proposed and partially evaluated for this service.

Although it consists of simple circuitry and is adaptable to remote control, the Variscan system is hampered by the same limitations which beset the image orthicon in conventional operation.

Variable optical magnification shows the most promise for obtaining greater resolution but requires the aiming of a reflecting mirror or of the entire camera.

While the required image tube is not presently available, the Vareo lens is nevertheless another electronic method which should give the desired performance. It also lends itself readily to remote control. In addition, the expanded image could be intensified in the image tube to maintain a more constant light input to the image orthicon, should this be desirable.

* * *