0

Measurement of Modulation Transfer Function of Focal Plane Arrays and Imaging Systems

Final Report
Project Number DAAL01-93-R

Submitted 11 May 1994

to:

Dr. John Pellegrino
Army Research Lab
AMSRL-SS-SF
2800 Powder Mill Rd.
Adelphi, MD 20783

DAAL01-93-K-0067

by:

Dr. Glenn D. Boreman
Principal Investigator
Associate Professor, Electrical Engineering

Center for Research in Electro-Optics & Lasers (CREOL)
University of Central Florida
Orlando, Florida 32816
Ph: (407) 658-6815
FAX: (407) 658-6880

39pp

TABLE OF CONTENTS

Introduction

A method for measuring the MTF of focal-plane arrays (FPAs) has been developed[1-3] which uses the statistical properties of laser speckle. The entire area of the focal plane is characterized, and no optics are required for target projection. The random nature of the test pattern avoids phasing effects between the target and the detector-array structure, which greatly relaxes alignment tolerances as compared to other methods. The technique is applicable to arrays that have intentional nonlinearity of response, as well as to those arrays that are inherently linear. The test can be performed on any focal-plane configuration, either one dimensional (1D) or two dimensional (2D). The data processing is usually performed by an off-line computer. However, the test is also useful for real-time diagnostics, to facilitate adjustment of focal-plane operating parameters. In the real-time case, the necessary signal processing can be performed on a digital oscilloscope.

Speckle MTF measurement techniques measure the transfer function of a system by evaluating its response to a random-noise input and comparing the Fourier spectra of the input and the output.

The MTF relates the input and output power spectral density (PSD)

$$\mathrm{PSD}_{\mathrm{out}}(\xi) = \mathrm{PSD}_{\mathrm{in}}(\xi)\ \mathrm{MTF}^2(\xi) \ . \tag{1}$$

The input PSD is then filtered by the square of the transfer function to produce the output power spectrum. The output PSD is the squared magnitude of the Fourier spectrum of the FPA data. We will show that the input PSD is of constant magnitude and variable test frequency, so that the MTF is the square root of the output PSD, as a function of the test frequency. It should be noted that the relationship used in the computations is the square root of both sides of Eq.(1)

$$\mathrm{MTF}(\xi) = \sqrt{\frac{\mathrm{PSD}_{\mathrm{out}}(\xi)}{\mathrm{PSD}_{\mathrm{in}}(\xi)}} = \mathrm{Constant} \times \sqrt{\mathrm{PSD}_{\mathrm{out}}(\xi)} \tag{2}$$

where the square root of the output PSD is calculated as the magnitude of the FFT of the array data.

The design equations for the speckle MTF method are reviewed first. Data-processing procedures are next considered, with examples of intermediate steps and final results taken from data acquired during the preliminary design review (PDR), 13 and 14 April 1994. We then provide the physical layout of the measurement system demonstrated, and a complete listing of the parts, prices, and manufacturers. Mechanical drawings of the custom-fabricated parts are included.

Design Analysis

Figure 1 is a schematic of the instrument that was demonstrated for the MTF characterization of FPAs. The laser radiation enters the sphere at the input port and reflects many times on the diffuse interior surface of the sphere before exiting from the output port. The baffle precludes any direct line-of-sight path between the ports. The diameter of the sphere is 2.54 cm, and the ports are each 4 mm diameter. The radiation exiting the sphere is uniformly distributed and has random phase. The aperture is placed at the output port to control the spatial-frequency content of the speckle. The speckle pattern propagates directly to the focal plane by the process of diffraction, without any imaging optics. The polarizer is optional, being used to increase the contrast of the speckle patterns obtained. The polarizer does not change the frequency content of the data.

The spatial-frequency content of the speckle pattern is determined by the dimensions of the aperture and the distance from the aperture to the focal plane. The two-slit aperture used and the spatial-frequency power spectrum produced are seen in Fig. 2. The power spectrum of the speckle irradiance is related[4] to the aperture function by an autocorrelation operation. The speckle produced has a narrowband spatial-frequency content, as seen in Fig. 3. The spatial frequency of any paticular MTF measurement is

$$\xi = L/\lambda z \, , \tag{3}$$

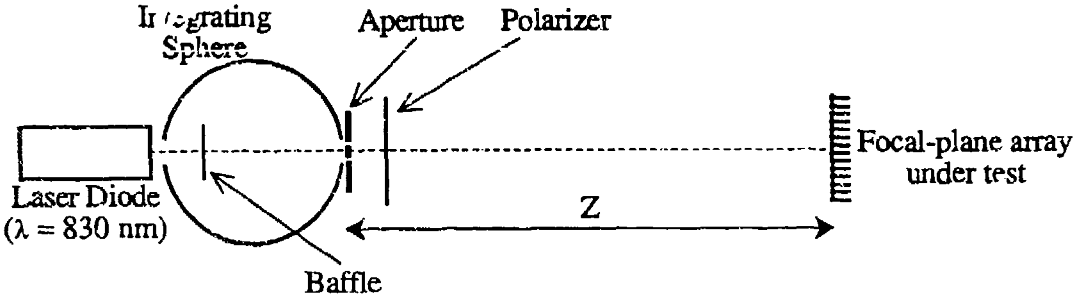


Figure 1. Schematic of instrument for measuring MTF of focal plane arrays.

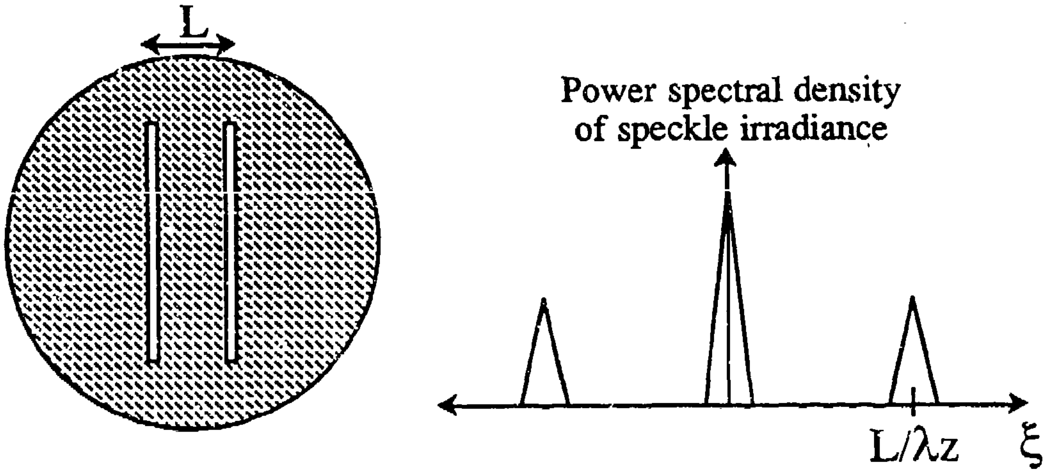


Figure 2. Two-slit aperture and the corresponding spatial-frequency power spectrum.

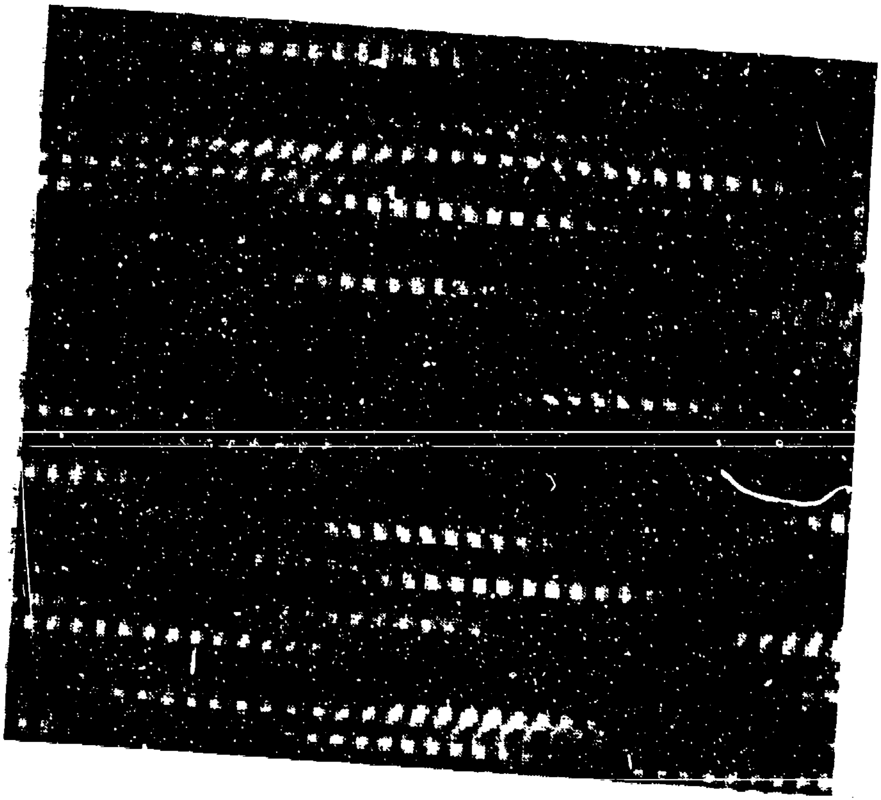


Figure 3. Typical narrowband speckle data.

where L is the separation distance of the slits, λ is the wavelength of the laser radiation (830 nm), and z is the aperture-to-focal-plane distance. The spatial frequency of the speckle can be changed by changing the aperture-to-focal-plane distance z. The highest spatial frequency will be generated when the distance z is minimum.

We designed a single aperture to be able to test FPA's having pixel spacings Δx between 7 μm and 35 μm, from dc to their respective Nyquist frequency, calculated as

$$\xi_{\mathrm{Nyquist}} = 1/2(\Delta x) \ . \tag{4}$$

The narrowband nature of the test pattern allows measurement of MTF over the entire spatial-frequency range[3] of the focal plane even past the spatial Nyquist frequency because ambiguity in interpretation of the frequency is avoided. We assumed that the closest allowable spacing from the FPA to the aperture is 1 cm. By Eq. (3), the slit spacing L is equal to 600 μm. Thus we can generate the Nyquist frequency for the 7-μm-spacing array of 71.4 cy/mm. For the 35-μm-spacing FPA, the Nyquist frequency is 14.3 cy/mm, generated for a minimum z = 5.06 cm. If the number of samples in any data record is N, then the FFT that is used to calculate the spectrum will have its folding frequency at the $(N/2)^{\mathrm{th}}$ component.

The distance z that generates dc will set the longest distance for the system. We calculate this as the distance that puts the peak of the sideband triangle at the first component of the FFT. The maximum distance is

$$\frac{\xi_{\mathrm{Nyquist}}}{\xi_{\mathrm{dct}}} = \frac{\left(\dfrac{L}{\lambda \ z_{\mathrm{min}}}\right)}{\left(\dfrac{L}{\lambda \ z_{\mathrm{max}}}\right)} = \frac{\left(\dfrac{N}{2}\right)}{1} \ , \tag{5}$$

which yields

$$z_{max} = z_{min} \times \frac{N}{2} \tag{6}$$

The width of the slits determines the width of the base of the triangles in the PSD, and is set at 1/10 of the slit separation L, giving a slit width of 60 μm. We have used a 10:1 ratio for slit spacing to slit width in the past and obtained satisfactory results, considering both flux transfer and localizing the peak of the sideband.

The next dimension of the aperture to consider is the slit height. The only consequence that the height has on the laser speckle is the power in the final overall pattern. The slits must be as tall as possible yet stay within the 4-mm-diameter exit port of the sphere. We chose 80% of that diameter for better uniformity and determined the height of the slits as 3.16 mm.

Data-Processing Procedures

We begin here with the direct array data a(i,j) of the speckle pattern, assuming that the array data has been digitized so that each detector value is available individually. All computations are made in the host computer.

Calculate the mean of the array data <a> and subtract the mean from the data to yield a(i,j) - <a>.

This will get rid of the large dc spike in the spectrum, allowing normalization at the first frequency component past dc in the FFT.

Take the 1D FFT of each line of mean-subtracted data, and take the absolute value of the FFT.

Note that |FFT{a(i,j) - <a>}| yields the square root of the PSD of {a(i,j) - <a>}.

Average |FFT{a(i,j) - <a>}| over all lines in the frame.

This increases signal-to-noise ratio in the spectrum[5] by averaging independent speckle data records.

Normalize the maximum value to 1 of |FFT{a(i,j) - <a>}|.

This normalizes the spectrum at the first frequency component past dc in the FFT, corresponding to the lowest frequency in the baseband component, exclusive of the dc spike.

Note the maximum height of the sideband component, and the frequency of its maximum value.

The component # in the FFT can be related to spatial frequency at the FPA as follows. Assuming that there is the same number of samples (N) in the data record as detector pixels, then the Nyquist frequency $\xi_{Nyquist} = 1/(2\Delta x)$ corresponds to the (N/2)th component past dc in the FFT. This allows identification of the spatial frequency of each FFT component.

Repeat the above steps for each spatial frequency of interest.

Perform a second-order polynomial fit to the MTF data.

We have found that a second order polynomial works well for curve fitting.

Normalize the resulting curve so that the zero-frequency intercept is unity.

This normalizes the MTF to 1 at $\xi = 0$.

We demonstrate the above steps with actual array data collected during the PDR. Figure 4 is an example of direct array data. Figure 5 shows the corresponding single-line mean-subtracted |FFT|. Figure 6 shows the effect of averaging over the 60 lines in the data record and in Fig. 7 this averaged spectrum is normalized to 1 at $\xi = 0$. Figures 8 - 11 show the direct array data, the single-line mean-subtracted |FFT|, the 60-line average spectrum, and the normalized average spectrum for a higher spatial frequency speckle pattern.

Performing the data processing steps above yield the MTF shown in Fig. 12 for the particular array tested during the PDR.

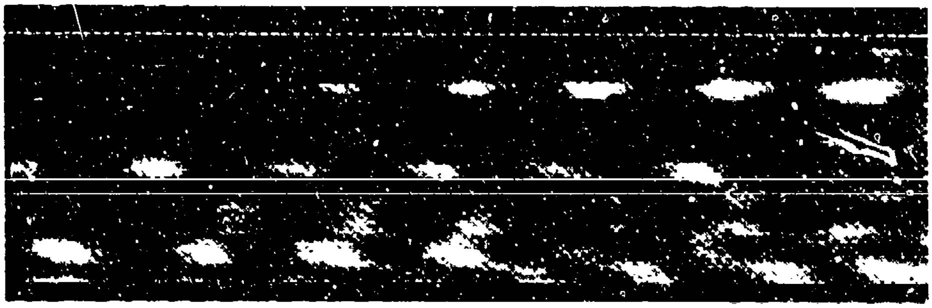


Figure 4. Direct array data.

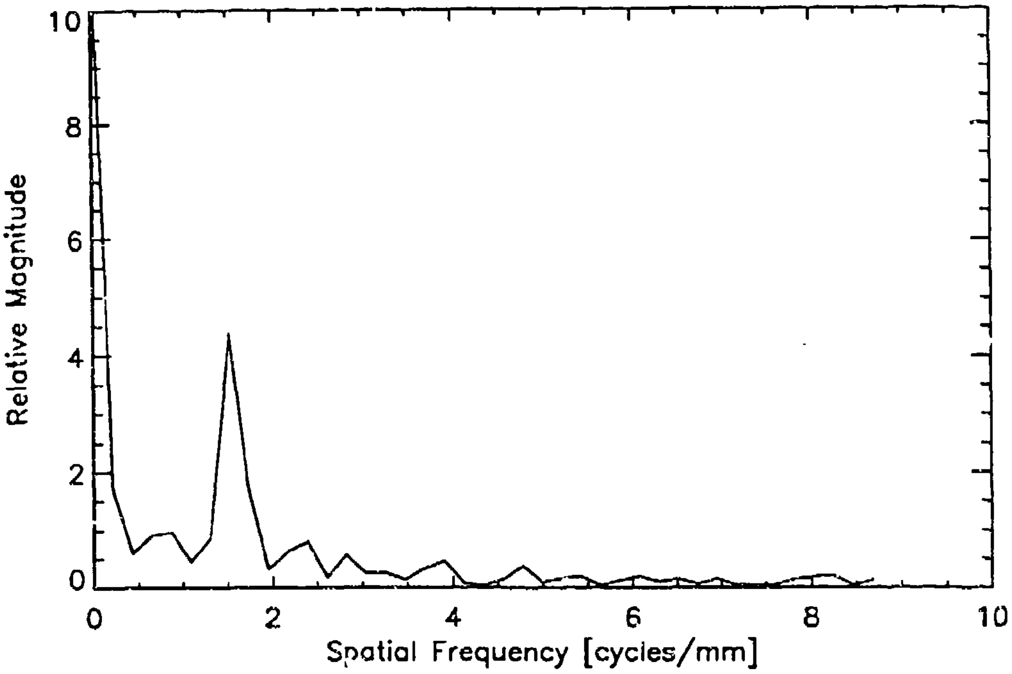


Figure 5. Mean-subtracted |FFT| of a single line of data from Fig. 4.

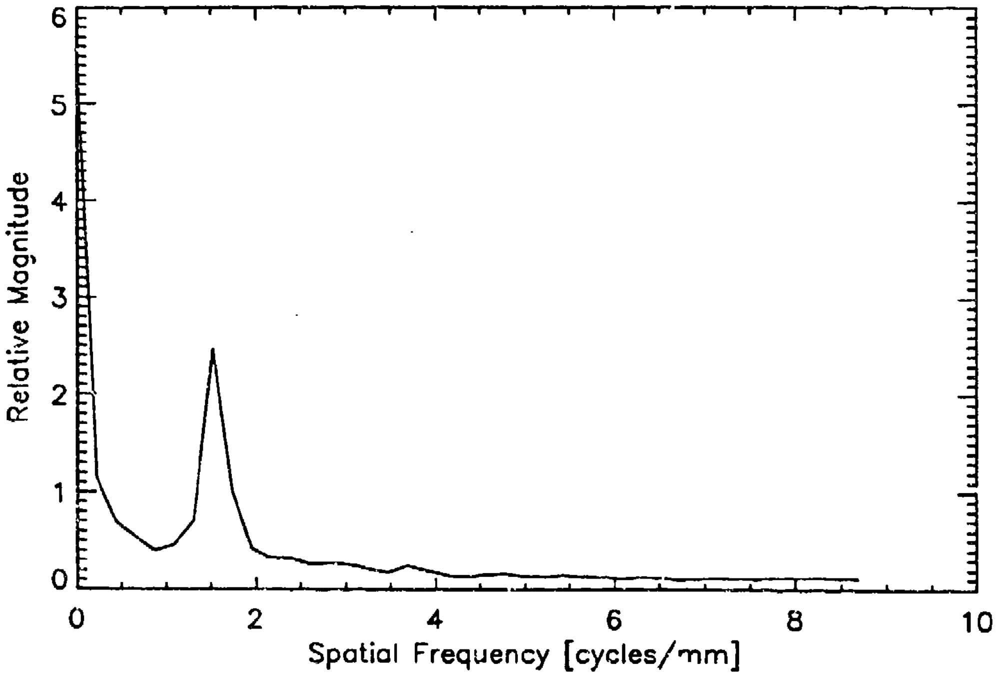


Figure 6. Average of mean-subtracted |FFT|s from 60 lines of data from Fig. 4.

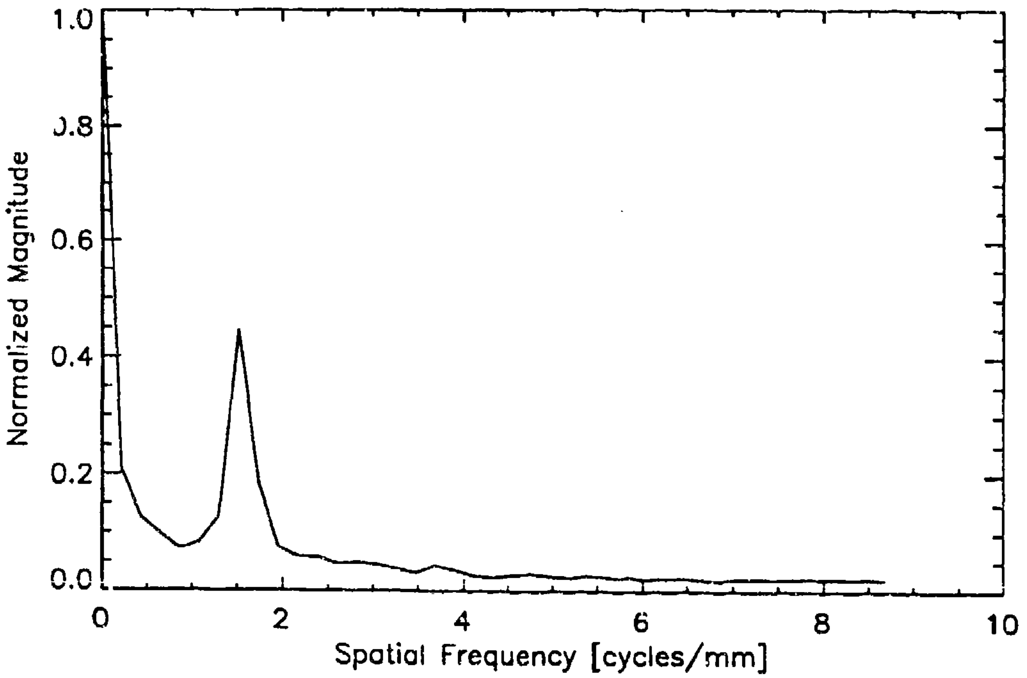


Figure 7. Average mean-subtracted |FFT| from Fig. 6 , normalized to 1 at dc.

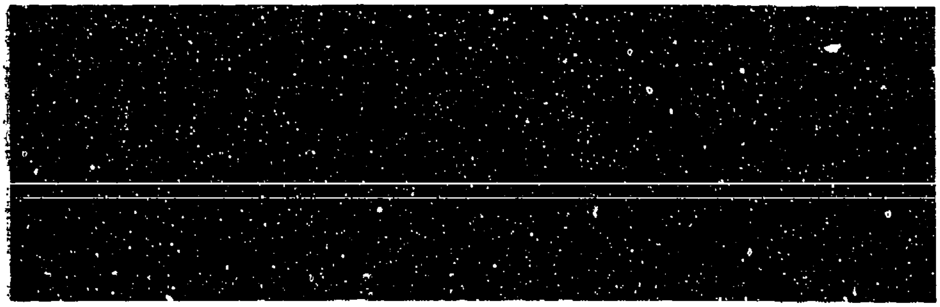


Figure 8. Direct array data, at a higher spatial frequency than Fig. 4.

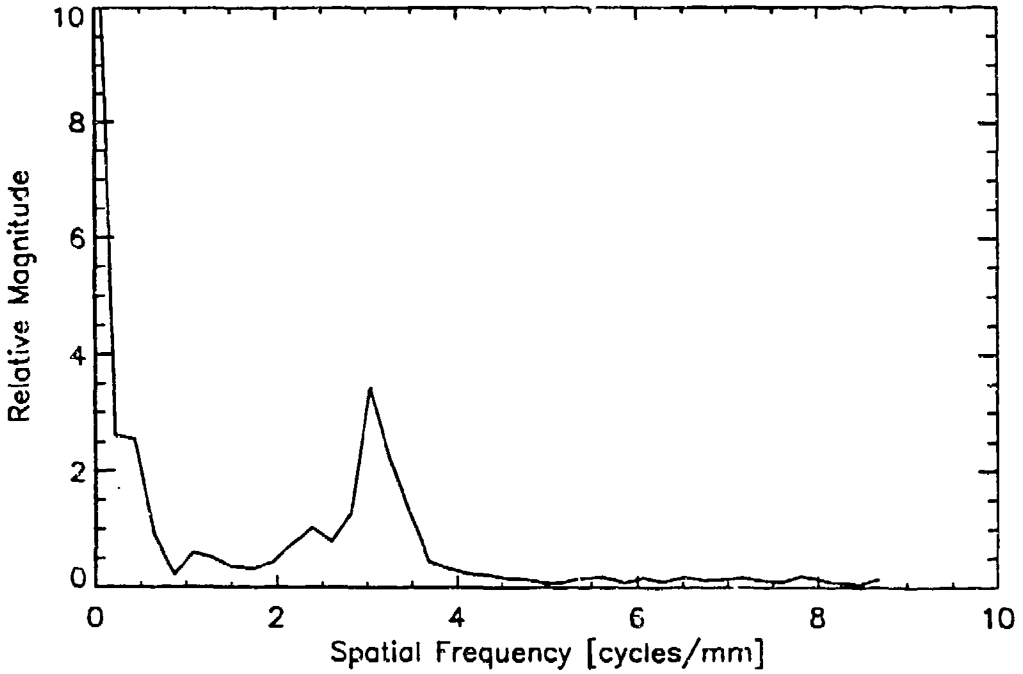


Figure 9. Mean-subtracted |FFT| of a single line of data from Fig. 8.

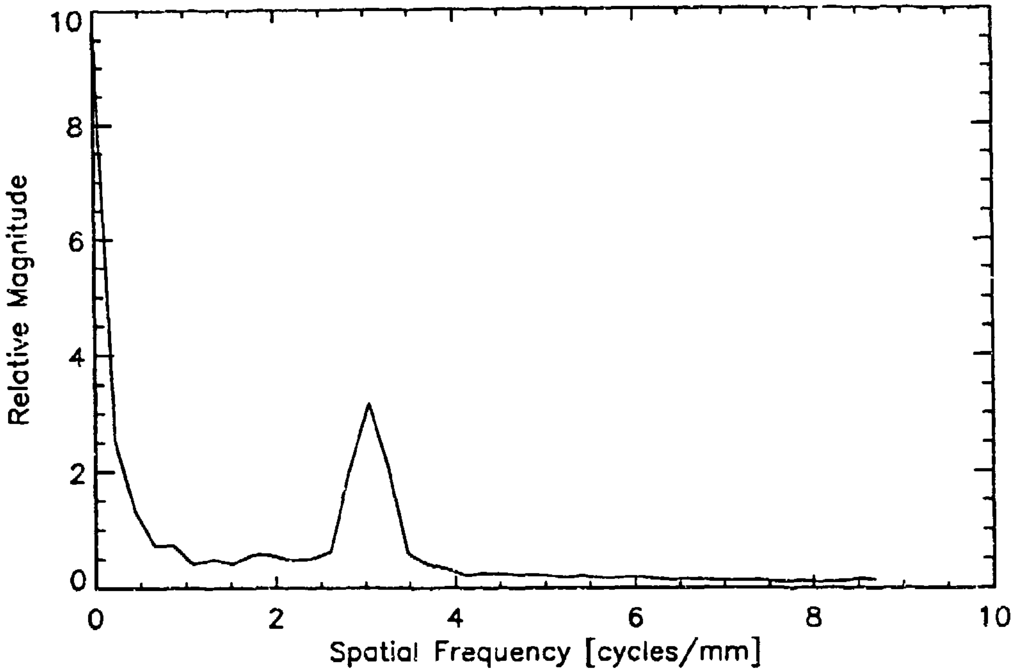


Figure 10. Average of mean-subtracted |FFT|s from 60 lines of data from Fig. 8.

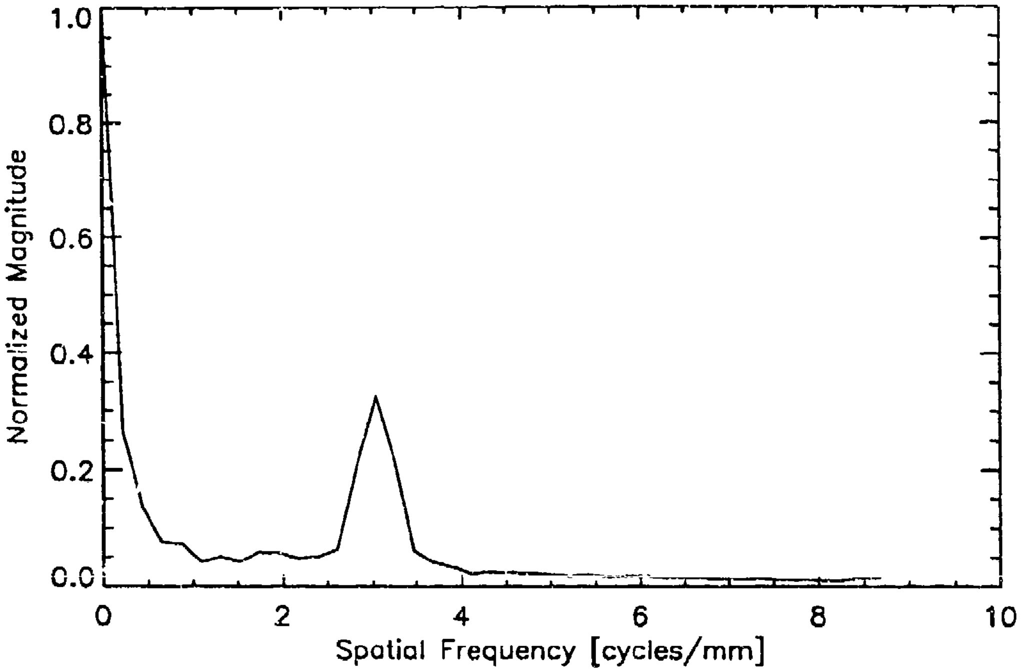


Figure 11. Average mean-subtracted |FFT| from Fig. 10 , normalized to 1 at dc.

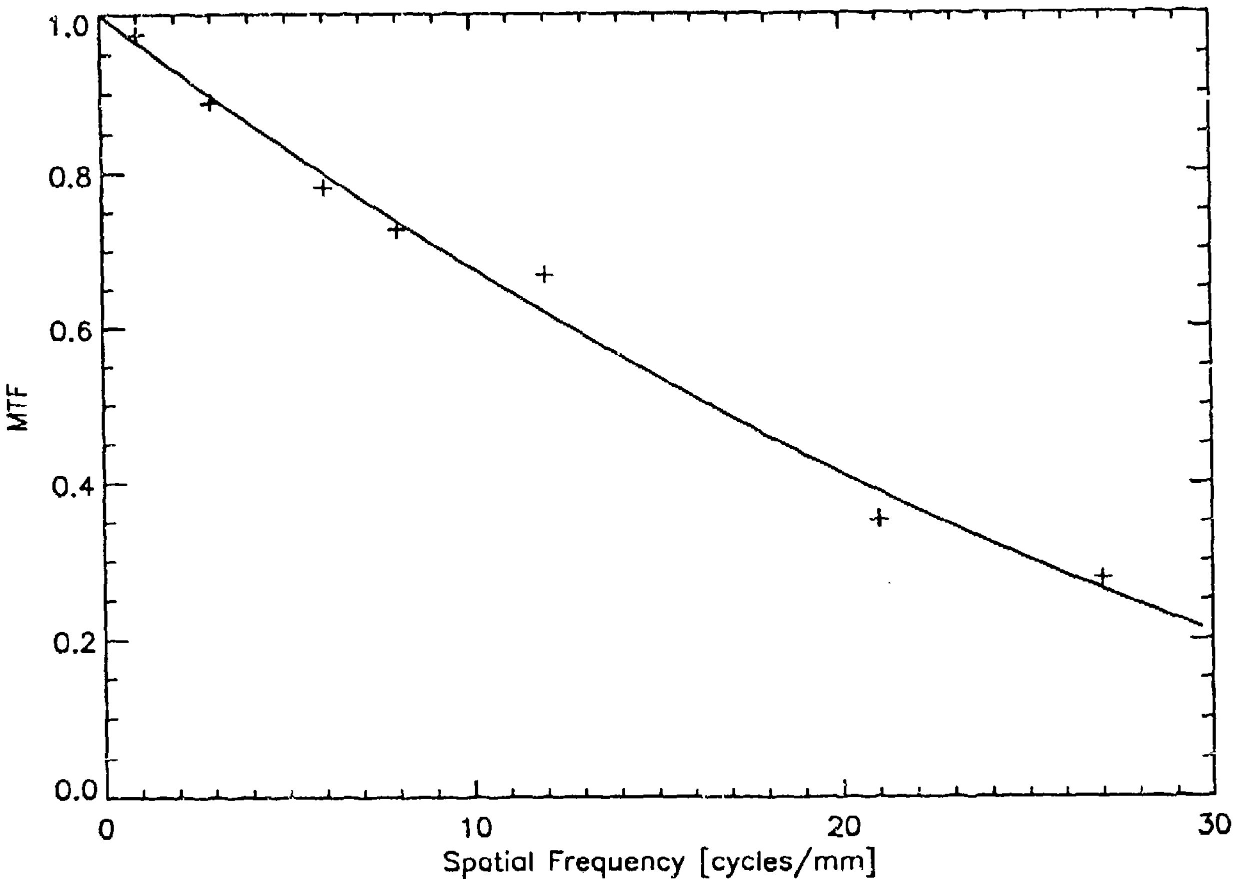


Figure 12. Measured MTF for the FPA tested.

Crosses are measured data, solid line is the second-order polynomial fit.

The speckle MTF measurement technique is applicable to both FPAs that are linear by design (e.g., the Sarnoff frame-transfer imagers), and to FPAs that are nonlinear by design (e.g., the Fairchild 1 × 1024 and the Fairchild 2D interline-transfer arrays). We have investigated[6] the behavior of the spatial-frequency content of laser speckle under thresholding operations, a severe type of nonlinearity. We found that the fundamental-frequency signature is preserved with only a few percent distortion under thresholding. Harmonic-distortion terms are introduced, but they are at higher frequencies than the test frequency and do not affect the MTF measurement. The nonlinearity that is designed into the imagers mentioned above is less abrupt by far than the thresholding, so the effect on the MTF measurement should be negligable. This should be true as long as the responsivity curve can be described as a single-valued mapping.

Also, (1D) arrays can be tested by the speckle MTF technique. The spectra that are calculated are inherently 1D, so no computational difference is involved in the FFTs. Because only a single data record is measured at a time, the averaging process that increases the signal-to-noise ratio for the spectra must be performed with new speckle patterns. While it is possible to physically move the array under test so that it sees an new speckle pattern, a more convenient method can be used that does not require moving parts. By pulsing the laser diode, a statistically independent speckle pattern is generated. Thus, a single 1D data record can be acquired, then the laser is pulsed before acquisition of each following data set until enough data records had been acquired to provide the desired amount of smoothing. We used 60 records in the example measurements above in the case of the 2D array. For 1D array measurements, fewer data records would be required to achieve the same signal-to-noise ratio because each data record is completely independent. For the 2D measurement, a degree of correlation exists between the data records because of the finite size of the speckles.

There are benefits to be gained from a real-time visualization of the data processing, rather than the more complete off-line analysis described above. A digitizing oscilloscope can be configured to acquire a specific line of video, perform the FFT and display the magnitude of the FFT in real time. This would provide for convenient bench-top diagnostics that would facilitate fine adjustment and optimization of the FPA operating parameters such as timing and voltages for the clock drivers. The display of |FFT| for a particular line of video would allow optimization of these parameters, with the strength of the frequency component a convenient figure of merit to quantify the imager performance. A test at a spatial frequency 2/3 to 3/4 of Nyquist should provide a useful diagnostic.

The equipment we recommend is the Tektronics TDS644A digitizing oscilloscope, with option 05 for video triggering. This instrument has sufficient bandwidth (500 MHz) and buffer size (2000 point) for the acquisition of waveforms from the FPAs. The oscilloscope will perform FFTs in real time on any particular line of video. The signal-to-noise ratio would not benefit from an average over the lines of video (not an option, without going to an external computer control, at which point it is not real-time anymore), but should be valuable for laboratory diagnostics. The oscilloscope would be useful for other experimental uses as well. We include manufacturer's information on the digitizing oscilloscope as an appendix.

Physical Layout of the Measurement System

The layout of the system schematically described in Fig. 1 is seen in Fig. 13. The item numbers in Fig. 13 refer to the parts list in the following section. The aperture-to-focal-plane distance (z) of Eq.(3) will determine the spatial frequency of the test. Figure 14 is a nomograph for conversion of distance to spatial frequencies, consistent with Eq.(3).

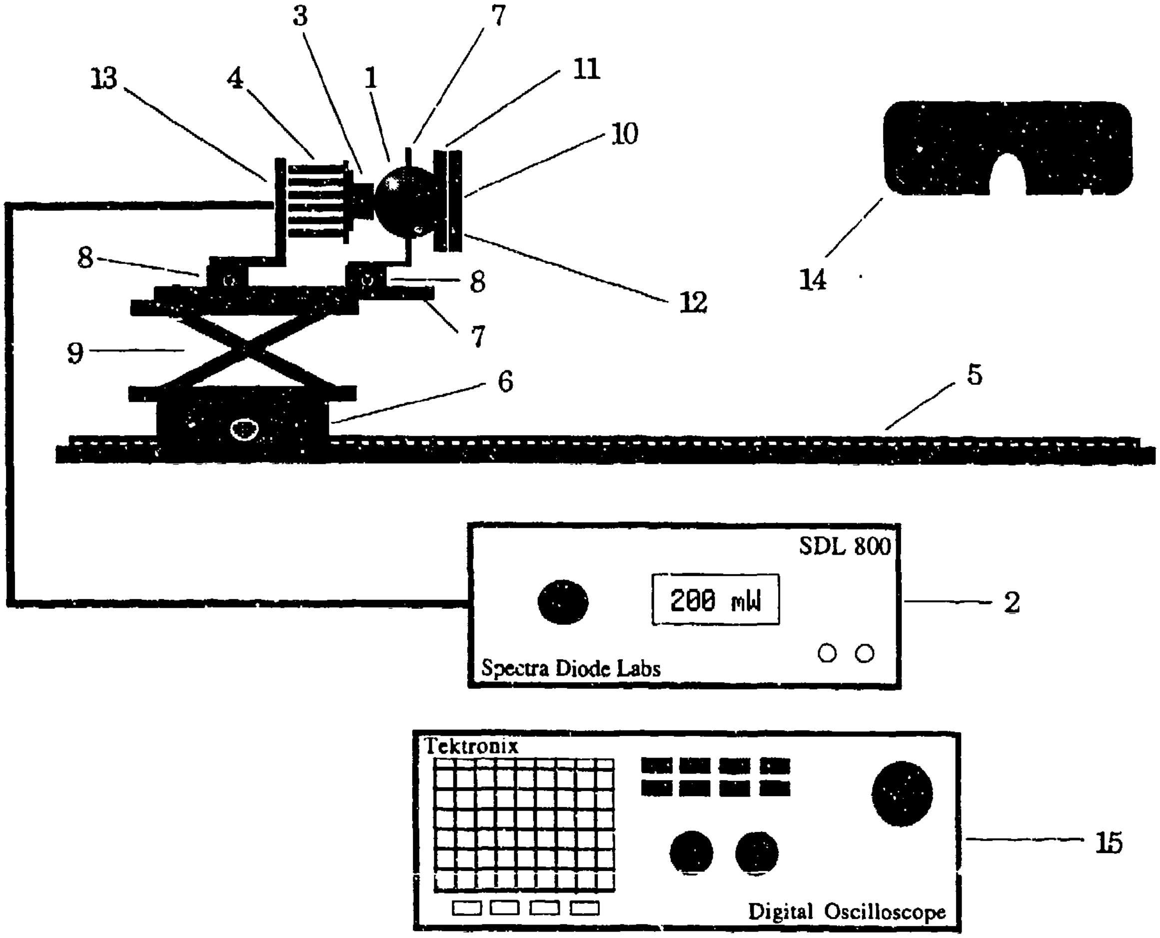


Figure 13. Physical layout of the measurement system.

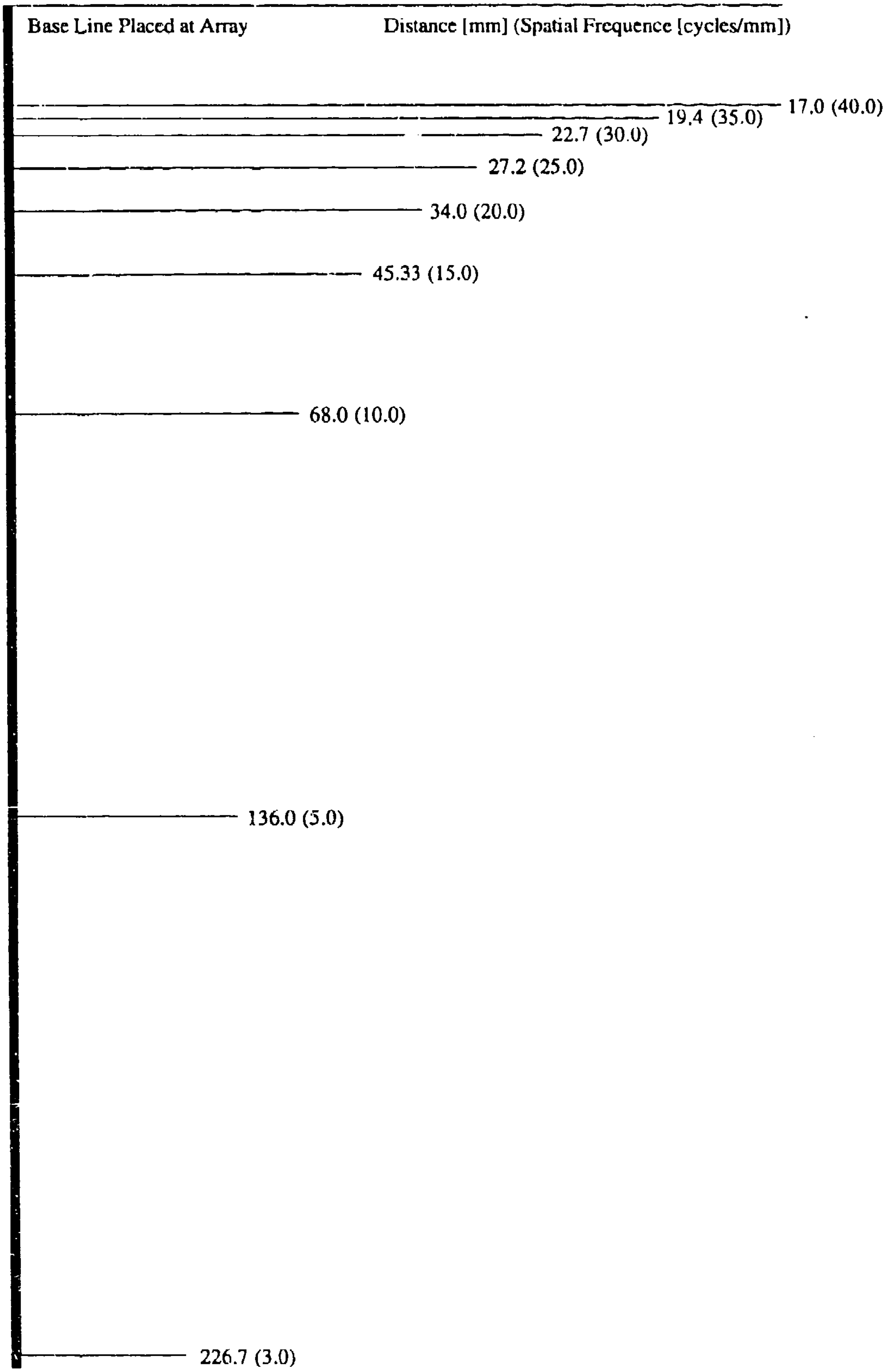


Figure 14. Nomograph for conversion of distance to spatial frequency, consistent with Eq. (3).

List of Materials, Equipment, and Instrumentation

A complete list of parts is given below, including manufacturer, part number, and price. The item numbers refer to the diagram seen in Fig. 13. Mechanical drawings for custom-fabricated parts are included as Figs. 15 - 17.

Item	Description/part number	Price ($)
1.	2.54-cm-diameter integrating sphere with 4-mm-diameter input and ouput port, and baffle mounting L-bracket included, interior coating is Spectralon® Mfg: Labsphere	500
2.	SDL-5430-A1 laser diode 200 mW , $\lambda = 830$ nm Mfg: Spectra Diode Labs	1,880
3.	SDL-800 laser diode driver Mfg: Spectra Diode Labs	1,950
4.	SDL-801-H heat sink Mfg: Spectra Diode Labs	25
5.	PRL-24 optical rail, 24" Mfg: Newport	281

6.	PRC-3 rail carrier, 3.5"	78
	Mfg: Newport	
7.	MRL-6 micro rail, 6"	38
	Mfg: Newport	
8.	MCF micro carrier - flat	40
	Two required	40
	Mfg: Newport	
9.	#270 lab jack	530
	Mfg: Newport	
10.	#05P108AR.16 polarizer, 1/2" diam	457
	Usable range: 740-860 nm	
	Mfg: Newport	
11.	Double-slit aperture (custom fab - drawing in Fig. 15)	300
	Mfg: Texas Laserworks	
12.	Aperture/polarizer holder assembly	n/a
	(custom fab - drawing in Fig. 16)	
	Material: anodized aluminum, rubber spacer, screws	
	Mfg: machine shop	

13.	Heat sink assembly (custom fab - drawing in Fig. 17)	n/a
	Material: anodized aluminum	
	Mfg: machine shop	
14.	LGS-NDGA laser goggle, each	318
	One required for each person using instrument simultaneously	
	Mfg: Fred Reed Optical	
15.	TDS 644A digitizing oscilloscope (optional)	19,895
	Option 05 - video trigger	1,495
	Mfg: Tektronics	

Manufacturer List

Labsphere
PO Box 70
North Sutton, NH 03260
(603) 927-4266

Spectra Diode Labs
80 Rose Orchard Way
San Jose, CA 95134
(408) 943-9411

Newport Corp.
1791 Deere Ave.
Irvine, CA 92714
(714) 863-3144

Texas Laserworks
PO Box 154875
Waco, TX 76714
(800) 328-5390

Fred Reed Optical
PO Box 27010
Albuquerque, NM 87125
(805) 265-3631

Tektronix
PO Box 4600
Beaverton, OR 97076
(800) 426-2200

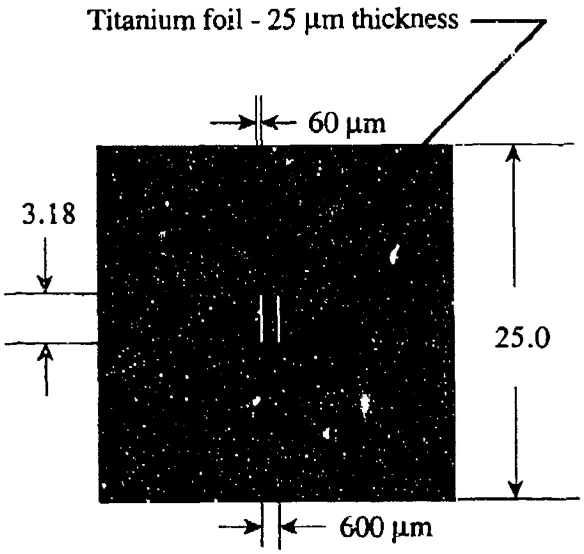


Figure 15. Custom fabrication drawing for item #11, two-slit aperture. Dimensions are in mm, unless otherwise noted.

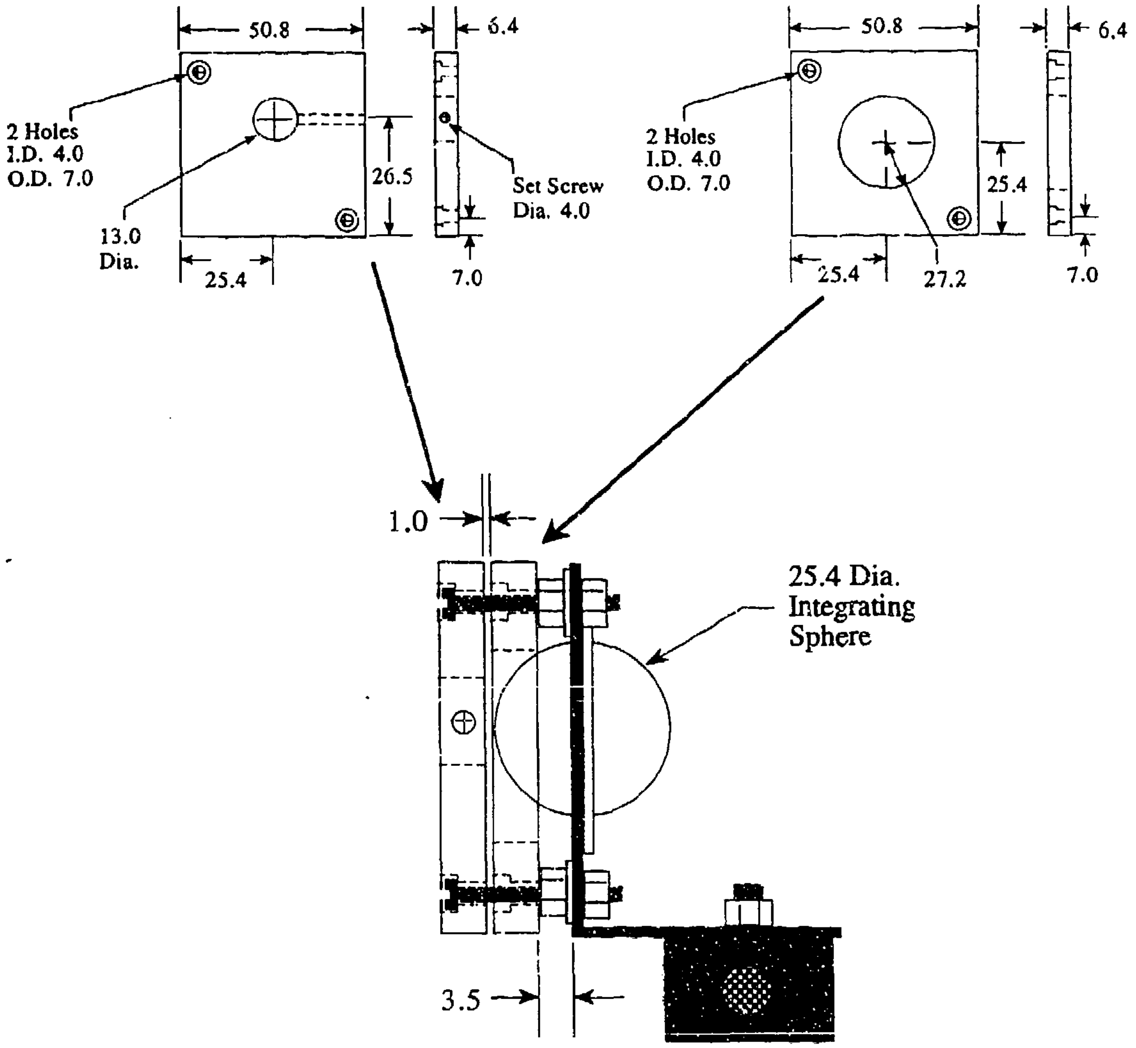


Figure 16. Custom fabrication drawings for item #12, aperture/polarizer holder assembly. Aperture (item # 11) is mounted between the plates, with a 1-mm rubber sheet as a cushion. Dimensions are in mm, unless otherwise noted.

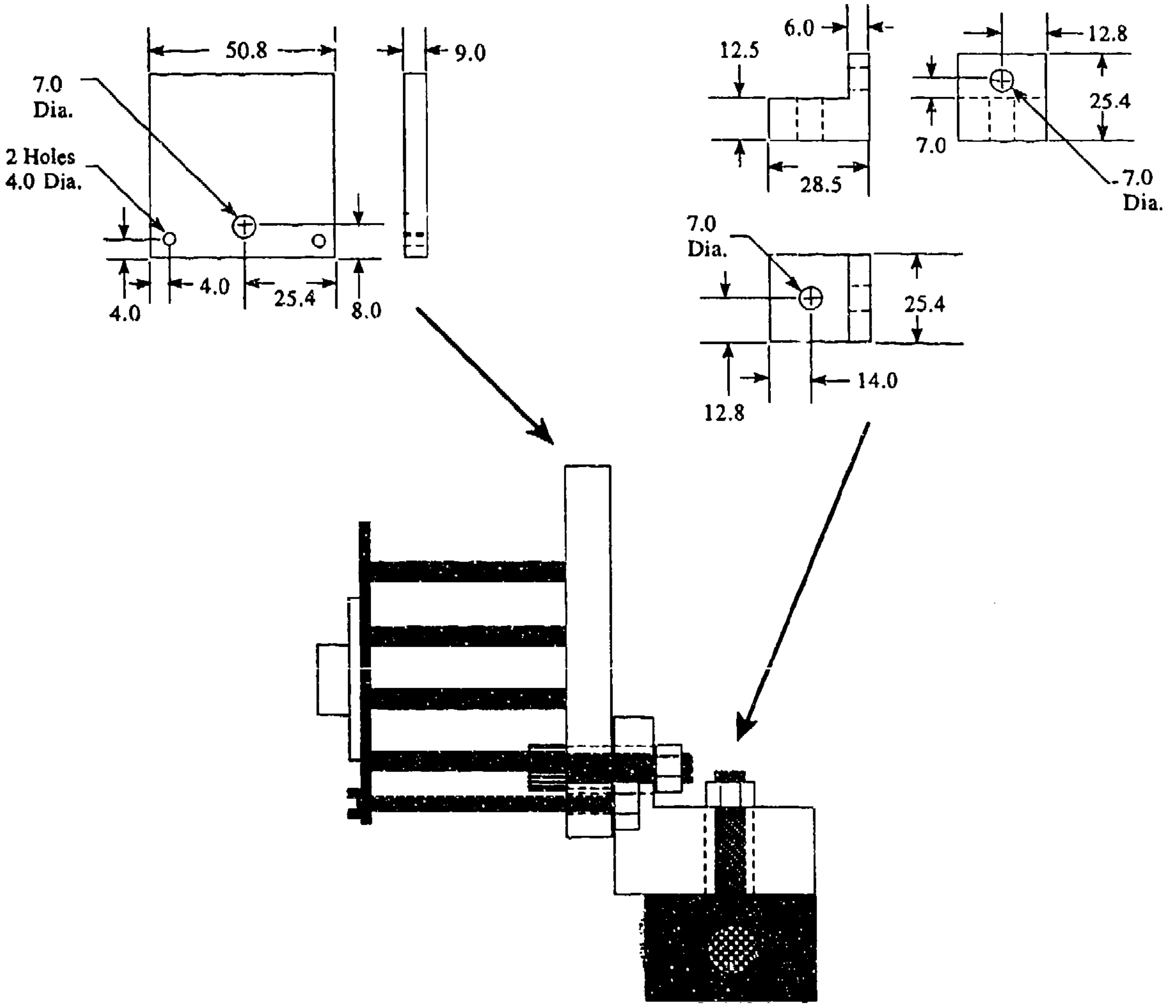


Figure 17. Custom fabrication drawings for item #13, heat sink assembly.

Dimensions are in mm, unless otherwise noted.

Conclusions

A method for measuring the MTF of focal-plane arrays has been developed and successfully demonstrated that uses the statistical properties of laser speckle as a test target of variable spatial frequency. This measurement procedure does not require critical alignment, and is applicable to both 1D and 2D FPAs, and is robust to nonlinearities in the sensors. The computations associated with the MTF measurement are usually performed offline on a small computer, but they can also be performed with a digitizing oscilloscope for real-time diagnostics.

Complete layout and parts list have been provided in order to facilitate the construction of this test equipment.

References

1. G. D. Boreman and E. L. Dereniak, "Method for measuring MTF of CCDs using laser speckle," Optical Engineering **24**, 148-150 (1986).

2. G. D. Boreman, Y. K. Sun, and A. B. James, "Generation of laser speckle with an integrating sphere," Optical Engineering **29**, 339-342 (1990).

3. M. Sensiper, G. Boreman, A. Ducharme, and D. Snyder, "Modulation transfer function testing of detector arrays using narrow-band laser speckle," Optical Engineering **32**, 395-400 (1993).

4. J. W. Goodman, in *Laser Speckle and Related Phenomena*, J. C. Dainty, ed., Springer-Verlag, 1984, pp. 35-40.

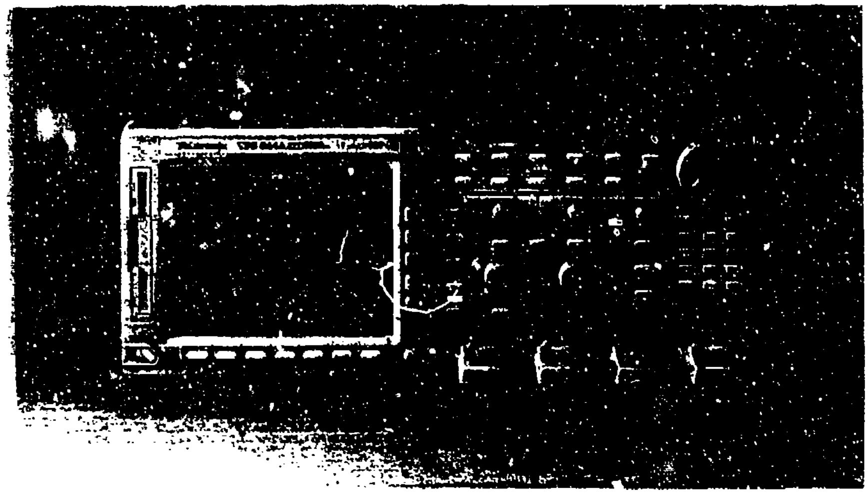
5. J. S. Bendat and A. G. Piersol, *Random Data: Analysis and Measurement Procedures*, Wiley-Interscience, 1971, pp.189-193.

6. A. Ducharme, G. Boreman, and D. Snyder, "Effects of intensity thresholding on the power spectrum of laser speckle," Applied Optics **33**, 2715-2720 (1994).

Appendix - Digitizing Oscilloscope Manfacturer's Information

Tektronix

TDS 500 Series
TDS 600 Series
Digitizing Oscilloscopes



2 GS/s sampling on four channels with the TDS 644A and TDS 640 combined with powerful logic, runt and pulse width triggering make them ideal for design and debug of today's higher speed digital systems. The TDS 544A and TDS 540 offer 1 GS/s on a single channel, record lengths to 50,000 points, the same powerful triggering as the TDS 644A and TDS 640 and a unique HiRes mode for single shot acquisition with up to 12 bits of resolution. The TDS 644A and TDS 544A have a high-resolution color monitor and 3.5" floppy disk drive standard as well as a powerful video trigger option.

The TDS 520, 540, 544A, 620, 640, and 644A represent a new generation of digitizing oscilloscopes, designed to keep pace with current and evolving needs in advanced design. They are also powerful tools for manufacturing test, R&D, and telecommunications applications.

Like the other members of the TDS Series, TDS 500 and TDS 600 digitizing oscilloscopes offer significant advantages over other instruments in four major areas:

High-fidelity acquisitions. In addition to their high sample rates, 1 GS/s and 2 GS/s, TDS 500 and TDS 600 Digitizing Oscilloscopes provide wide dynamic range, flat response, 8-bit vertical resolution, fast overdrive recovery, calibrated DC offset, 1 mV/division sensitivity and internal self-calibration. 2 GS/s sampling in the TDS 600 provides a full 500 MHz of real time bandwidth. The TDS 544A improves acquisition memory efficiency with its Fastframe™ segmentable memory.

Powerful and flexible triggering. TDS 500 and TDS 600 scopes help debug digital designs quickly with 10 extended triggering functions, including pulse width, four-input logic state and pattern, glitch and runt. Icons illustrate functions to facilitate learning and operation. A powerful video trigger option is available on the TDS 644A and TDS 544A which provides individual field and line triggering on all popular formats including HDTV.

Multiprocessor architecture. A Motorola 68020, Tek TriStar™ digital signal processor, and a powerful proprietary display processor combine to provide the power for waveform math, high-speed averaging, automatic limit testing, live measurements and variable persistence display.

Affordable performance that is easy to use. Extensive user interface design and testing has led to a truly intuitive line of instrumentation. A familiar front panel layout with dedicated vertical, horizontal and trigger controls, and a graphical user interface with icons help users easily grasp the operating details. A color monitor on the TDS 544A and TDS 644A enables the user to rapidly distinguish multiple waveforms and measurements. On-line help provides a convenient built-in reference manual.

500 MHz bandwidth

Sample rates to 2 GS/s on four channels

2 and 4 input channels

Pulse width, 2 ns glitch, runt, pattern and state triggering

1 mV/div – 10 V/div sensitivity

Infinite and variable persistence

Record lengths to 50,000 points per channel

8-bit vertical resolution and up to 12 bits with HiRes

High resolution color monitor

3.5" DOS floppy disk drive

Color Grading

Vertical accuracy to 1%

Tek TriStar™ (DSP) processor for fast waveform processing and live measurement updates

Advanced signal processing functions

Waveform pass/fail testing

25 automatic measurements

Full GPIB programmability

Desktop publishing outputs

3 year warranty

HDTV Video trigger option

Segmentable acquisition memory

Unique and advanced performance features include:

Limit testing. Compares waveforms against a template "on-the-fly", stopping acquisition or automatically saving the waveform whenever it violates the template. The TDS 644A and TDS 544A allow for template comparisons of math waveforms such as FFT. Templates can be easily created on-board by specifying waveform tolerances or down-loaded over the GPIB and saved in non-volatile waveform memories or on floppy disk.

Color graded variable persistence. The TDS 544A and TDS 644A provide historical information by color grading samples as they are acquired over time. TDS520/540/620/640 have intensity graded variable persistence for displaying signal changes.

Twenty five automatic measurements. Eliminate the need for division counting and manual cursor setup measurements. Icons in the measurement menu clearly illustrate what each measurement does. In addition, measurement "gating" allows the user to select a specific part of a waveform for measurement. Live measurements make it easy to see the effects of changing circuit conditions.

TEKPROBE™ interface. Provides flexible probing solutions including the P6205 high bandwidth active probe. The TDS 500/600 with the P6205 reduces adverse loading effects with 1 MΩ input impedance and less than 2 picofarads of capacitance. What you see is really what is there. The P6205 comes standard with the TDS 600 Series and optionally with the TDS 500 Series.

Advanced signal processing. TDS 500/600 waveform analysis can be extended through the addition of live FFT analysis, waveform integration, and differentiation.

TDS 500 Series TDS 600 Series Electrical Characteristics

	TDS 520/620	TDS 540/640/544A/644A
Channels	2 + 2 auxiliary	4
Samplers	2	4
Bandwidth[1]	500 MHz[2]	500 MHz[2]
Sensitivity		
CH 1, CH 2	1 mV to 10 V/div	1 mV to 10 V/div
CH 3, CH 4	NA	1 mV to 10 V/div
AUX 1, AUX 2 (TDS 520)	100 mV, 1.0 V, 10 V/div	NA
AUX 1, AUX 2 (TDS 620)	1 mV to 10 V/div	NA
Position Range	± 5 Divisions	± 5 Divisions
Offset		
CH 1, CH 2 AUX 1, AUX 2 (TDS 620)	±1 V from 1 to 99.5 mV/div ±10 V from 100 mV to 995 mV/div ±100 V from 1 to 10 V/div	±1 V from 1 to 99.5 mV/div ±10 V from 100 mV to 995 mV/div ±100 V from 1 to 10 V/div
CH 3, CH 4	NA	±1 V from 1 to 99.5 mV/div
AUX 1, AUX 2 (TDS 520)	100 mV/div ±5 V 1 V/div ±5.0 V 10 V/div ±50 V	NA

Maximum Sample Rate

	TDS 520	TDS 540/544A	TDS 620	TDS 640/644A
One Channel	500 MS/s	1 GS/s	2 GS/s	2 GS/s
Two Channels	250 MS/s	500 MS/s	2 GS/s	2 GS/s
Four Channels	NA	250 MS/s	NA	2 GS/s

Vertical System

DC Gain Accuracy – TDS 500 ±1.0%, TDS 600 ±1.5%.

Vertical Resolution – 8 bits (256 levels over 10.24 vertical divisions).

Analog Bandwidth Selections – 20 MHz, 100 MHz, and full (Except Aux 1 and Aux 2 on TDS 520 are full BW only).

Input Coupling – ac, dc or GND.

Input Impedance Selections – 1 MΩ in parallel with 10 pF, or 50 Ω (ac and dc coupling).

Maximum Input Voltage – ±400 V (dc + peak ac). Derate at 20 dB/decade above 1 MHz. 1 MΩ or GND coupled.

Channel Isolation – ≥100:1 at 100 MHz and ≥30:1 at bandwidth for any two channels having equal Volts/div settings.

AC Coupled Low Frequency Limit – ≤10 Hz when ac 1 MΩ coupled. ≤200 kHz when ac 50 Ω coupled.

Acquisition Modes

Peak Detect (TDS 520/540/544A only) – High frequency and random glitch capture. Captures glitches of 4 ns using acquisition hardware at all real-time sampling rates.

Sample – Sample data only.

Envelope – Max/min values acquired over one or more acquisitions.

Average – Waveform averages selectable from 2 to 10,000.

Hi-Res (TDS 520/540/544A only) – Vertical resolution improvement and noise reduction on low-frequency signals, e.g. 12 bits at 50 µs/div and slower.

FastFrame™ (TDS 544A only) – Acquisition memory size segmentable with trigger rate up to 50,000 per second from 50 to 5,000 points per frame (independent of the number of channels).

---

[1] Reduce the upper bandwidth frequencies by 2.5 MHz for each °C above 30°C.
[2] 1 mV/div: 250 MHz, 2 mV/div: 350 MHz

Electrical Characteristics (continued)

Time Base System

	TDS 520/540/544A	TDS 620/640/644A
Time Bases	Main, Delayed.	
Time/Division Range	500 ps to 10 s/div	500 ps to 5 s/div.
Time Base Accuracy	±25 ppm over any interval ≥ 1 ms	±100 ppm over any interval ≥ 1 ms
Record Length	500 to 15000 pts. (50K pts. optional)	500 to 2000 pts.
Pre-Trigger Position	0 to 100% of record	20% to 80% of record

Trigger Types

EDGE **(main and delayed)**	Conventional level driven trigger. Positive or negative slope on any channel or rear panel auxiliary input (Except TDS 520). Coupling Selections: dc, ac, noise reject, HF reject, LF reject.
PULSE (main)	
WIDTH	Trigger on width of positive or negative pulse either within or not within selectable time limits. Time limits settable from 2 ns to 1 s.
GLITCH	Trigger on or reject glitches of positive, negative or either polarity. Minimum glitch width threshold is 2.0 ns, with 200 ps resolution.
RUNT	Trigger on a pulse that crosses one threshold but fails to cross a second threshold before crossing the first again.
LOGIC (main)	
PATTERN	Specifies a logical combination (AND, OR, NAND, NOR) of the four input channels (Hi, Lo, Don't Care). Trigger when pattern stays True or False for user specified time.
STATE	Any logical pattern of channels 1,2 and 3 (AUX1 on TDS 520/620) plus clock edge on channel 4 (AUX2 on TDS 520/620). Triggerable on positive or negative clock edge.
Video (TDS 644A and TDS 544A option)	
NTSE **PAL** **HDTV** **FlexFormat™**	Trigger on a particular line of individual, odd/even, or all fields. Trigger on a specific pixel of a line by using video trigger with delay by events. Choose horizontal sync polarity. Choose from popular HDTV formats (1125/60, 1050/60 1250/50, 781.5/60) or use FlexFormat™ for other HDTV-type formats by defining frame rep rate, number of lines and fields, and sync timing structure.

Triggering System

Triggers – Main, Delayed.

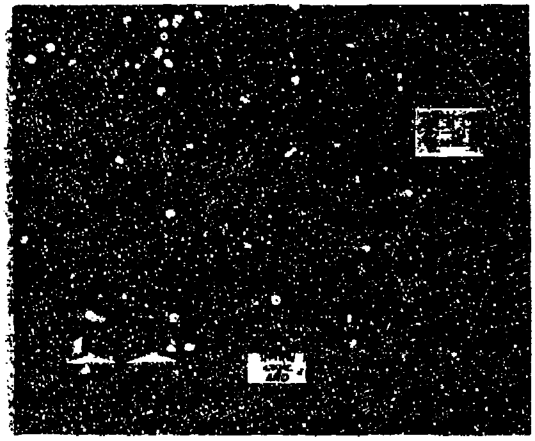
Main Trigger Modes – Auto, Normal, Single.

Delayed Trigger – Delayed by time, events, or events and time.

Time Delay Range – 16 ns to 250 s.

Events Delay Range – 1 to 9,999,999 events.

External Rear Input – (except TDS 520) ≥1.5 kΩ; Max input voltage is ±20 V (dc + ac peak).



Pulse and logic triggering in the TDS 500 and 600 help quickly isolate fault conditions in high speed digital systems. The TDS 644A/544A color monitor makes complex displays easy to read.

Display

Waveform Style – Dots, vectors, variable persistence selectable from 250 ms to 10 S, infinite persistence, and intensified samples.

Color – Standard palettes and user definable colors for waveforms, text, graticules, and cursors. Measurement text and cursor colors matched to waveform. Waveform collision areas highlighted with different color. Statistical waveform distribution shown with color grading through variable persistence.

Color Grading (TDS 644A/544A only) – With variable persistence selected, historical timing information is represented by temperature or spectral color scheme providing "z-axis" information about rapidly changing waveforms.

Gray Scaling (TDS 520/540/620/640) – With variable persistence selected, waveform points time-decay through 16 levels of intensity.

Update Rate – For 500 point waveforms with infinite persistence mode selected: 130/sec (TDS 500); 100/sec (TDS 600) typically.

Graticules – Full, grid, cross hair, frame. NTSC and PAL with video trigger option.

Format – YT and XY.

Fit to Screen – Entire acquisition memory displayed on screen.

Zoom

The zoom feature allows waveforms to be expanded or compressed in both vertical and horizontal axes. Allows precise comparison and study of fine waveform detail without affecting ongoing acquisitions. When used with Hi-Res or Average acquisition modes, Zoom provides an effective vertical dynamic range of 1000 divisions or 100 screens.

Measurement System

Automatic waveform measurements –

Period	Frequency
High	Low
+ Width	– Width
Maximum	Minimum
Rise	Fall
Peak to Peak	Amplitude
+ Duty cycle	– Duty cycle
+ Overshoot	– Overshoot
Propagation delay	Burst Width
Mean	Cycle Mean
RMS	Cycle RMS
Area	Cycle Area
Phase	

Continuous update of up to four measurements on any combination of waveforms.

Thresholds – Settable in percentage or voltage.

Gated – Any region of the record may be isolated for measurement using vertical bars.

Snapshot – Performs all measurements on any one waveform showing results from one instant in time.

Cursor Measurements – Absolute, Delta; Volts, Time, Frequency, NTSC IRE and Line Number with video trigger option.

Cursor Types – Horizontal bars (volts); Vertical bars (time); operated independently or in tracking mode.

Waveform Processing

Waveform Functions – Interpolate-selectable sin(x)/x or linear, Average, Envelope.

Advanced Waveform Functions – FFT, Integration, Differentiation.

Arithmetic Operators – Add, Subtract, Multiply, Divide, Invert.

Autosetup – Single button, automatic setup on selected input signal for vertical, horizontal and trigger systems.

Waveform Limit Testing – Compares incoming or math waveform to a reference waveform's upper and lower limits.

Computer Interface

GPIB (IEEE-488.2) Programmability – Full talk/listen modes. Control of all modes, settings, and measurements.

Hardcopy

Printer – HPThinkjet, Epson, PostScript, Interleaf, Deskjet, Laserjet, color PostScript, TIFF, PCX, BMP (Microsoft Windows), DPU 411/412, PCX color, RLE color.

Plotter – HPGL.

Interface – GPIB standard.

Hardcopy Interface (Standard on TDS 544A/644A, optional on TDS 520/540/620/640) – Centronics and RS-232.

Storage

Waveforms – (TDS 520/540/544A) 4 full 15,000 point records (50 K with option). (TDS 620/640/644A) 4 full 2000 point waveforms

Setups – 10 front panel setups.

Floppy Drive (TDS 644A/544A only) – Store reference waveforms, setups, and image files on 3.5" 1.44 MByte or 720 KByte DOS format floppy disk.

CRT

Type (TDS 520/540/620/640) – 7 in. diagonal, magnetic deflection. Horizontal raster-scan. P4 White phosphor.

Type (TDS 644A/544A) – 7 in. diagonal, NuColor™ liquid crystal full color shutter display, 256 color levels.

Resolution – 640 horizontal by 480 vertical displayed pixels (VGA).

Power Requirements

Line Voltage Range – 90 to 250 V RMS.

Line Frequency – 47 to 63 Hz.

Power Consumption – 300 Watts max.

Environmental and Safety

Temperature – Operating: 0 to +50°C. Nonoperating: –40 to +75°C (with floppy drive +4 to +50°C).

Humidity – Operating and nonoperating: Up to 95% relative humidity at or below +40°C; to 75% relative humidity from +41 to +50°C (with floppy drive: operating to 80% at or below 29°C, to 20% from +30°C to +50°C.

Non-operating to 90% at or below 41°C, to 5% from +41°C to 50°C.)

Altitude – Operating: 15,000 ft., Nonoperating: 40,000 ft.

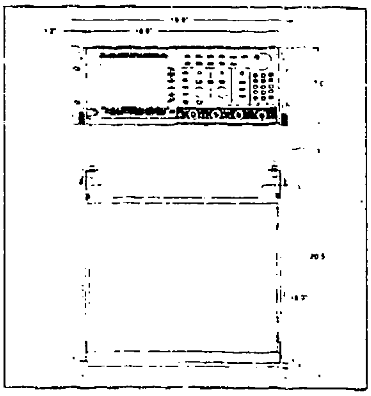
Electromagnetic Compatibility – Meets MIL-STD-461C, CE-03, Part 4, Curve #1, meets VDE 0871, Category B, FCC rules and regulations, Part 15, Subpart J, Class A.

Safety – Listed UL 1244; CSA – C22 No. 23; Tektronix self-certification to comply with IEC 348 recommendations.

Physical Characteristics

Weight – Net: Approximately 12.3 kg (27 lb). Shipping: Approximately 20.0 kg (44 lb).

Dimensions – Height: 236 mm (9.3 in.) with feet; 193 mm (7.6 in.) without feet. Width: 445 mm (17.5 in.) with handle. Depth: 432 mm (17.0 in) with front cover installed.



Ordering Information

TDS 500
TDS 600
Digitizing
Oscilloscopes

TDS 520/540/544A Standard Accessories

- ☐ 2 ea P6139A Probes (TDS 520)
- ☐ 4 ea P6139A Probes (TDS 540/544A)
- ☐ Reference (070-8316-01)
- ☐ User Manual (070-8317-01)
- ☐ Programmer Manual (070-8318-04)
- ☐ Front Cover (200-3696-00)
- ☐ U.S. Power Cord (161-0230-01)

TDS 620/640/644A Standard Accessories

- ☐ 2 ea P6205 FET Probes (TDS 620)
- ☐ 4 ea P6205 FET Probes (TDS 640/644A)
- ☐ Reference (070-8505-01)
- ☐ User Manual (070-8506-01)
- ☐ Programmer Manual (070-8318-04)
- ☐ Front Cover (200-3696-00)
- ☐ U.S. Power Cord (161-0230-01)

Instrument Options

- ☐ **Option 05 (TDS 644A/544A only)** – Add Video Trigger; NTSC, PAL, HDTV, FlexFormat™
- ☐ **Option 1K** – K218 scope cart without power strip
- ☐ **Option 1M (TDS 520/540/544A only)** – 50K Memory Length
- ☐ **Option 1P** – HC100 4 pen plotter
- ☐ **Option 2P** – Tektronix Phaser 200e thermal wax transfer color printer
- ☐ **Option 1R** – Rack Mount
- ☐ **Option 2D (TDS 620 only)** – Delete 2 ea P6205 active probes
- ☐ **Option 2F** – Extended waveform math; FFT, Integration, Differentiation
- ☐ **Option 4D (TDS 640/644A only)** – Delete 4 ea P6205 active probes
- ☐ **Option 13 (TDS 520/540/620/640 only)** – Add RS-232C and Centronics hardcopy interfaces.
- ☐ **Option 9C** – NIST and MIL-STD-45662A Calibration Certificate
- ☐ **Option 22 (TDS 520 only)** – Two additional P6139A Probes
- ☐ **Option 23 (all except TDS 640/644A)** – Add 2 ea P6205 active probes
- ☐ **Option 24 (TDS 620/640/644A only)** – Add 4 ea P6139A probes
- ☐ **Option 29 (TDS 520/540/620/640 only)** – TD100 Data Manager
- ☐ **Option B1** – Service Manual
- ☐ **Option M2** – Extends warranty coverage through the first five years of product ownership
- ☐ **Option M3** – Extends warranty coverage through the first five years of product ownership and provides 4 ea calibrations; one each in years two, three, four, and five.
- ☐ **Option M8** – Provides 4 ea calibrations; one each in years two, three, four, and five.

Probes

- ☐ **P6139A** – Passive Probe
- ☐ **P6205** – FET Probe
- ☐ **P6408** – TTL Logic Probe
- ☐ **P6711** – 500 nm to 950 nm optical converter
- ☐ **P6713** – 1100 nm to 1700 nm optical converter
- ☐ **P6009A** – High Voltage Probe
- ☐ **AM 503S** – DC/AC Current Probe System*

Recommended Accessories

- ☐ Service Manual 070-8312-01 (TDS 520); 070-8314-01 (TDS 540); 070-8507-01 (TDS 620); 070-8508-01 (TDS 640); 070-8713-00 (TDS 544A); 070-8718-00 (TDS 644A)
- ☐ Tektronix Phaser 200e Color Printer
- ☐ K218 Scope Cart
- ☐ TVC 501 Time Interval to Voltage Converter (requires TM 500/5000 mainframe)
- ☐ C-9 Scope Camera
- ☐ C-9 Hood Adaptor (016-1145-00)
- ☐ Security Cable (012-1388-00)
- ☐ Soft-sided Carrying Case (016-0909-01)
- ☐ Transit Case (016-1135-00)

Software

- ☐ **S45F030** – EZ TEST Program Generator
- ☐ **S3FT400** – WaveWriter; AWG and waveform creation
- ☐ **S3FT001** – Tek TMS; Test Management System
- ☐ **S3FG910** – Labwindows

Cables

- ☐ RS232 (012-1298-00)
- ☐ Centronix (012-1250-00)
- ☐ GPIB (1 meter) (012-0991-01)
- ☐ GPIB (2 meters) (012-0991-00)

International Power Options

- ☐ **Option A1** – Universal Euro, 220 V, 50 Hz
- ☐ **Option A2** – UK 240 V, 50 Hz
- ☐ **Option A3** – Australian 240 V, 50 Hz
- ☐ **Option A4** – North American 240 V, 60 Hz
- ☐ **Option A5** – Switzerland 220 V, 50 Hz

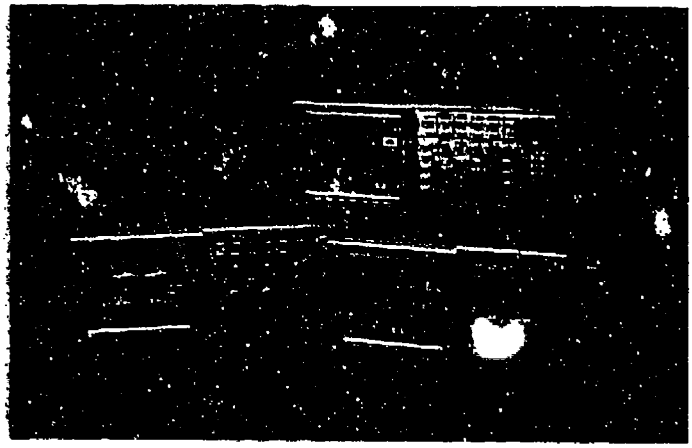
*International power options required on instruments and selected accessories for operation outside U.S

Warranty Information

Three years warranty, covering all labor and parts, including CRT, and excluding probes.

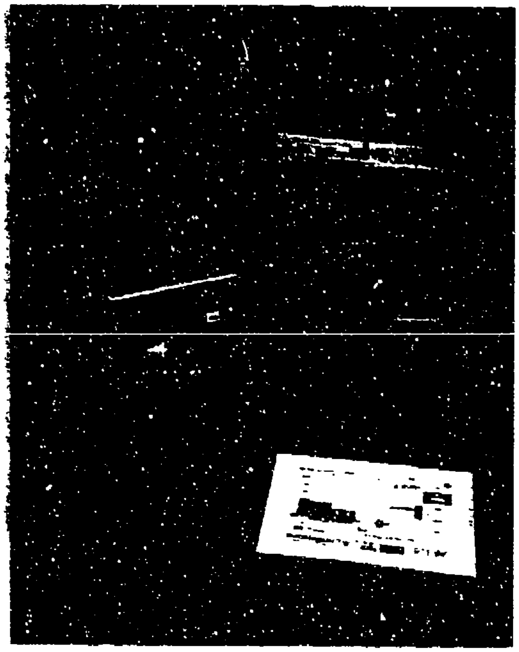
DAVE JACKSON
660-2727

The TDS Family of Digitizing Oscilloscopes



In addition to the TDS 500 and TDS 600 Series, the Tektronix TDS family of digitizing oscilloscopes includes the:

- TDS 400 Series with four channels at 100 MS/s and 150 MHz to 350 MHz bandwidth for electronic and electro-mechanical design applications.
- TDS 820 with 8 GHz bandwidth and 0.4 ps timing resolution for cost effective device characterization and telecommunciations installation and manufacturing applications.



Choose from a broad selection of accessories including the Tektronix Phaser 200e color printer

For further information, contact:

U.S.A., Africa, Asia, Australia, Central & South America, Japan
Tektronix, Inc.
P.O. Box 500
Beaverton, Oregon 97077-0001
For additional literature, or the address and phone number of the Tektronix Sales Office or Representative nearest you, contact: (800) 426-2200

Belgium: Brussels
Phone: 32(2) 725 96 10
FAX: 32(2) 725 99 53

Canada: Barrie
Phone: (705) 737-2700
FAX: (705) 737-5588

Denmark: Copenhagen
Phone: 45 44 53 54 55
FAX: 45 44 53 07 55

Eastern Europe, Middle East, and Austria
Tektronix Ges.m.b.H.
Doerenkampgasse 7
A-1100 Vienna, Austria
Phone: 43(222) 68-66-02-0
FAX: 43(222) 68-66-00

Finland: Helsinki
Phone: 358(0) 7282 400
FAX: 358(0) 7520033

France and North Africa
Tektronix S.A.
ZAC Courtaboeuf, 4 Av du Canada
B P 13
91941 Les Ulis Cedex, France
Phone: 33(1) 69 86 81 81
FAX: 33(1) 69 07 09 37

Germany: Koeln
Phone: 49 (221) 96969-0
FAX: 49 (221) 96969-362

Italy: Milan
Phone: 39(2) 84441
FAX: 39(2) 8950-0665

Japan: Tokyo
Phone: 81(3) 3448-4611
FAX: 81(3) 3444-0318

The Netherlands: Hoofddorp
Phone: 31(2503) 13300
FAX: 31(2503) 37271

Norway: Oslo
Phone: 47(2) 165050
FAX: 47(2) 165052

Spain: Madrid
Phone: 34 (1) 404.1011
FAX: 34 (1) 404.0997

Sweden: Stockholm
Phone: 46(8) 29 21 10
FAX: 46(8) 98 61 05

Switzerland: Zug
Phone: 41(42) 219192
FAX: 41(42) 217784

U.K.: Marlow
Phone: 44 (0628) 486000
FAX: 44 (0628) 47 4799

Tektronix sales and service offices around the world
Algeria,
Argentina
Australia,
Austria,
Bahrain,
Bangladesh,
Belgium,
Bolivia,
Brazil,
Bulgaria,
Canada,
Chile,
People's Republic of China,
Colombia,
Costa Rica,
Cyprus,
Czechoslovakia
Denmark
Ecuador,
Egypt,
Finland,
France
Germany,
Greece
Hong Kong,
Iceland,
India,
Indonesia,
Ireland,
Israel,
Italy,
Ivory Coast,
Japan,
Jordan,
Korea
Kuwait,
Lebanon
Malaysia,
Mexico,
The Netherlands
New Zealand
Nigeria,
Norway
Oman
Pakistan
Panama,
Peru
Philippines
Poland
Portugal
Saudi Arabia
South Africa
Singapor
Spain
Sri Lanka
Sweden,
Switzerland
Taiwan
Thailand
Tunisia,
Turkey
United Arab Emirates
United Kingdom
Uruguay
Venezuela
Zimbabwe

1/93 TG 25M 55W-8862-0

Tektronix