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More on Color Compensating Filters with Infrared Film*

The density shifts of the individual layers of color infrared film resulting from exposure through magenta, red, green, and cyan color compensating filters was investigated.

Abstract: *Further studies were carried out to investigate the density shifts of the individual layers of color infrared film resulting from exposure through magenta, red, green, and cyan color compensating filters. Laboratory studies using step wedges for plotting characteristic curves and statistical studies with photographs taken over varying terrain were considered. The characteristic curves showed the shifts. The CC40 filters appeared to give the best results to effect the superimposition of either the blue or green layer upon the red layer so that the red layer and shifted layer have the same sensitivity. The statistical studies showed that not enough data points had been sampled to conclusively establish normality and independence of each of the three imaging layers. It is felt that the independence of the three layers could not completely be established because of the overlapping sensitivity of the green and red layers. The attenuation factor indicates that it may have some effect in aiding the establishment of the independence of the three layers.*

Introduction

The shift of the characteristic curves of color infrared film results in a change in the color balance of the film. The new color balance often can be beneficial and a knowledge of the changes can result in variations of basic densitometric analysis depending upon the target of interest.

A series of 21 level step wedges were exposed on Kodak Film Type 2443 using a sensitometer operated by the Photographic Reproduction Laboratory of the Canadian National Air Photographic Library. The wedges were exposed with a Wratten 12 (W12) filter in combination with each of the following color-compensating (CC) filters:

CC20R	CC20M
CC30R	CC30M
CC40R	CC40M
CC50R	CC50M
where R = Red	M = Magenta
CC20G	CC20C
CC30G	CC30C
CC40G	CC40G
CC50G	CC50C
G = Green	C = Cyan.

The purpose of the study was to examine the shift of the characteristic curves of the three layers of the CIR film.

* This paper was originally presented as "Statistical Analysis of the Effect of Red, Green, Magenta and Cyan Color Compensating Filters on Color Infrared Film" at the ASP-ACSM Convention, February 27 to March 5, 1977, Washington, D.C. This paper has been modified to include only the new information that was presented at that time.

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The second part of the study involved the analysis of aerial photographs exposed through each of the filter combinations. The photographs were obtained by the Canada Centre for Remote Sensing. A sample of each photograph was analyzed with a scanning microdensitometer and the resulting digitized data were used for a statistical study. A 64 × 64 matrix of density points was taken from the digitized data and statistics carried out, which resulted in the analysis of 4096 density points, a significant increase from the first attempted statistical analysis (Worsfold, 1976).

Because of space requirements, only figures for the magenta series of filters are presented in this paper.

The characteristics and properties of color infrared film (CIR) are well known (Tarkington and Sorem, 1965; Fritz, 1967; Kodak Publication M-69, 1976). Any of the three image layers can be density shifted (Fritz, 1967; Pease and Bowden, 1969; Worsfold 1976). Changes in color balance can be beneficial and can result in enhancement of certain image layers. Cochrane (1968) stressed the need for color balance studies and Malan (1974) outlined a method to change color balance, without the use of densitometer studies, which he describes as semi-quantitative. Malan's requirements were consistent processing conditions and a stock of film with similar characteristics. It has been shown that color balance shifting can be used within limits to restore improperly exposed or filtered photographs (Lockwood and Sauer, 1975). A study was carried out by Worsfold (1972) to assess the effects of color-compensating filters on CIR film, and applied statistics were carried out in an attempt to place color balance shifting on a more quantitative basis (Worsfold, 1976). Worsfold's results (1972) were confirmed in field tests by Tarnocai and Thie (1974). The Worsfold results (1976) indicate that more data points were needed for statistical testing.

Film/Filter Data

The characteristics of CIR film are well documented (Fritz 1967; Kodak Publication M-69, 1976). The use of color-compensating filters causes an increase in the density of the blue and green layers that results in an apparent enhancement of the red layer. In this paper, the filters used were CC Magenta, CC Green, CC Red, and CC Cyan. The density series used were CC20, CC30, CC40, and CC50. The CC20 filters change the exposure of the standard film (exposure through a W12 filter) by one-third of an *f*-stop. CC30, CC40, and CC50 filters will change exposure accordingly; therefore, exposure through each filter combination was adjusted. Figure 1 shows the increase in absorption for increasing magenta density with CCM filters, data taken from Kodak Technical Publication B-3 (1971).

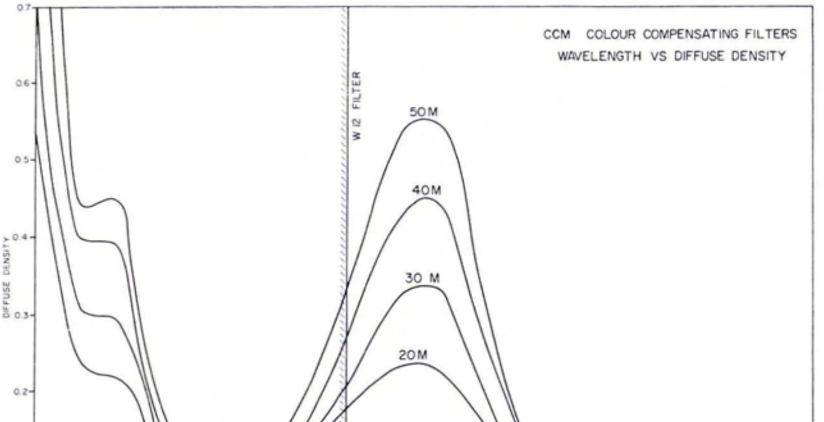

Fig. 1. Diffuse density curves for CCM filters.

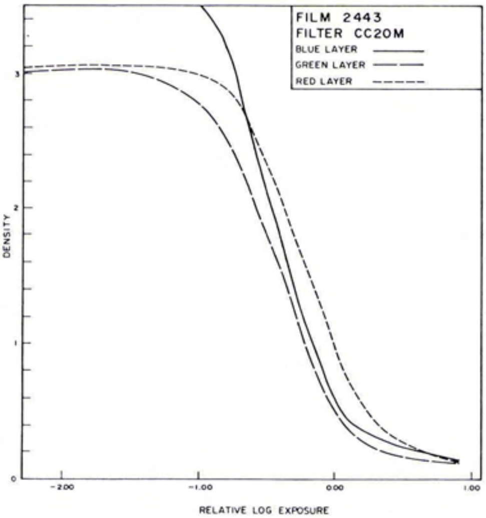

Fig. 2. D log E curve for CC20M test wedge.

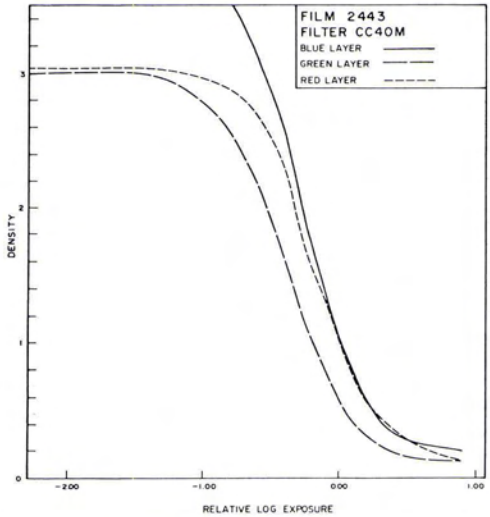

Fig. 4. D log E curve for CC40M test wedge.

Procedure

One roll of color infrared film was exposed using the Canada Centre for Remote Sensing sensitometer. A 21 division step wedge was exposed on the film using the various filter combinations. The resulting characteristic curves were plotted. Figures 2 to 5 show the curves obtained for the magenta filters. A W12 standard was plotted and shown as Figure 6 and the Kodak theoretical curve is shown as Figure 7 for comparison. A single roll of film was used to control the processing in order to ensure constancy of the plotted curves.

The resulting density data were compared with the W12 standard. Using the W12 as a zero reference, the density difference between the standard and the combinations was calculated. The deviations from the W12 for the CCM series are shown as Figures 8 to 10 for each of the blue, green, and red layers. From these graphs the amount of density increase for each layer for each combination can be seen.

A sample of each filter combination was analyzed from film that was recorded by the Canada Centre for Remote Sensing. The data film was recorded at an altitude of

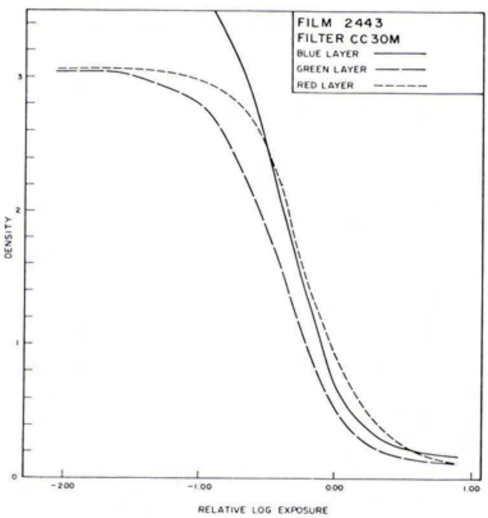

Fig. 3. D log E curve for CC30M test wedge.

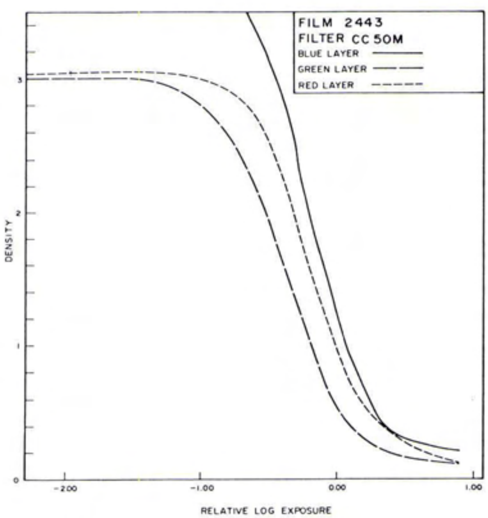

Fig. 5. D log E curve for CC50M test wedge.

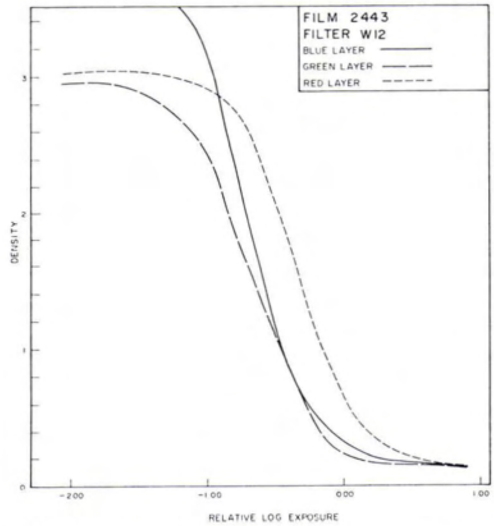

FIG. 6. D log E curve for W12 test wedge.

10,000 feet over a varying terrain (i.e., open fields, water, forested areas). Four Vinten 70 millimeter cameras were operated simultaneously and each set (CC20, CC30, CC40, and CC50) of filters (green, red, cyan, and magenta) was exposed at the same time to ensure that the same terrain was being observed for each type of filter.

Each of the samples was analyzed by using a Technical Operations Incorporated, Scandig Scanning Microdensitometer located in the Remote Sensing Laboratories of the Engineering Faculty of Memorial University

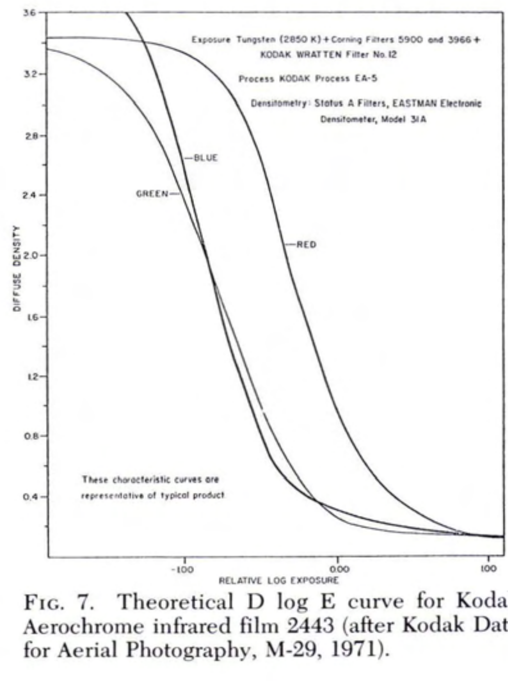

FIG. 7. Theoretical D log E curve for Kodak Aerochrome infrared film 2443 (after Kodak Data for Aerial Photography, M-29, 1971).

of Newfoundland. The optical densities were recorded in the X and Y directions. The digitized data were recorded with a Kennedy Digital Magnetic Tape Recorder. The digitized data were then analyzed using an IBM 370 computer with standard statistical computing packages. The statistical analysis involved the normalization of the digital data using a procedure outlined by Brooner and Simonett (1971). The following statistics were carried out using the digitized output from the sample film:

(1) univariate descriptive statistics,
(2) bivariate descriptive statistics,
(3) univariate frequency distributions, and
(4) bivariate frequency distributions.

In order to provide a standard, four frames of W12 standard data also were analyzed by the same methods.

By using the scanning microdensitometer and the SPSS computer program, the author was able to analyze 4096 density points per photograph (SPSS, 1975). This was a significant improvement over the 100 density points of earlier results (Worsfold, 1976).

RESULTS

Figures 2 to 5 show the characteristic curves for the magenta series of filters. Examination of the curves shows that the most noticeable density shift occurs with the blue layer. The greater the density of the CC filters, the greater the density increase of the layer affected. Both the green and red curves also experience a density increase but not of the same magnitude as the blue values.

The CCR filters are similar to the CCM filters. The blue layer undergoes a large density increase and the green and red layers a minor density increase. The CCG and CCC filters act in a similar manner; for both sets the green layer undergoes the greatest increase with the blue and red layers undergoing minor increases. Figures 8, 9, and 10 show the comparison density shifts with respect to a standard wedge (Figure 6).

The statistical studies carried out on the various selected images show basic agreement with the shifts that are evident when filtration is applied to the step wedge samples. The univariate statistics using mean, median, mode, range, variance, and standard deviation all show the density shifts and give statistical measure to the shifts so that comparisons can be made. The statistics confirm that for the blue layer, both the magenta and red filters show shifts with respect to the W12 standard blue layer. The green layer shows shifts of the green for the CCG and CCC filter combinations. The red layer ex-

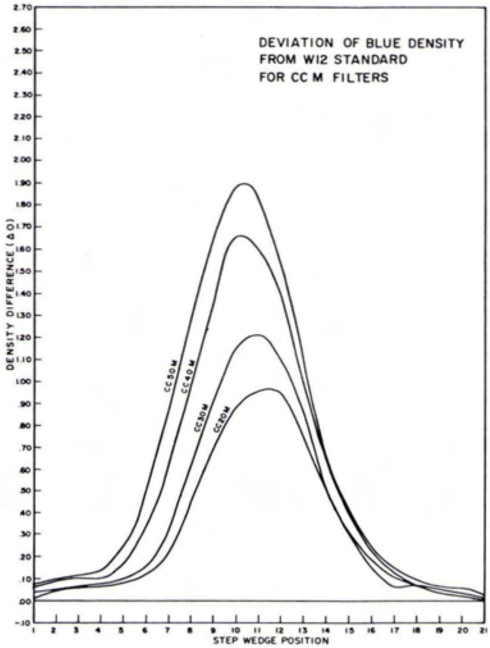

FIG. 8. Density differences between W12 standard and CCM, blue layer.

periences a small increase in relative density for all four filters.

An examination of kurtosis values for the various filter combinations shows that 62 percent of the blue values were greater than one and 94 percent of the values were greater than zero, no values were considered excessively peaky. The green layer showed 50 percent greater than one and 94 percent greater than zero with only 6 percent considered peaky. The red density layer showed 44 percent great than one, 94 percent greater than zero, and no values excessively peaky. An examination of skewness showed that blue values were consistently clustered about both the right and left sides of the mean, the green values were negative and thus clustered to the right of the mean, and red values clustered to the left of the mean, and all positive. This is true for all density increments of the filter combinations.

Bivariate statistics were undertaken in order to attempt to determine correlation between the layers. Examination of the W12 standard indicates that there is not a strong linear relationship between the blue and green density values. The relationship between the blue and red and the green and red show values of the correlation coefficient varying between ± 0.53 and ± 0.82 which indicates a moderately strong linear relationship.

The correlation coefficient for the magenta series of filters shows that there is weak correlation for blue-versus-red values and moderately strong correlation for blue-versus-green and green-versus-red. For the green filters there is moderately strong correlation between the blue and green and the blue and red but weak correlation between the green and red density values. The CC red filters show strong correlation for the green-versus-red density values, weak correlation for the blue-versus-red, and weak to

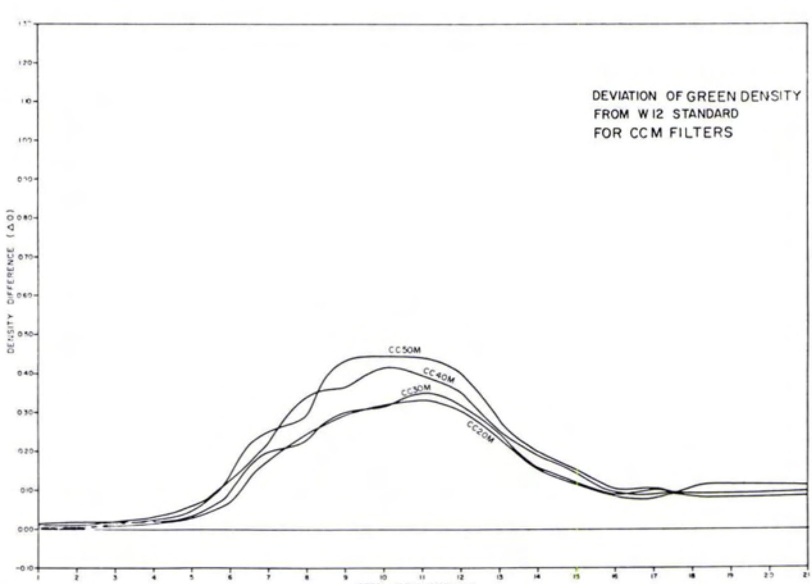

FIG. 9. Density differences between W12 standard and CCM, green layer.

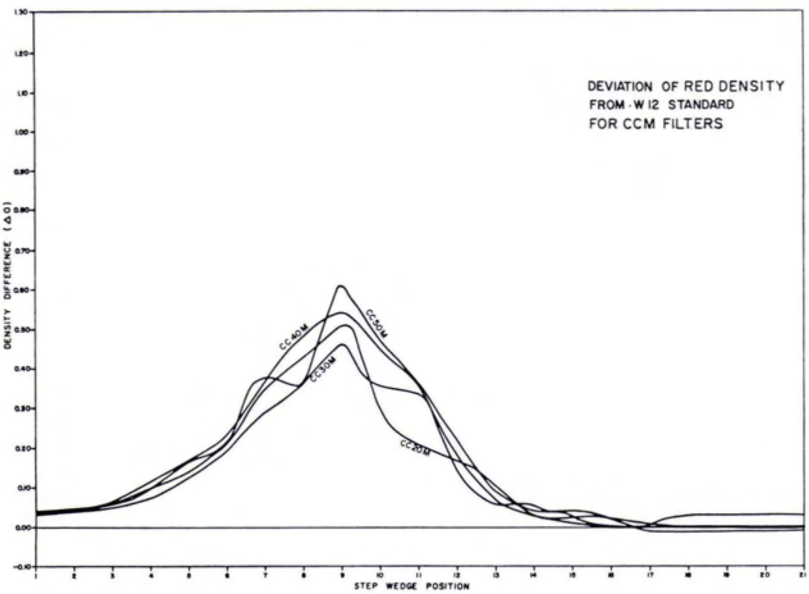

FIG. 10. Density differences between W12 standard and CCM, red layer.

strong correlation for the blue-versus-green. In the last set, the cyan shows moderate correlation for all possible cases.

The remainder of the statistics, calculated for the bivariate case, enable the drawing of the regression line. For the W12 standard, the slope of the regression line for the blue and green case indicates the line is almost flat with respect to the X-axis. The blue and red and green and red slopes are moderate and vary by about 0.5.

For the magenta series of filters the slope for the blue-versus-green plot varies by about 0.5 while the blue-versus-red slope is almost flat with respect to the X-axis. The green-versus-red slope for the magenta series approaches 1.0.

The slope of the regression line for the blue-versus-green case varies by about 0.5 for the green series of filters. This is also true for the blue-versus-red case. The green-versus-red slope is fairly flat and varies by about 0.3.

For the red color-compensating filters the green-versus-red slope is very steep and approaches 1.0. The blue-versus-red slope is flat and varies by about 0.15 while the blue-versus-green slope of the regression line varies from 0.14 to 0.67.

The cyan series of filters shows slopes for the regression lines for all three cases to vary by about 0.5.

Frequency curves confirm the calculated univariate statistics, and scattergrams representing bivariate combinations of the three density layers visually confirm the regression statistics.

Discussion

The major shifts of the characteristic curves are in agreement with the known shifts (Worsfold, 1976). The shift is proportional to the value of density of the color-compensating filter used. In each instance, a density shift of the other two density layers also occurs. This shift is minor in comparison to the major shift and is caused by the attenuation factor (Worsfold, 1976). For each series of CC filters there is one layer for which the value of the major shifted curve approaches the value of the red curve. Therefore, direct comparison between either the blue and/or green layer and the red layer can be obtained, indicating that a relationship can be made between the ratio of the green or red radiation and the near-infrared radiation. This can be carried out if the characteristic curves belong to the same distribution, but it is only relevant for the photograph being used.

The statistics confirm that the shifts that take place as shown by the wedges also take place when sample imagery is used. The values obtained for kurtosis indicate that the distributions are more peaked than the normal curve (kurtosis = 0 for normal curve, SPSS, 1975). This is true for both the W12 standards and the test samples. The W12 standard showed by the skewness value that the standard density values were spread equally on both sides of the mean with values consistently ± 1.0. This indicates near normality (skewness = 0 for normal distribution, SPSS 1975). For the test samples the blue layer values had characteristics similar to the standard, but the green values were clustered to the right of the mean and the red values clustered to the left. This information could not be reduced to apply to any particular filter density.

The bivariate statistics were calculated in order to determine if there was any correlation between the various density layers. The W12 standard shows that the blue and green values appear independent of each other and that the blue and red and green and red have a moderate dependency. Examination of the various filter combinations failed to establish dependency between the various layers, indicating that the optical densities were dependent upon wavelength and not each other. This indicates that, by shifting the characteristic curves so that two or more are members of the same distribution, density ratios and relative density differences can be computed that would be characteristic of the terrain classification. The bivariate tests show that the density values depend upon the wavelength and not each other; therefore, when comparisons are made between density values, they can actually be made between the amount of energy recorded in different wavelength ranges.

Two complications still exist. The first is the attenuation factor which has not been accounted for and the second, the green layer is sensitive over the 500 to 690 nanometer range and the red layer is sensitive over the 500 to 900 nanometer range. Thus, the green and red sensitivities overlap into the blue range. Both the overlaps are moderately sensitive. The attenuation factor may help to negate this sensitivity overlap but further studies will be necessary to understand the true impact.

Examination of the frequency curves and the kurtosis values indicate that more density points will have to be sampled before normality can be established and before the skewness values can be understood. There are no apparent reasons for the green values to cluster to the right of the mean and the red values to cluster to the left. The bivariate statistics do not indicate conclusively whether there is or is not dependency between the layers although independence is indicated.

Conclusions

Although graphs have been presented only for the magenta color compensating filters, similar graphs were plotted for the green, red, and cyan data. In all cases the same shifts occurred to the data in either the blue or green layer. The results show that the magenta and red filters can be used to shift the blue layer and the green and cyan filter can be used to shift the green layer.

Depending upon the emulsion and its age, the magenta and red filters can be used to shift the blue layer until it becomes approximately superimposed upon the red curve. The statistics show occurrence of the shift. Once the shifted layer has been superimposed upon the red curve, it can be assumed that the curves have the same sensitivity; therefore, direct comparisons can be made between the two layers. The green and cyan filters shift the green layer so that it becomes superimposed on the red curve. Therefore, comparisons can be made between the amount of green radiation and the amount of infrared radiation or the amount of red radiation and the amount of infrared radiation. The CC40 filter appears to be the best filter to use for the film used in this test as demonstrated for this CIR emulsion.

The statistics indicate that more points should be analyzed because it was not possible to establish normality of the distributions or complete independence of the radiation for each spectral region. The lack of independence may be due to the overlapping sensitivities of the green and red layers.

Acknowledgments

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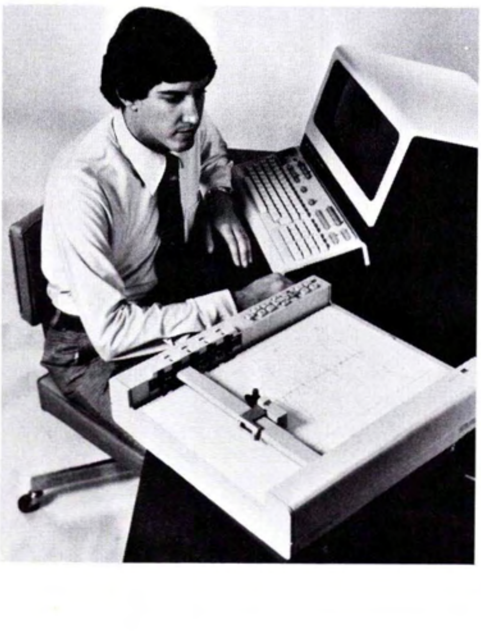
Engineering Reports

Business—Equipment—Literature

Gordon R. Heath

New Hewlett-Packard Multicolor Graphic Plotter with Microprocessor is Fast, Efficient for Low Timeshare Costs

Microprocessor-based circuits in this new ISO A3 (28 by 40 cm and 11 by 17 inch) flatbed timeshare plotter improve operating efficiency to reduce timeshare computer and transmission costs. This new four-color Hewlett-Packard Model 7221A Graphic Plotter has features not found in other currently available remote terminal plotters. Among these are internal arc and circle generation, and user-defined dashed line patterns. Any sequence of plotter instructions can be stored in the buffer memory as macro-instructions for recall as many times as needed. Up to 64 different macro-instructions can be stored at one time. For more information please contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, California 94304.



Hewlett-Packard Introduces Prerecorded Programs

Prerecorded programs, which solve many important civil engineering calculations when used with HP-67 and HP-97 programmable personal calculators, have been announced by Hewlett-Packard Company. The new Civil Engineering Pac I, which costs $45, contains 18 different programs which enable civil engineers and architects to perform difficult and often time consuming calculations in minutes. Programs have been recorded on tiny magnetic cards which are inserted into the calculator. The user need only key in the variables to find the correct answer. Among the programs included in the Pac are Vector Statics, Cantilever Beams, Steel Column Formula, Linear or Angular Deformation, and Bolt Torque.

The HP-97 is a fully programmable calculator that features a quiet printer, 224 fully merged steps of program memory, and a "smart" magnetic card reader. The HP-67 is the pocket-sized version of the HP-97. The HP-97 and HP-67 are priced at $750 and $450 respectively. Please contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, California 94304.