

Electro-Optical Sensors--Specifications and Standards

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ABSTRACT: Electro-Optical Sensors Systems are now being used as remote sensors in the earth's atmosphere and in outer space. To date, specifications have been individual, and standards, such as are applicable to photograph sensors, have not been developed. The authors call attention to this problem, both for Reconnaissance and Mapping Cameras. They summarize the answers to a questionnaire which was distributed to manufacturers and users of electro-optical sensors systems in member nations, requesting information on the tests they are conducting and their suggestions for standards.

It may be timely for Commission I to organize a working group to develop a Document of Procedures for testing image quality of electro-optical systems.

HISTORY: The members of the International Society for Photogrammetry and Remote Sensing have acquired extensive records of the earth's resources and topography using film cameras. These cameras were tested for image quality and they were calibrated for their geometric characteristics using national or international standards. Standards made it possible to control image quality and make comparisons; for manufacturers and for users they are essential. The standards laboratories in many countries were active in setting up test criteria and calibration procedures; they correlated their ideas at ISPRS Congress Meetings. The Proceedings for Calibrating Mapping Cameras, for instance, was developed by members of Commission I. A section on modulation transfer functions was subsequently added. These standards assure the aerial surveyor of the quality of his equipment. Most surveyors will probably continue their present film cameras, modified perhaps by improved lenses and forward motion compensation.

Sensors in space are another matter. Here the opportunities exist for obtaining information on the solar system and the universe of galaxies which is not otherwise available. The German Metric camera and the United States Large Format camera, which are photographic, have mined pure gold; but there are problems--we have not yet learned how to reload the camera while in space, nor how to return the film to earth for processing without returning the satellite which carries the camera. Launch and retrieval costs many millions of dollars, and must be kept to a minimum. To avoid the satellite return, electro-optical sensors and a satellite-to-earth data link were and are employed. TV monitors receive the pictures on earth where they are viewed and analyzed. Both Russia and the United States have sent electro-optical probes throughout and beyond the solar systems with imagery returned over millions of miles; the transmission methods made the probes successful. The data that is received on earth has been acquired in what is called "near real time". Commercial television, of course, can be "real time", and is controlled by well-developed standards.

A different type of electro-optical system which uses a charge couple device (CCD) as its detector is becoming quite popular. The CCD is an array of small pixels positioned at the focus of a lens. It changes the photons directed to each pixel to a charge which is proportional to the number of photons received.

Nineteen replies were received. (Complete answers will be sent to those who replied and to those who request them.)

There was technical disagreement on all questions. Some replies follow:

1. The 3 bar target should be used for comparison with other sensors; system MTF can only be determined from a single line or point; the effective bits number for pixel type sensor is more important; it is not practical, the test is too difficult to perform.

2. Most respondees said that a flat Lambertian background could provide a test for uniformity of pixel response, but: colorimetry must be considered; the light source needs to be a diffuse reflector of integrating sphere; the best source for uniformity is spatially flat, has the same cone angle and same color; no, our investigations show there are test structures in these images; yes, if you are able to calibrate for lens transmission loss.

3. Most respondees agreed that illumination loss of a wide-field lens could be corrected except that: if the system is shot noise limited the correction does not correct the degraded SNR that is present at the edge of the field; yes, with a special antivignetting lens or through digital radiometric calibration; yes, if there is sufficient light to provide a pixel-to-pixel $S/N = 3.0:1$.

4. Question 4 requested opinions on whether there were orientation problems with respect to bar targets. Answers differed: Theoretically there is no problem; yes, if system resolution is angle dependent; Since systems discussed are spatially sampled, performance varies with spatial phase of targets; multiple targets representing various phasings must be presented; Two separate orientation problems can be referred to as phasing and aliasing. Resolution can be accomplished by taking a number of trials and averaging. The aliasing problem results in unresolved bar patterns between the $1/2$ Nyquist and Nyquist spatial frequencies.

5. Question 5 asked how resolution was defined when the optical image was placed in different positions on the pixels. There were various answers: to find the place where 80 percent response can be detected between lines or derive the point spread function; It is just one of the characteristics of E-0 systems that will limit resolution and should not require the definition to be changed. Definitions should remain consistent from sensor to sensor; Any object will have a position dependent response due to aliasing if the resolution is close to the Nyquist; In addition to the dependence on angle, the resolution depends on the relative alignment of the (optical) image of bars to the pixels; So long as the statistical problem discussed in Question 4 is accounted for, the fact that individual pixels have nonuniform response is accounted for in the measurements; we think you mean radiometric resolution, that is defined by signal-to-noise ratio.

6. Should optical transfer tests be performed and with what target? received various suggestions: yes, prefer edge trace; it gives more information than a bar target; It is easily instrumented for in E-0 systems as a continuing manufacturing test in addition to visual evaluation; yes, for CCD video cameras: bar targets; single edge for satellite cameras, natural objects (edges); yes, for laboratory tests we always use ARC test charts; perhaps MTF

for system prediction or confirmation. Sine-wave targets should be used; Image of an edge such as a razor blade has proven to be an accurate measurement of E-0 system MTF.

7. Question 7 requested the responsee "to make any comments you consider relevant on image quality testing, particularly with respect to visual and IR targets you are using". If you are evaluating terrain imagery from aircraft or spacecraft what are your criteria? There are many answers, differing slightly or significantly: only a few are quoted here and are incomplete: (For complete answers refer to special section), I am concerned with detectability, measurability, pixel average gradient, effective bits number, and MTF; From an operational perspective the only valid rating is the sensor's capability to do its job; standardized computerized measurement techniques should be considered, as many E-0 systems collect information with more dynamic range than can be displayed visually, yet is useful to automatic target recognizers; Random noise and position accuracy of each pixel on output are critical quality parameters and should be tracked by uniform inputs; The most useful parameters are resolution, radiance response, effect of V/H on radiance response and resolution, and uniformity of spectral response; There is a need for standard instrumentation, operated in a standard manner and used in standard analytic methods;...some allowance should be made for post-collection (?) such as tone and spatial enhancement; CCD and photodiodes are being developed (by Kodak) for visible and IR systems. They will describe several (in future papers); Utility measures, such a NIIRS rating, are important, system variations needs to be accounted for (angular orientation of targets, scene radiance, color, contrast, environmental stress, operating adjustments); Needed: Radiometry: MTF: illumination loss; signal to noise ratio; $SNR = f(\text{gray value})$ Geometry: principle point; focal length; distortion; warm-up effects; for the first we consider geometric resolution, radiometric resolution, geometric distortion, and electronic distortion. For the second, our criteria are geometric resolution, sharpness, and vignetting; I am not in position to answer specific questions. However, I think I can make some comments on details in Questions 4 and 5. My comments relate to the results of research on digital pointing versus observation of hard copy images...I concluded that errors in visual point pointing due to the orientation of a target in the pixel pattern could be 0.2 pixel. However, by digital pointing the precision can be reliably as low as 0.1 pixel. Therefore, to obtain the best results from digital data, digital processing is necessary...The questionnaire deals with visual objects. I think that has limited applications, ultimately we must look at digital processing...however, it is time that a suitable target be designed for testing electro-optical systems; for spacecraft we are using a natural target of known reflectance (measured with a field radiometer) and atmospheric corrections (Sperry-Turner model); Pixel response Non-Uniformity (PRNU) needs to be addressed as do Pixel-to-Pixel S/N, peak to peak signal to RMS noise. A knowledge off this quantity allows separation of shortcomings in the sensor up to the detector output from those which are introduced by processing and display.

These somewhat condensed answers to the questionnaire show the need for more detailed discussion before it will be possible to agree on a standard. Digital processing will determine the accuracy of data (and maps) and should be investigated in depth to the satisfaction of our Users.

A short study conducted at Hill Air Force Base is applicable to the questions and answers. A computer program was written which would show the image characteristics of CCDs. The results are shown graphically in Figures 1 to 10.

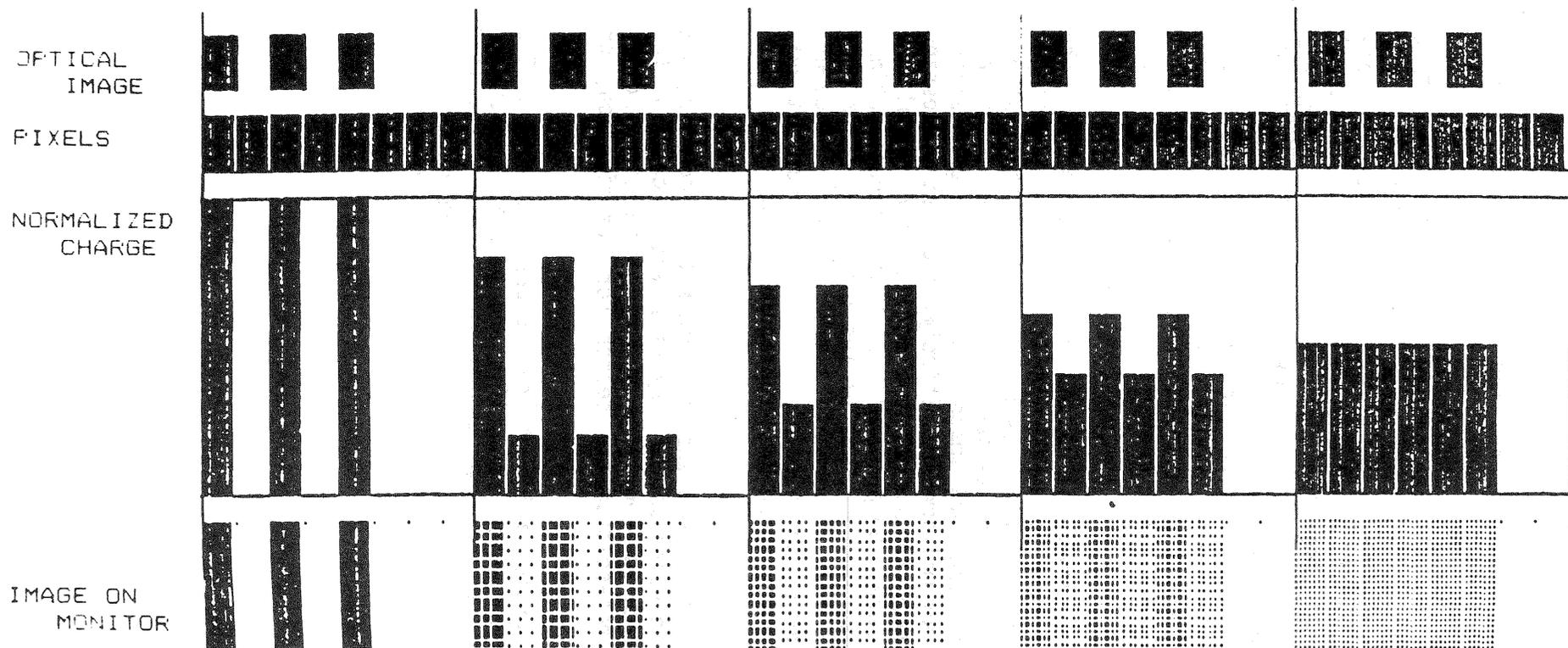
The top line shows optical images of perfect three bar targets positioned directly above pixels having the same width. Optical images of bars and spaces were 12 microns (24 microns total) and the pixels were 10 microns separated by spacing 2 microns thick. Assuming no degradation between the input light energy to the pixels and the visual output at the monitor the bars are perfectly resolved, as shown in the bottom line of Figure 1. This represents the charge in the pixels, and is here shown as density. The following figures show the output from the pixels as the optical image (unchanged) is moved laterally in steps of one micron (0.001 millimeters) across the face of the detector. When the light from the bars is evenly distributed, i.e., the optical image of a bar is evenly divided between two pixels, the image on the monitor is a uniform blur--the Nyquist Limit. As larger optical images are used, there is no even blur, the output images appear as a function of the position, a little ragged to the eye. Both lines perpendicular to the pixels and the rotated lines show the difficulty of measuring MTF, the line edge being very uneven to the 0.002 mm slit of a microdensitometer.

When these graphs are being analyzed, it should be remembered that the Nyquist Limit for this specific case is equivalent to 42 optical lines per millimeter and a magnification of at least 5 is needed to make the best eye critical of the image quality. Secondly, we have used an optical image that is not degraded, which means that the real image must be very high quality, probably several hundred lines per millimeter. Thirdly, the post processing which allows calibration accuracy to one or two microns for radial and tangential distortion, which locates the principal point of autocollimation, the point of symmetry, and measures the shape of the effective surface of the focal plane (if that is still important) needs to be a procedure investigated and agreed upon among knowledgeable personnel in our National Standards Laboratories and E-0 experienced User-Photogrammetrists.

SUMMARY: As a minimum, the technical problems of agreement are complex, but the advantages gained using electro-optical systems are necessary for maintaining progress in our search for knowledge of the solar system and the universe, as well as in our not-so-dramatic search (or verification) of conditions on earth.

The authors suggest: that in consideration of the increasing number of E-0 systems that are being used from which scientific and geometric data are being obtained, that a problem of standards exists that warrants detailed technical discussion, and consideration of establishing a Working Group in Commission I to investigate, in depth, and provide direction for standards.

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OPTICAL IMAGE: BAR WIDTH = 12 MICRONS, SPACE = 12 MICRONS

PIXEL ARRAY: PIXEL WIDTH = 10 MICRONS, SPACE = 2 MICRONS

MAGNIFICATION = 440

Fig. 1

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PIXEL ARRAY
WITH OPTICAL
IMAGE ROTATED
20 DEGREES

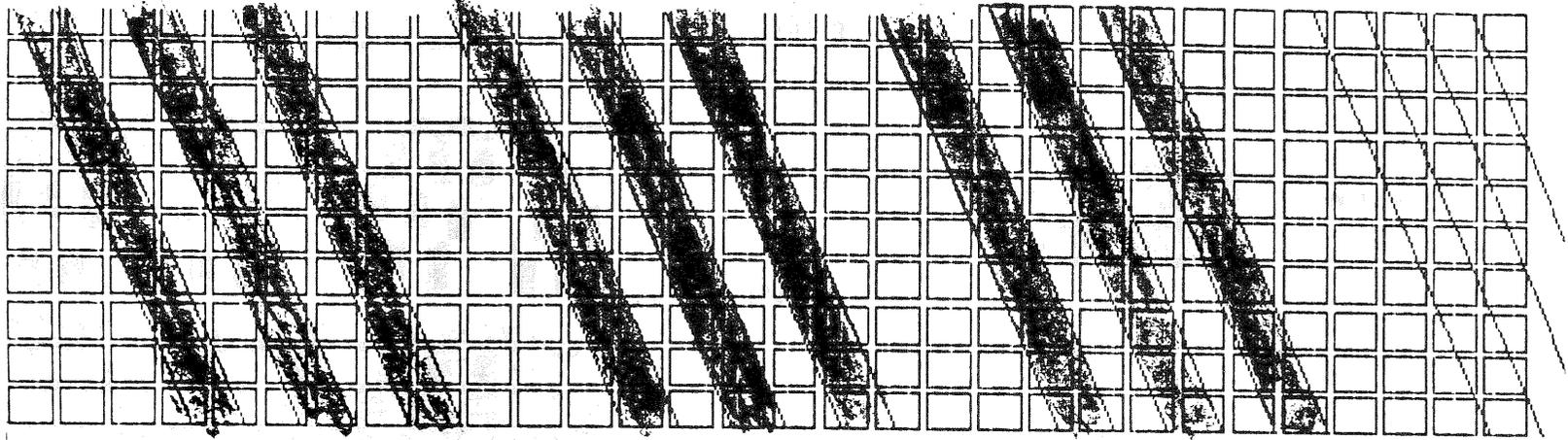
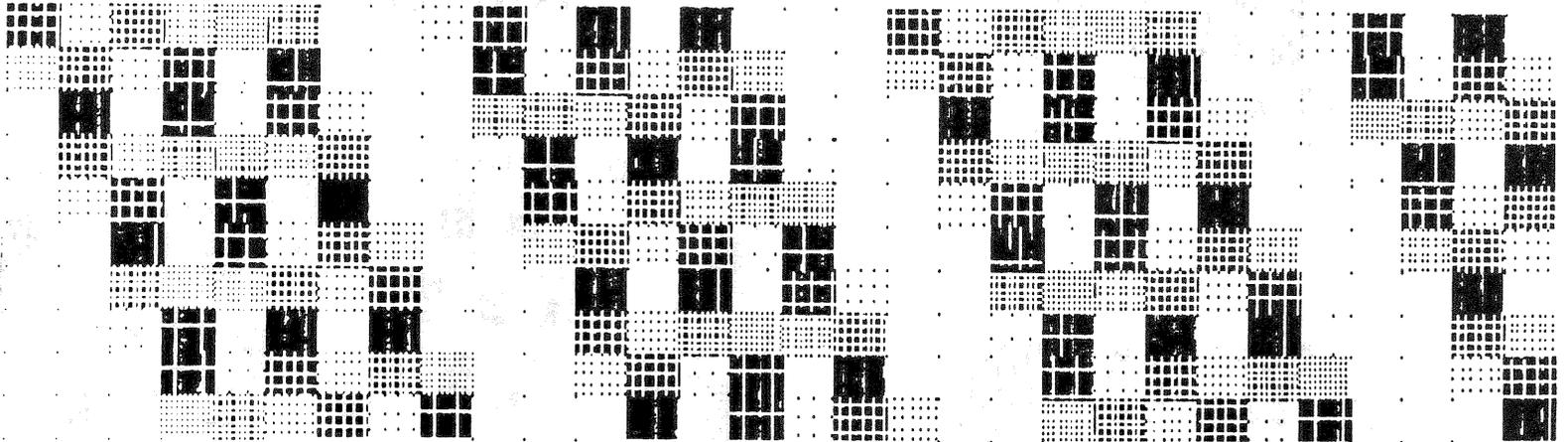


IMAGE ON
MONITOR

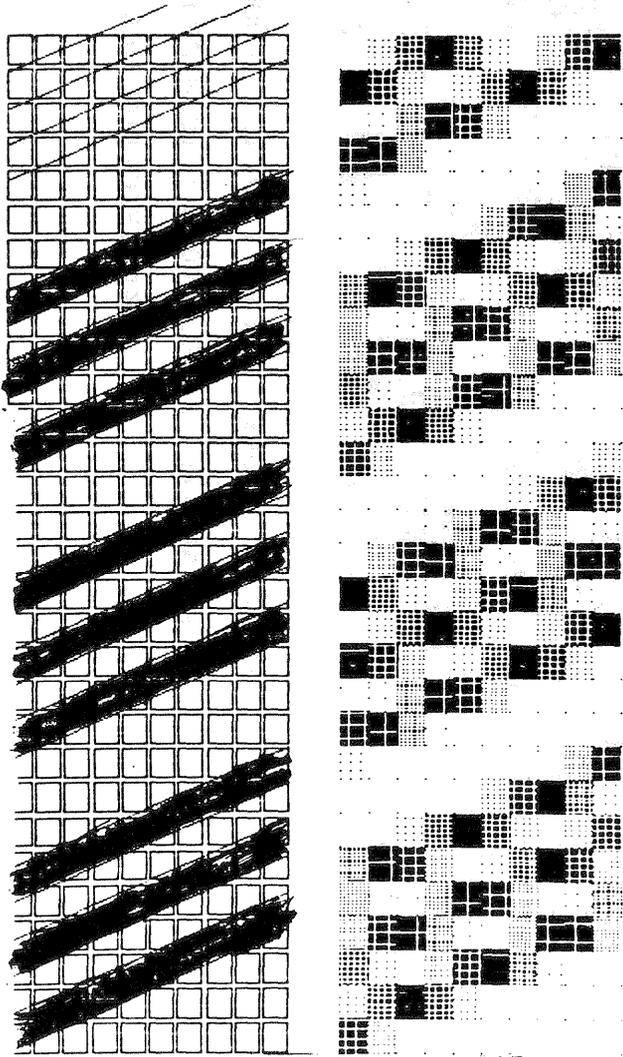


OPTICAL IMAGE: BAR WIDTH = 12 MICRONS, SPACE = 12 MICRONS

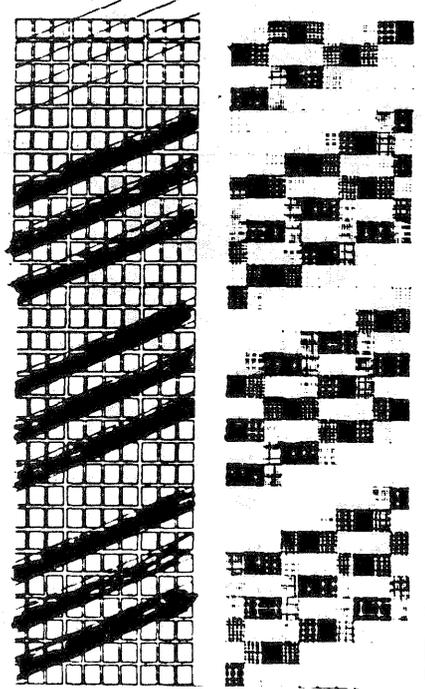
PIXEL ARRAY: PIXEL WIDTH = 10 MICRONS, SPACE = 2 MICRONS

MAGNIFICATION = 590

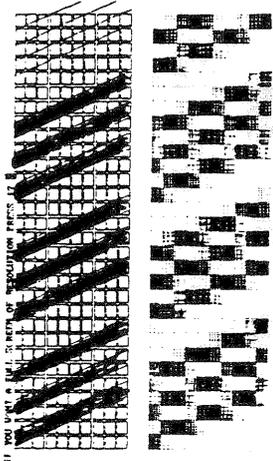
Fig. 2



Mag = 385



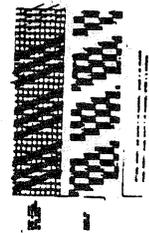
Mag = 251



Mag = 164



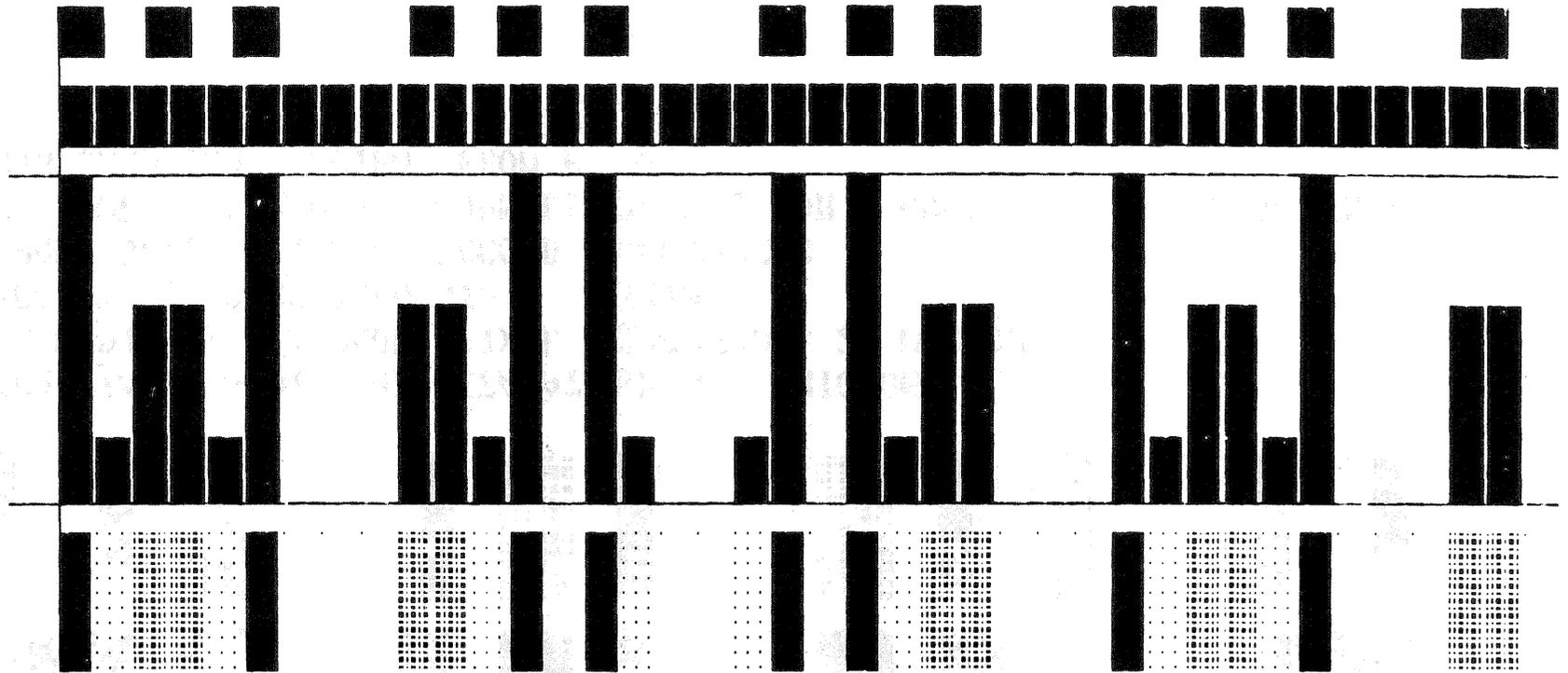
Mag = 106



Mag = 70

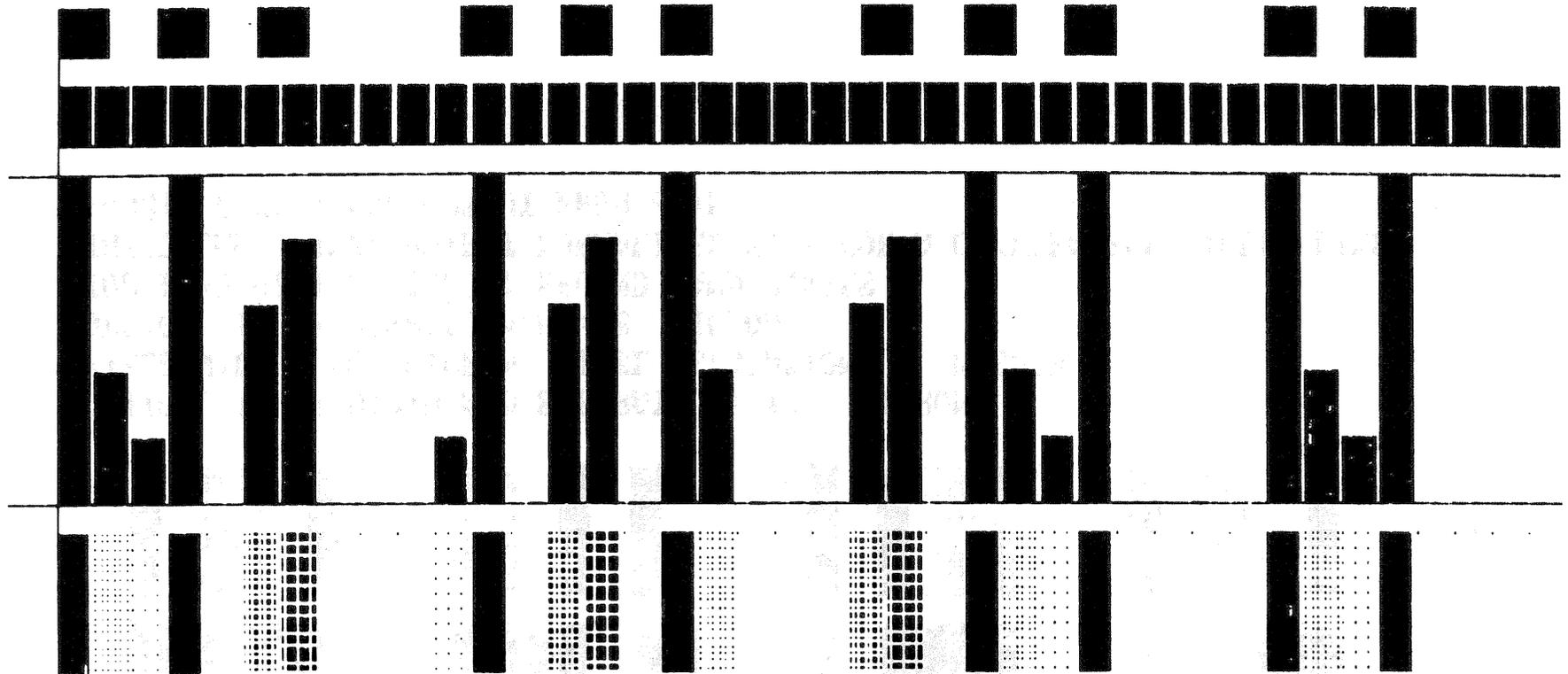
OPTICAL IMAGE: BAR WIDTH = 12 MICRONS, SPACE = 12 MICRONS
 PATTERN ARRAY: PATTERN WIDTH = 18 MICRONS, SPACE = 2 MICRONS
 PHOTOCOPIATION =

Fig. 3



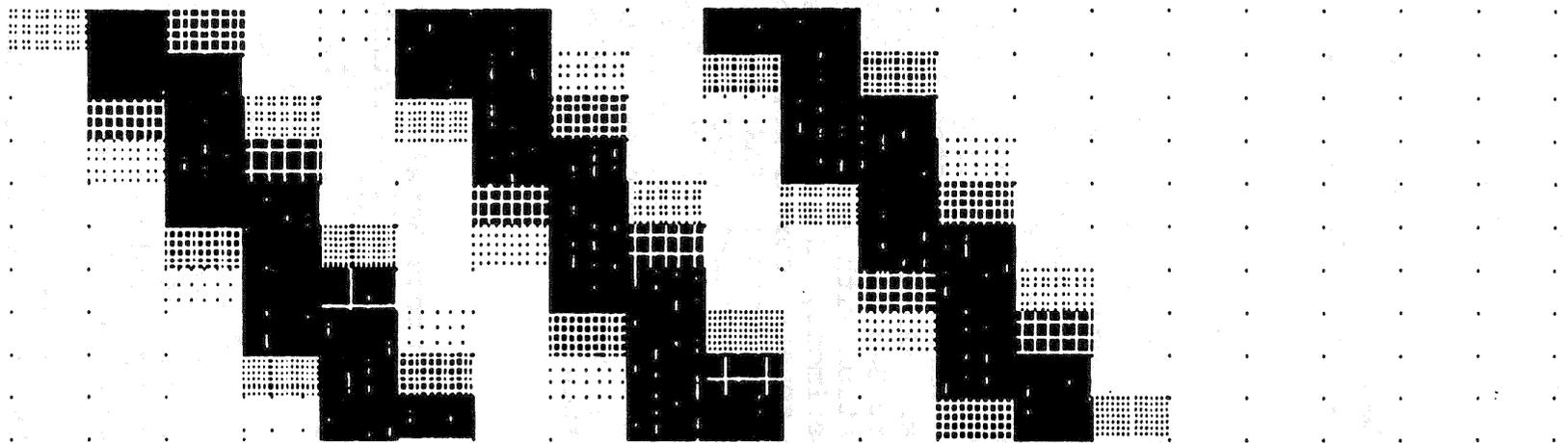
OPTICAL IMAGE WIDTH AND SEPARATION= 14 MICRON
 PIXEL WIDTH= 10 MICRON PIXEL SEPARATION= 2 MICRON
 OPTICAL IMAGE DISPLACEMENT= 0 MICRON
 TOP BAND OPTICAL IMAGE; SECOND BAND PIXELS
 THIRD BAND PIXEL OUTPUT NORMALIZED TO 1 FOR A COMPLETELY FILLED PIXEL
 FOURTH BAND IMAGE OUTPUT FROM PIXELS

Fig. 4



OPTICAL IMAGE WIDTH AND SEPARATION= 16 MICRON
 PIXEL WIDTH= 10 MICRON PIXEL SEPARATION= 2 MICRON
 OPTICAL IMAGE DISPLACEMENT= 0 MICRON
 TOP BAND OPTICAL IMAGE; SECOND BAND PIXELS
 THIRD BAND PIXEL OUTPUT NORMALIZED TO 1 FOR A COMPLETELY FILLED PIXEL
 FOURTH BAND IMAGE OUTPUT FROM PIXELS

Fig. 5



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BAR TARGETS ROTATED 50 DEGREES
WIDTH: 24 MICRONS
SPACE: 24 MICRONS
PIXELS: WIDTH: 10 MICRONS
SPACE: 2 MICRONS

FIG 6