A DEFLECTION-MODULATION CATHODE-RAY-TUBE DISPLAY

by

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Abstract

A cathode-ray-tube display is reported which combines the two-dimensional aspects of a normal television display with the quantitative aspects of a cathode-ray oscillograph. Both advantages and limitations of this "deflection-modulation display," which has a striking three-dimensional appearance, are discussed. The illustrative examples shown here resulted from scanning a transistor with a small-diameter electron beam, and using the induced current as a video signal. Additional applications are suggested.

I. INTRODUCTION

A television picture is a common method of electronically displaying information with two independent variables. The two independent dimensions correspond to the X and Y coordinates in a television display and the information is presented by intensity modulating the cathode-ray-tube (CRT) beam to produce the picture. The television picture is quite suitable for converting a scene viewed at one location to an image viewed at another. It is not as well suited for displaying scientific information when a more quantitative knowledge of the information to be displayed is desired. For this reason, television-signal processing that improves contrast, outlines certain areas of given intensity, and otherwise improves the information content of the signal has been receiving increased attention.[1 †]

The number of brightness levels that can be distinguished on a television picture is limited, and the relationship between these levels or "shades of gray" is qualitative. It is often desirable to distinguish between more information levels in a scientific display than is possible with a television display and also to compare quantitatively the differences in signal level. A common information display with one independent variable that satisfies these scientific requirements is the cathode-ray oscillograph, where the vertical deflection is proportional to the information signal and the horizontal displacement is proportional to the independent variable. The difference between two signal levels can be compared quantitatively within the accuracy of the deflection linearity and the trace width. Normally, quantitative comparisons with an accuracy of a few per cent are possible.

II. A DEFLECTION MODULATION DISPLAY (DMD)

Johnston[2] attempted to combine the quantitative aspects of the cathode-ray oscillograph with the two-dimensional aspects of the TV picture. He scanned a coarse raster on a cathode-ray tube using an electron beam of constant intensity and introduced the information into the display by deflecting the scanning beam vertically a distance proportional to the information signal. He used this display for current-density measurements on electron beams that he was studying. Figure 1 shows a similar display with a 64-line raster; the vertical deflection of each line is clearly discernible. In Fig. 1 the vertical displacement of the CRT electron beam is caused by electron-beam-induced currents in the case of a transistor being scanned by an auxiliary electron probe

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† The Mariner-IV photographs of Mars which have been widely publicized are examples of the signal processing used in present-day television images.

as described by Everhart, Wells, and Matta.[3] A similar signal generated by a flying-spot scanner could have been used with equal success.

The wide spacing between lines in Fig. 1 allows each line to be examined individually; by measurement, quantitative information concerning each line's displacement can be obtained, and thus the signal strength for a given position on the sample can be evaluated. A three-dimensional effect is also apparent in Fig. 1. This effect can be enhanced and a more dramatic picture obtained by using more lines in the raster. Figure 2 shows the same information display on a 256-line raster. Dark areas in this figure correspond to areas over which the density of lines has been greatly decreased by deflection, or the speed of the CRT beam has been increased, resulting in a reduced screen brightness, or both. Light areas correspond to line bunching or line overlap. The net effect is an intensity difference between different areas and a striking three-dimensional effect. There are certain areas where the beam traces overlap considerably and the three-dimensional effect is somewhat weakened. Actually, to the trained eye, a form of "X-ray vision" is possible, i.e., one seems to be looking through the display and seeing contours behind areas "normally visible" to the eye. These areas of information overlap may be distracting and disturbing to the untrained observer. A normal television display with the same information is shown in Fig. 3. Here the brightest areas correspond to the maximum deflection in Fig. 2, and the dark areas correspond to zero deflection in Fig. 2. Regions labeled 1, 2, 3, and 4 in Figs. 2 and 3 correspond. Region 1 is an area of transistor base covered by an oxide layer. Region 2 is an area of the base covered by an evaporated aluminum contact. Region 3 is another region covered by the passivated oxide layer and region 4 is the emitter region. The emitter connection is a thermal-compression-bonded gold lead whose shadow is seen in Figs. 2 and 3 crossing all regions.

The deflection modulation display (DMD) of Fig. 2 contains more information in many areas than does the television display of Fig. 3. In particular, note the contrast between regions 2 of Figs. 2 and 3; in Fig. 3, region 2 appears uniformly gray, whereas in Fig. 2 it has a decided texture which, upon referring to Fig. 1, is seen to be a small amplitude variation superimposed on the average beam deflection. The information content of Fig. 2 in this area thus is higher than that of Fig. 3. However, in region 2 there are certain areas in which information is superimposed because the traces overlap. The distraction (reduction of information) in those areas can be altered by rotating the apparent direction of scan, as shown in Fig. 5, which should be compared with Fig. 4, because these two have a slightly different character than the first three figures discussed. (In Figs. 4 and 5, the center area appears somewhat higher in relief than it did in Figs. 1, 2, and 3. This effect is due to a higher electron beam energy, which was used in generating the display, and is not a function of the display itself.) A comparison of Fig. 4 and 5 shows that altering the perspective from which the information is viewed increases the information content of certain areas and decreases the content of other areas. Thus the information of certain areas can be enhanced in this manner. The viewing angle was rotated by rotating the generating pattern with respect to the raster scanned over it. This procedure corresponds to rotating the negative in a flying-spot scanner.

III. CONTRAST

To understand the shading of the deflection modulation display, it is helpful to consider the basic equation for the light intensity from a scanned area on the screen:

$$\text{Light Intensity} = K\, f(V_0)\, \frac{I}{v} \tag{1}$$

Normally, in cathode-ray tube optics, the accelerating voltage V_0 must remain a constant to insure proper focusing. Thus, both K and $f(V_0)$ are constant. In a television display, the velocity v with which the spot moves across the screen is constant, and the intensity is varied by modulating the CRT current I. However, in the deflection-modulated display, I is normally held constant and the intensity varies depending on how fast the spot moves across the screen i.e., the higher the spot velocity v, the lower the intensity. This decrease in intensity is particularly noticeable on the sides of the "hills" of Fig. 2, 4, and 5.

Another way of lowering the intensity is to decrease the net area bombarded by the CRT beam, i.e., widening the spaces between the lines; this effect is quite noticeable on the side of the hill which appears closest to the observer, near the bottom of these figures. Correspondingly, the display becomes more intense when the lines are bunched closer together, or when they overlap, as they may do is some areas. The spot never travels at a velocity slower than the unmodulated display; therefore, the unmodulated display can be set at a gray level as shown in the micrographs and the bunching or over-lapping of traces will cause an increase in intensity, i.e., brighter areas, and either increased spot velocities or increased spacing between lines will cause a decrease in intensity.

IV. INFORMATION CONTENT

The information content of the deflection-modulated display is limited by the spot diameter of the CRT beam for noise-free signals, and by the signal-to-noise ratio of the information for noisy signals. If the maximum allowed deflection is 30 times the CRT spot diameter, for example, 30 distinct levels can be resolved on the display produced by a noise-free signal. If noise is present, random deflections of the CRT beam will be superimposed on the signal-produced deflection. The actual number of levels which can be distinguished in this case is proportional to the ratio of peak signal to RMS noise at the CRT deflection plates and will always be less than the value for a noise-free signal. The proportionality constant depends on the confidence desired in distinguishing different levels and is somewhat less than unity.[4]

Photographs of television displays are limited to approximately 20 distinguishable brightness levels, or "shades of gray," and the relationship between different levels is qualitative, not quantitative. Photographs of deflection-modulated displays, however, have the same number of information levels as the display CRT, and the relationship between different levels is easily measured. The nonlinearity of the photographic process is relatively unimportant for a deflection-modulated display. The one-to-one correspondence between points on the original object and the television picture are exchanged for the three-dimensional appearance and quantitative interpretation of the deflection-modulated display.

V. IMPROVEMENTS

By performing simple operations on the information signal, the information content of a deflection-modulated display may be considerably improved. For example, the use of a logarithmic amplifier produces a deflection proportional to the logarithm of the signal, which is very useful for certain types of information. Alternatively, by producing a short pulse each time the information signal passes through a given value, say 50% of the maximum allowed value, and using this pulse to alter the CRT brightness by momentarily increasing (or decreasing) the CRT current, a contour line is produced on the deflection-modulated display which corresponds to an equipotential contour on a map. By producing these equideflection contours at different levels of the signal, say, 25, 50, and 75% of the maximum value, the display may be more easily interpreted. Similarly, the color of a multicolor display can be altered as the signal amplitude increases to produce a color-coded contour map.

As mentioned above, where considerable overlapping of scanned areas occurs, the three-dimensional aspect of the display is impaired and information from two different areas is superimposed, and therefore subject to confusion. This confusion may be avoided by blanking the CRT beam before serious overlapping occurs. Blanking in this manner would require a memory of where the beam has already scanned, and thus would require a simple computer control. By scanning the deflection-modulated display from bottom to top then, and blanking before serious overlap occurs, an improved three-dimensional display can be generated.

VI. CONCLUSION

The deflection-modulation display has certain advantages over the normal intensity modulation display as is commonly used in television. In areas where information overlap does not occur, the deflection-modulation display has higher information content for signals with adequate signal-to-noise ratio. In addition, the areas of the display with maximum information content can be altered by rotating the generating scan but not the display CRT scan. The image of the deflection-modulation display has a striking three-dimensional character, which may prove useful for information presentation in many areas of science and engineering. This display has already proved to be useful in the measurement of current density in electron beams in the measurement of induced currents in semiconductor devices due to electron beam bombardment, and should prove equally useful for such related instruments as the scanning X-ray microprobe analyzer,[5] and the scanning electron diffraction camera.[6] A possible future use of this display is the rapid presentation of high information output from digital computers, where the normal two coordinates of an IMD may be used as independent variables, and the apparent third coordinate as the dependent variable.

VII. ACKNOWLEDGMENTS

The author is grateful to S. R. Pedersen for the construction of the amplifier which mixes the frame sweep with the information signal, and to several colleagues for discussions of this material. Professor O. J. M. Smith conceived the idea of intensity-modulating the beam at distinct levels of video signal to produce contour lines on the deflection-modulation display.

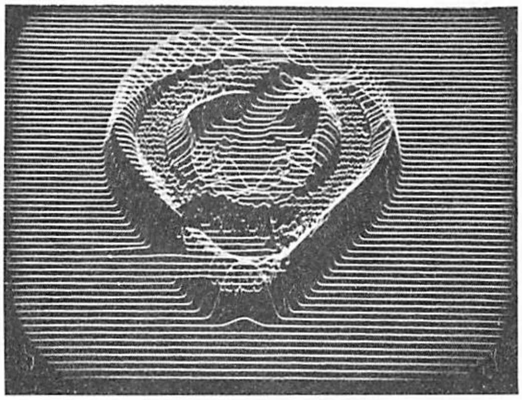

Fig. 1. Deflection-modulation display of an NPN transistor generated by electron-beam-induced currents. Scanning electron beam voltage = 15 kv; 64 line raster.

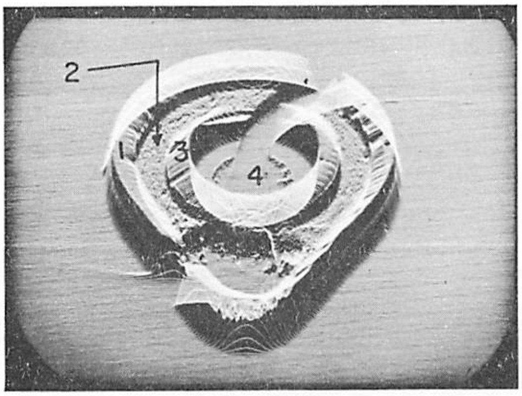

Fig. 2. Deflection-modulation display of same subject as Fig. 1; 64 line raster.

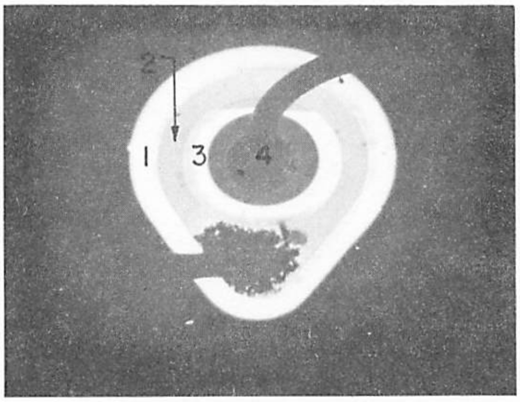

Fig. 3. Television display of same subject as Fig. 1; 1024 lines.

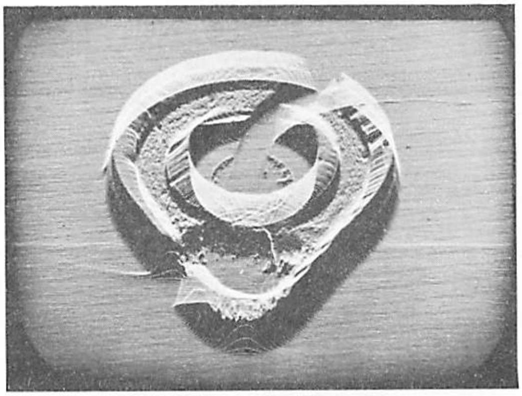

Fig. 4. Deflection-modulation display of same subject as Fig. 1; scanning electron beam voltage = 21 kv; 256 line raster.

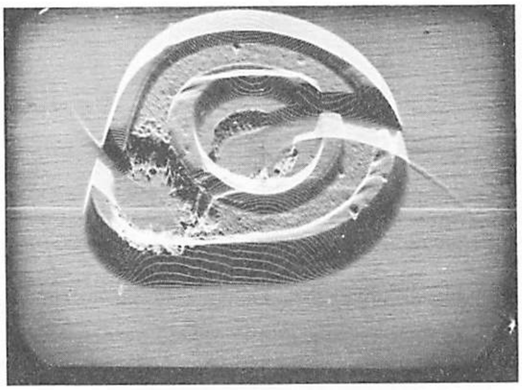

Fig. 5. Deflection-modulation display of same subject as Fig. 4; raster rotated on sample to rotate perspective of display.

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