OSCILLOSCOPE CAMERA EVALUATIONS

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QUALITY DIVISION

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Normal Process Development
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MASTER

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MASTER

ABSTRACT

An evaluation was performed on two cameras used to photograph rasters on model L10 oscilloscopes. Focusing devices were fabricated and tested for use with these cameras.

INTRODUCTION

The model 105 Mast camera and model 197A Hewlett Packard camera are used to photograph rasters on model L10 oscilloscopes. A raster (see Fig. 1) is written on the CRT face with $0.5 \mu\text{s}$ time markers. A time interval between signal pulses is measured with reference to the time marks. This history is photographed with a camera and measured on an Oscar film reader. Time resolution of a raster measurement is dependent upon optical and electronic limitations. The Mast and Hewlett Packard cameras were tested to determine the optical limits of time resolution when used with L10 oscilloscopes and Royal-X pan film.

CAMERA PARAMETERS

The Mast camera (see Fig. 2) operates at 0.25 magnification and uses a Wollensak lens of 51 mm focal length. Consequently its depth of field (allowable variation of the object plane for an acceptable focus) is approximately sixteen times its depth of focus (allowable variation of the image plane for an acceptable focus). The Hewlett Packard camera operates at approximately 0.72 magnification with a 75 mm focal length Wollensak lens. Its depth of field is about twice its depth of focus. In short, the Mast camera is less sensitive to object displacement but more sensitive to image displacement than the H.P. camera. There are two types of Mast cameras. Type I uses a conventional focusing method while type II utilizes a spring technique to assure a repeatable distance from lens to film. The equivalent change in object distance does not defocus an image because of the large depth of field. The type II Mast camera is somewhat cumbersome for loading and unloading film holders because of impeding conditions of adjacent cameras in a bunker.

Stopping down a lens increases its depth of field, thus reducing its sensitivity to image defocus. If a lens is nearly diffraction limited (aberration free) stopping down will degrade a focused image. If aberrations are significant, stopping down will improve resolution both on and off the focal plane.

EVALUATION MEASUREMENTS

A sample of 30 film holders was measured for depth which produced a mean depth (to the film emulsion) of 4.76 mm and standard deviation of 0.12 mm. These values pertain to the center portion of a film holder. For most film holders a depth was constant over its surface within 0.08 mm but some varied as much as 0.15 mm. Focusing devices

were constructed by attaching a 20 power microscope to an aluminum plate containing frosted glass located 4.76 ± 0.03 mm from its reference plane (the camera - film holder plane of contact). With the microscope prefocused on the frosted surface (frosted surface towards camera) a reference focal plane is established for optimum focus. Translation was also provided for scanning an image. Similar devices (with reduced magnification) were constructed for the H.P. cameras (see Appendix A for details).

The focus device was used to obtain resolution data for raster photographs. In order to simulate operating conditions a resolution chart was attached to a CRT face and illuminated with the P-11 phosphor light ($\lambda \sim 0.46 \mu\text{m}$). This procedure removes chromatic errors and reproduces any lens alignment or light scattering effects within the camera. Film holders were selected to simulate defocusing errors and tests were performed on axis, 32 mm off axis, in focus, 0.23 mm out of focus, and at various F stops for each camera. Photographs were also taken to check for repeatable resolution within an acceptable exposure and contrast variation. The major findings from these tests (taken on Royal X Pan film) are presented in Tables I and II. Resolution (line pairs/mm) is presented as seen at the CRT face. All tests were performed at the proper object and image conjugates corresponding to the operating magnification of each camera.

Distortion errors were measured from photographs taken of a precision grid pattern on a glass plate; the errors are 0.4% (based on a $0.5 \mu\text{s}$ interval) for each camera. The scope trace width was determined by measuring the ratio of a trace width to its $0.5 \mu\text{s}$ time interval marks on a well focused raster photograph. This yielded a trace width of $0.010 \mu\text{s}$. The lens under test was removed and placed on an optical bench. Aerial resolution was measured for each lens at various apertures and the results are presented in Table III.

CONCLUSIONS AND RECOMMENDATIONS

The aerial tests (Table III) imply that stopping down degrades the image resolution for either camera, while photographic resolution (Table II) improved for larger F numbers. This could be a result of P-11 phosphor afterglow from the CRT. Bunker technicians have found that stopping down improves raster photographs even at low light levels. Open aperture (f/1.5) is not recommended because of resolution loss while f/4 does not improve resolution (compared to f/2.8) significantly to justify the necessary increase in CRT beam current (which reduces the tube life). This extra load also tends to reduce the CRT resolution. An F number of 2 or 2.8 should be a good choice for either camera.

The limiting distinguishable trace width which can be photographed is approximately $1/2N$, where N is the resolution from Table I. This value divided by 24 (the measured distance for a $1 \mu\text{s}$ interval) yields a least distinguishable trace width to compare to the actual trace width of $0.010 \mu\text{s}$. These calculations for the worst conditions (off axis and defocused) yield the following for comparison.

<u>Camera</u>	<u>Least Resolved Trace at f/2.8</u>

Mast I	0.005 μ s
Mast II	0.003 μ s
HP	0.005 μ s

These values do not necessarily represent measurement limits since a raster pulse is read at one side of a trace width and some randomness is associated with the visual alignment during reading. These values represent the capability of a camera as compared to what the camera is expected to measure. A method is being considered for measuring the total uncertainty of a raster measurement - including electronic and human errors.

It should be mentioned that occasionally a film packet is found which has curvature in an unfavorable direction (see Fig. 2). This is a rare event and is easily detected in the dark room during film loading.

More quantitative and precise evaluations could be performed (i.e., modulation transfer function tests) but the method used for this report represents the operating conditions of a camera and can be easily performed on a camera at its work station.

In final conclusion, the Mast II camera has the better resolution; however, the significance of this difference is debatable. The Mast camera gives an advantage of a faster aperture ratio (due to its smaller magnification) and should prolong tube life. The difference in CRT radiance required for the two cameras can be determined from(1)

$$H = \frac{T \Pi N}{4(f/\#)^2 (m+1)^2}$$

or

$$\frac{\Delta N}{N} = 1 - \left(\frac{m_1 + 1}{m_2 + 1} \right)^2$$

where

- H = irradiance in the image
- N = radiance of the source (CRT)
- T = lens transmission (assumed to be 1.0)
- f = lens infinity F number (f/2.8 for both lenses)
- m₁ = Mast camera magnification
- m₂ = HP camera magnification

Calculation shows the difference to be 47% (less). How long this would prolong tube life is unknown to the author at this time.

(1) W. J. Smith, *Modern Optical Engineering* (McGraw-Hill Book Co., New York, 1966), p. 189.

Fig. 1. L10 Raster

FIG. 2. CONCEPTUAL DIAGRAM OF MAST CAMERA AND FILM CURVATURE

Table I. Film Tests (Field and Focus)

Camera	Defocus (mm)	Resolution (on Axis) (line pairs/mm)	Resolution (32 mm off Axis) (line pairs/mm)
Mast I	0.0	11	5.0
Mast I	0.23	4.0	4.0
HP	0.0	16	5.0
HP	0.23	14	4.0
Mast II	0.0	11	6.4
Mast II	0.23	11	6.4

Table II. Film Tests (Resolution V/S Aperture)

Camera	f/#	Resolution (on Axis, Center Field)
Mast	1.5	5.0
Mast	2	9.0
Mast	2.8	11
Mast	4	13
HP	1.9	14
HP	2.8	16
HP	4	18

Table III. Optical Bench Tests

Camera	f/#	Measured Resolution (line pairs/mm)	Contrast	Diffraction Limits ($\lambda = 0.46 \mu\text{m}$) (line pairs/mm)
Mast	1.5	> 114	Poor	238
Mast	2	> 114	Medium	178
Mast	2.8	~ 114	Good	127
Mast	4	81	Good	89
HP	1.9	144	Poor	393
HP	2.8	144	Medium	266
HP	4	128	Good	186

APPENDIX A

The microscope is prefocused on a frosted glass plate (see Fig. 3) located at the mean depth to Royal-X pan film (as determined from measurement of various film holders). If the magnified image is displaced slightly (~ 0.06 mm) from the frosted surface, image blurr becomes observable. The microscope is prefocused on the frosted surface and locked into place by the two set screws shown in Fig. 3. The complete focus device is attached to the camera by use of sliding latches on the camera back. Translation for the Y axis is accomplished by sliding piece No. 4 along its slots. The knurled nuts (piece No. 5) should be tightened just enough to retain piece No. 4 when no external force is applied, but to allow translating with ease during image scanning. Translation along the X axis is obtained by sliding the entire assembly with respect to the camera. The camera projector lens can be refocused by loosening its set screw and adjusting the focus knob located at the bottom side of the camera. After focusing the camera, the set screw should be tightened enough to prevent slipping during film loading and unloading. The microscope yields a 7 mm field of view as seen at the raster image.

Image focus is less sensitive for the HP camera and consequently, a 6 power magnifier lens allows precise focus, provided that the frosted glass is properly located with respect to the camera. Fig. 4 shows the mechanics of this device. Piece No. 3 retains lens position for proper focus while the spring tension is adjusted by the knurled nut (piece No. 4). This should be adjusted to provide just enough tension to prevent slipping from the device's weight. Over tension will produce undue stress on the frosted glass. The image can be scanned by pivoting piece No. 1 and sliding the lens assembly along the elongated hole in piece No. 1. The lens assembly can be removed for cleaning by unscrewing it from the knurled nut (piece No. 4). This assembly is a 3 element lens system and provides a 29 mm field of view with excellent sharpness to the edge of field. The focus device is attached to a conventional focus plate and snaps onto a camera in the usual way. The frosted glass was repositioned to assure proper focus at the previously mentioned mean film depth.

Since the image light cone passes through the frosted glass, compensation must be made for the change in optical path length after removal of the focus device. When the device is removed, the new image position will be nearer to the camera. This focus change will be approximately $1/3$ the thickness of the frosted glass plate. The approximation will be very near the actual value for this plate thickness.

Fig. 3. Mast Camera Focus Device (from sketch FSSK-024-00)

Fig. 4. HP Focus Device (from sketch FSSK-024-00)