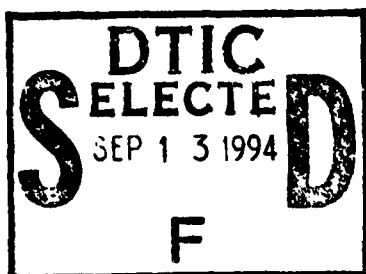AD-A284 237

MEASUREMENTS OF OPTICAL TRANSFER FUNCTION

OF DISCRETELY SAMPLED THERMAL IMAGING SYSTEMS

Stanley J. Pruchnic, Jr.,and
Gregory P. Mayott

E-OIR Measurements, Inc.

Paul A. Bell,

U. S. Army Night Vision and Electro-Optics Directorate
Communications-Electronics Command, Fort Belvoir, VA 22060-5677

ABSTRACT

Measurement of the Optical Transfer Function (OTF) of discretely sampled thermal imaging systems, e.g. parallel scanned FLIR systems, on which analysis is done in the cross scan direction, and staring focal plane arrays, is increasingly important as digital image acquisition device technology for the 3-5 and 8-12 micron (infrared) spectral regions is maturing. The traditional measurement methods used for continuous scan systems may not be valid for discretely sampled systems. This paper presents results of measurements of the OTF using a translating slit to obtain the Line Spread Function (LSF) for discretely sampled systems. Multiple frame acquisition is used for removal of temporal and fixed pattern noise. It is the intent of this laboratory effort to develop a measurement technique to be used when collecting OTF data for discretely sampled systems. The new measurement technique is potentially suitable for all systems, and if successful, will permit characterization of vertical system MTF. If this measurement method is found to be useful, it will be used to generate the OTF data used in the NVEOD FLIR92 model for further development and verification of the model.

94 9 09   006

94-29499

1. INTRODUCTION

Laboratory measurement of system Modulation Transfer Function (MTF) using a Line Spread Function (LSF) on thermal imagers with discretely sampled image planes offers a unique opportunity for optimizing the measurement effort using Night Vision Electro Optics Directorate (NVEOD) Image Evaluation Facility (IEF) laboratory measurement procedures. The IEF is recognized as the "National Bureau of Standards" for laboratory evaluation of infrared imaging sensors within the electro-optical community, and continues to press forward with new and innovative procedures for evaluating infrared sensors. As evidence of NVEOD's commitment to the electro-optics community, a new IEF facility, the Advanced Sensor Evaluation Facility (ASEF), has been commissioned to carry on the NVEOD tradition of excellence. This new facility incorporates one-of-a-kind collimating optics with the latest in image processing hardware to provide an exceptionally robust test bed for evaluation of second generation thermal imaging sensors[1].

It is the intent of this paper to evaluate different measurement techniques for the Optical Transfer Function (OTF) in a manner which will illustrate the advantages and disadvantages of each procedure in order to find a method or combination of methods which will accurately characterize the sensor system MTF before the display. Both procedures are based on the LSF method. The following is a comparison of a raster line sampling (RLS-LSF) procedure[2] using a stationary slit target and a moving slit (MS-LSF) procedure using slit target motion[3-6].

The RLS-LSF method has been used successfully in recent years to characterize the MTF for common module (scanning) sensors. Advanced second generation sensors may require modified test methods. These methods will be used to generate OTF data used in the NVEOD FLIR92 model[7].

2. EQUIPMENT

A staring focal plane array (FPA) thermal imager was used for the purpose of this test procedure[8]. The detector geometry and critical system specifications are given below. The MTF limits of the system are expected to be a function of either optical or detector characteristics. Test equipment required for LSF data acquisition includes a high precision accurate linear translation platform to provide slit target motion and a high bandwidth digitizing oscilloscope. Specifications for each of these as well as additional hardware follows:

Thermal Imager :

```
            512 X 512 pixel staring focal plane array
            Horizontal FOV  :    61.08  mrads
                    Pitch   :      .12  mrads
                    IFOV    :     .071  mrads
            Vertical   FOV  :    45.80  mrads
            Optics          :  200 mm fl,  f/1.2
```

```
Reflective Collimator :

        Focal Length          :     120"  (3048  mm)
        Exit Aperture         :      12"  (304.8 mm)

Translation Stage :

        Linear Step Resolution    :     0.00254   mm
        Angular Step Resolution   :     0.000833 mrads
          Angular Step Used       :     0.00833   mrads
          Oversample Factor       :     15

Slit Target :

        Linear Size           :        .0015" (.0381 mm)
        Angular Size          :        .0125 mrads

Digitizing Oscilloscope :

        Sample Bandwidth      :     100 Mhz
        Oversample Factor     :      10.0
        Sample Angular Size   :       0.012 mrads

Digitizing Frame Grabber :

        Sample Bandwidth      :      24 MHz
        Oversample Factor     :       2.5
        Sample Angular Size   :       0.047 mrads
```

3. MTF CALCULATION FROM LINE SPREAD FUNCTION

Line Spread Function (LSF) data acquired by either method is padded to obtain 1024 samples which are input into a standard Fast Fourier Transform (FFT) series algorithm to produce a resulting OTF data set. The MTF is obtained by calculating the modulus of the OTF, the square root of the sum of the squares of the real and imaginary parts. The DC component of the MTF is ignored and the subsequent data points are normalized to the maximum value in the data set. The resulting MTF curves are plotted as Normalized Magnitude vs. Spatial Frequency (cyc/mrad) and truncated to accentuate the area of interest.

4. MEASUREMENT PROCEDURE FOR RASTER LINE SAMPLING LSF METHOD

The test procedure for the Raster Line Sampling Line Spread Function (RLS-LSF) method utilizes a stationary slit placed in the object plane with a uniform blackbody source behind it. The slit image, as processed by the thermal imager, is sampled by a high bandwidth digitizing oscilloscope to obtain the LSF. The LSF waveform and an associated background waveform are acquired by averaging 256 consecutive waveforms for each. The background waveform is subtracted from the LSF waveform resulting in an LSF waveform with spatial fixed pattern noise and any DC level shift removed. The LSF is centered within the sample data set to accommodate phase calculation of the OTF.

The slit target is spatially optimized in order to maximize the LSF signal and reduce any ase effects associated with the FPA. By removing the background ay artifacts in the sampled data set relating to sample phasing of the FPA elements is removed. This results in an LSF which appears to be sample phase independent and provides repeatable MTF measurements. The sample bandwidth required for proper LSF data acquisition is usually empirically determined and must result in enough samples to accurately characterize the LSF. The LSF and MTF curves shown in Figure 1 and Figure 2 represent a data set which was sampled at a digitizing bandwidth of 100 MHz. For this bandwidth each sample increment would equal approximately .012 mrads, producing an oversample factor of the system horizontal detector pitch of 10.

5. MEASUREMENT PROCEDURE FOR MOVING SLIT LSF METHOD

The data set representing the acqui ... ьF is captured using a standard digitizing video frame grabber. S'ıce synchronous data is not available, the frame grabber must have some amount of oversampling to provide a stable sample of a detector element. The 24 MHz bandwidth of the frame grabber used for this procedure resulted in approximately 2.5 times oversampling of a detector element.

The LSF is acquired by a series of horizontal linear movements of a vertically oriented slit in the object plane. For each discrete step, 5 frames of image data are averaged by the frame grabber, pinpointing the slit spatial position within the focal plane. The translation stage positioning is optimized to ensure that the slit moves parallel to the object plane over the entire distance traveled. Total travel across the approximately 4.4 detector elements is achieved in 64 steps. At completion of data acquisition the 3-dimensional, (x,y,t), frame data set is saved for subsequent extraction of pixel array data.

Measurement of the Moving Slit Line Spread Function (MS-LSF) results in a highly spatially sampled LSF data set. To achieve an acceptable spatial sampling increment and to ensure appropriate response to the slit target edges, a step size smaller than the slit angular width is used. The selected step size of .00833 mrad produces approximately 20 samples across a detector element in the horizontal plane. It should be noted that this step size also allows for a significant number of samples across the active area/fill factor (which is defined as the detector IFOV) of the detector element. It is preferable to optimize the sample increment with respect to the detector IFOV. The total number of samples to acquire should be selected so that the slit target will translate completely through a detector element such that the resulting LSF clearly rises and falls to a mean value symmetrically about the LSF. The total travel for this procedure of .533 mrad allows for slit translation of approximately 4.4 horizontal detector elements.

The resulting set of LSFs from adjacent detector elements is shown in Figure 3. From this comparison plot, the detector or set of detectors which were properly sampled can be determined.

Each frame in the data set represents a discrete change in spatial position of the slit. By selecting a pixel through which the slit

passes and extracting that pixel for each frame in the data set, an array of pixel values representing the slit motion across that pixel is displayed. This array describes the LSF of the given detector element. A series of pixel arrays must be plotted to find a suitable pixel. The data set in Figure 3 shows three adjacent pixel arrays and the cycle of the slit translation across them. For this set of data, pixel array B represents an acceptable LSF data set, having a symmetrical LSF with tails clearly down to a mean value. The LSF and MTF curves shown in Figure 4 and Figure 5, respectively, represent the MS-LSF data set.

6. COMPARISON OF METHODS

6.1. Raster Line Scan Line Spread Function Method

The RLS-LSF method, intended for application to scanning systems, can provide useful MTF information when applied to discretely sampled systems having a raster line output. This MTF procedure will measure contributions from electronic sample-and-hold circuitry and spatial sampling interval which is a result of detector spacing. Since the stationary slit position is optimized at the center of a particular detector element, the uniformity of responsivity across the detector will not be measured and thermal crosstalk will not be fully characterized.

6.2. Moving Slit Line Spread Function Method

The MS-LSF method is most representative of the traditional MTF measurement, in that the entire detector is characterized as a result of slit translation. MTF contributors relating to uniformity of responsivity, crosstalk, and geometrical blur are included in this measurement. The MS-LSF method does not measure MTF contributions resulting from the output sample-and-hold electronics.

6.3. Results

The MTF and Phase Transfer Functions (PTF), shown in Figure 6 and Figure 7, describe, for the RLS-LSF method, an MTF that goes to zero at approximately 1/detector pitch (8.3 cyc/mrad). This is attributed to the fact that the RLS-LSF method characterizes the detector pitch. This is because the output electronics sample-and-hold circuit displays the sampled IFOV pixel intensity values for a time interval equivalent to the detector pitch. Thus, the Nyquist sampling rate associated with this cutoff (which is 1/(2*pitch), or 4.16 cyc/mrad) correlates well with measured horizontal Minimum Resolvable Temperature Difference (MRTD) limiting resolution as shown in Figure 8.

The MS-LSF MTF comparison plot in Figure 6 represents an MTF for a FPA which is not significantly MTF limited by either optical blur or crosstalk. The cutoff frequency at 14.1 cyc/mrad is the inverse of the angular size of the detector horizontal IFOV of .071 mrads. This is consistent with the fact that this method is measuring the MTF of the individual detector element.

5

7. MEASUREMENT ANOMALIES

This comparison of MTF measurement procedures has been limited to the horizontal image plane. For this particular thermal imager, characterization of the vertical image plane would involve added complications. LSF acquisition using the MS-LSF procedure reveals an unusual shape for the LSF of a single detector as shown in Figure 9. This plot represents the output of a single pixel as a horizontally oriented slit is stepped vertically across the image plane. The double peak is evidence of electronic processing. Each of the two peaks represents the output of the detector when the slit image was centered on the detector itself or an adjacent detector. This is consistent with claims that every horizontal line output is the result of averaging of vertically adjacent detector pairs. The RLS-LSF method was not evaluated for vertical MTF because the raster line scan data is in a horizontal format. Because of these artifacts, comparison of vertical MTF procedures will not be presented at this time.

8. CONCLUSION

Each of the two methods described in this paper represent MTF measures which include some but not all MTF components of the thermal sensor evaluated. The RLS-LSF method characterizes contributions from electronic sample-and-hold circuitry and spatial sampling interval which is a result of detector spacing (pitch). Yet this method does not represent any MTF contributions relative to uniformity of detector responsivity or MTF loss caused by edge effects of the detector array (e.g., crosstalk). The MS-LSF method measures contributions from geometrical optical blur, crosstalk and uniformity of detector responsivity, but does not measure the major MTF limiter due to the spatial sampling interval. A combination of these two methods may produce a system MTF representative of all the MTF components of the thermal sensor.

Two methods of characterizing components of system MTF for sampled imaging systems have been investigated, pointing out some advantages and disadvantages of the two methods. The results indicate each method can be used to bring out different aspects of the system. Continuing work will involve testing of various other systems, including advanced second generation systems, and evaluation of these procedures for vertical MTF. Direct MTF data may be acquired using fixed sine wave thermal targets to validate relationships between different procedures. If successful, system MTF will be fully characterized for modeling purposes.

9. REFERENCES

1.   J. C. Brown, C. M. Webb, P. A. Bell, R. T. Washington and R. J. Riordan, "AutoSPEC Image Evaluation Laboratory," Proc. SPIE, **1488**, pp. 300-311, (1991).

2.   "Performance Parameters of Thermal Imaging Devices", MIL-STD-1859, p. 6, (1981).

3. S. K. Park and R. Schowengerdt, "Image sampling, reconstruction, and the effect of sample-scene phasing," Appl. Opt., 21(17), pp. 3142-3151, (1982).

4. S. K. Park, R. Schowengerdt and M. Kaczynski, "Modulation transfer function analysis for sampled image systems," Appl. Opt. 23(15), pp. 2572-2582, (1984).

5. D. J. Bradley, C. J. Baddiley and P. N. J. Dennis, "The modulation transfer function of focal plane array systems," Proc. SPIE, **807**, pp. 33-41, (1987).

6.   S. E. Reichenbach, S. K. Park, R. Narayanswamy, "Characterizing digital acquisition devices," Opt. Eng., 30(2), (1991).

7.   L. B. Scott and J. A. D'Agostino, "FLIR92", Proc. SPIE, (1992), Orlando.

8.   Shotaro Fujino, Tetsuo Miyoshi, Masataka Yokoh and Teruyoshi Kitahara, "Mitsubishi thermal imager using the 512x512 PtSi focal plane arrays," Proc. SPIE, 1157, (1989), San Diego.
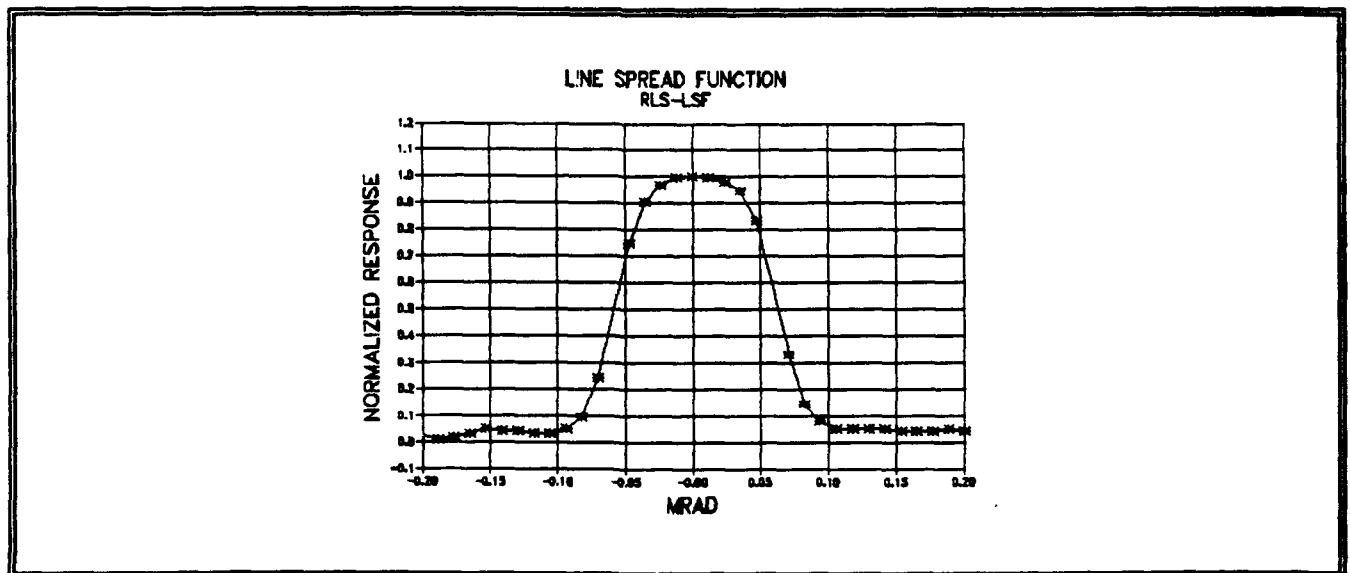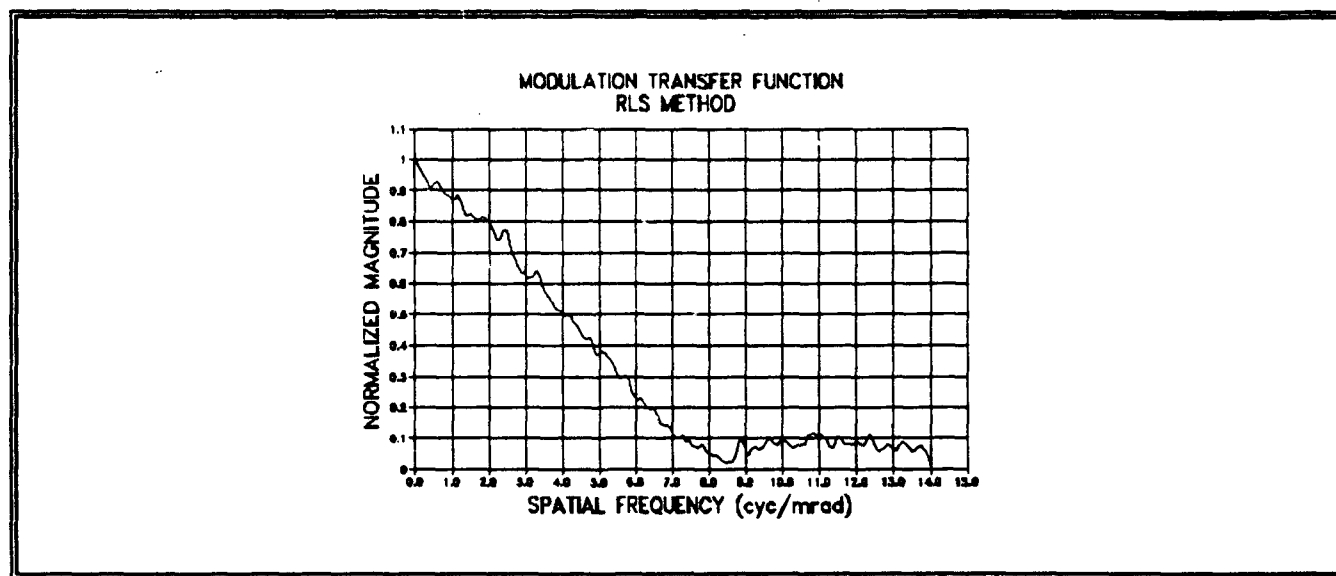
Figure 1 LSF using Raster Line Sampling(RLS-LSF) Method.

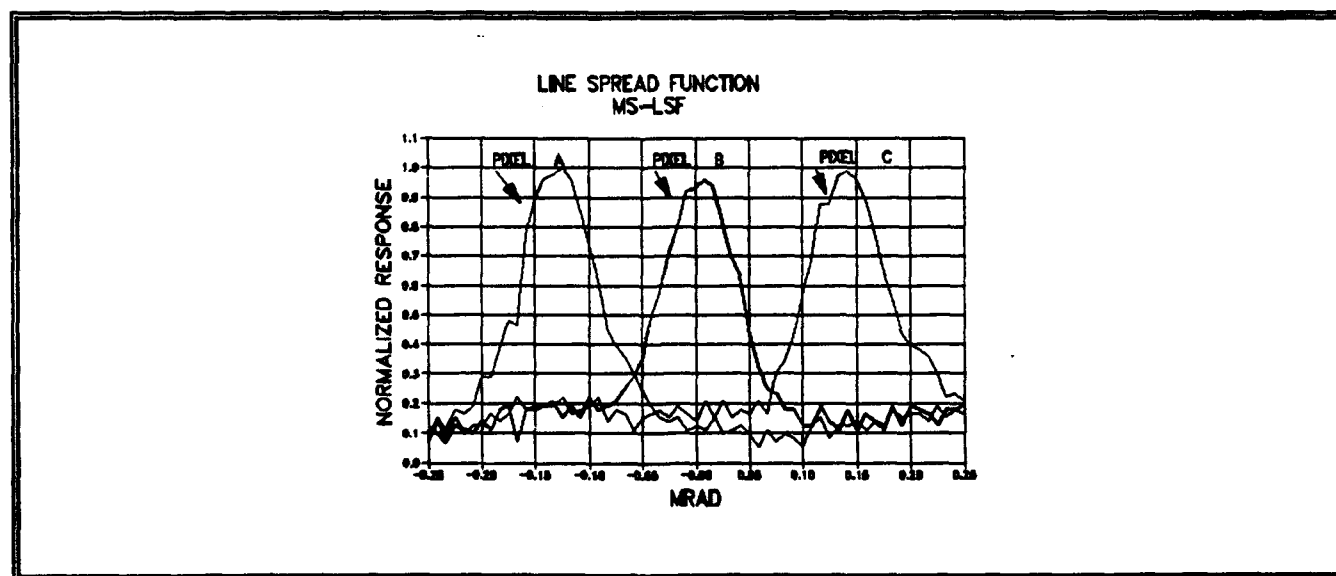Figure 2 MTF using RLS-LSF Method

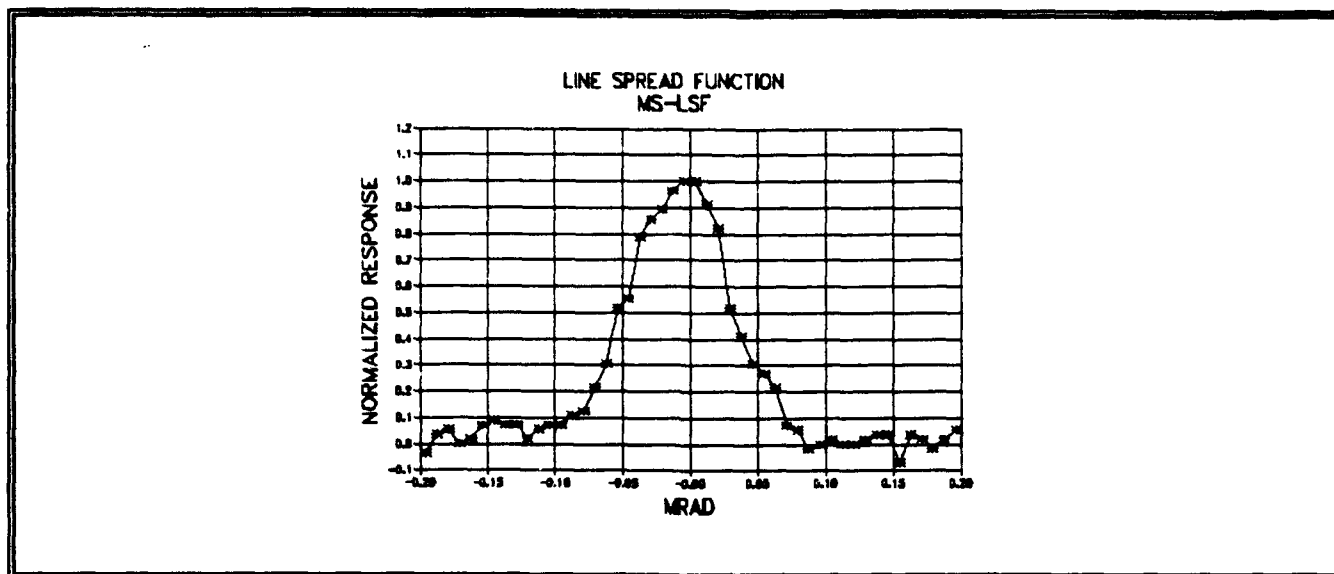Figure 3 LSF of 3 adjacent detectors using Moving Slit MS-LSF Method.

LINE SPREAD FUNCTION
MS-LSF

Figure 4 LSF using Moving Slit MS-LSF Method.

MODULATION TRANSFER FUNCTION
MS-MTF
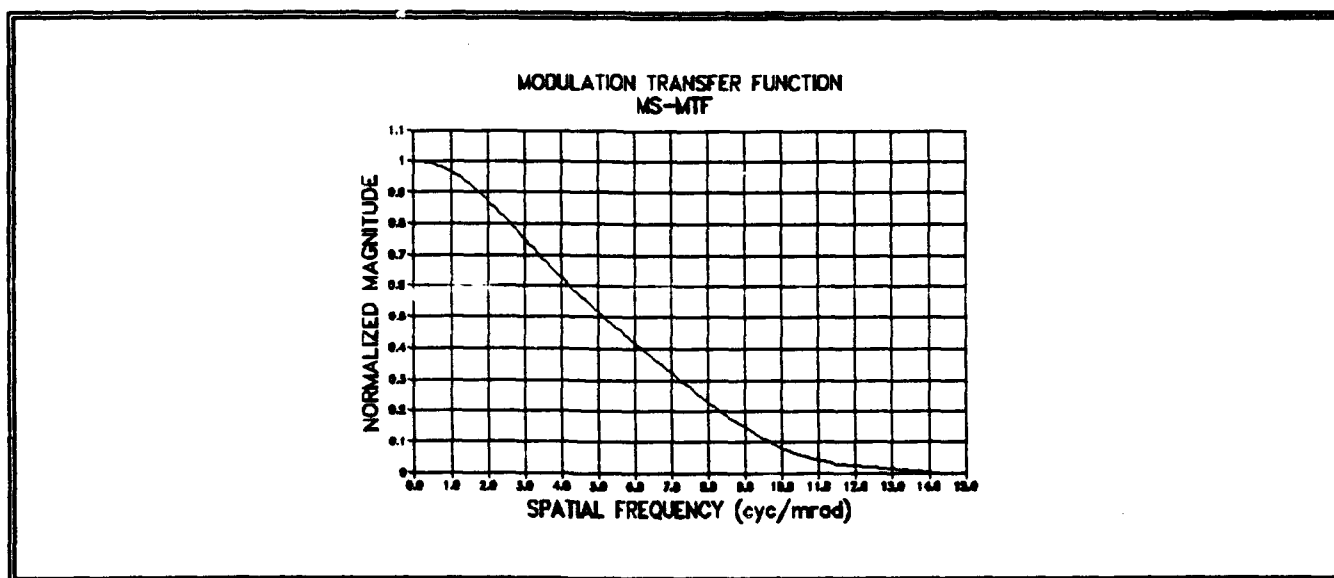
Figure 5 MTF using the MS-LSF Method

9

MODULATION TRANSFER FUNCTION
RLS—MTF vs MS—MTF
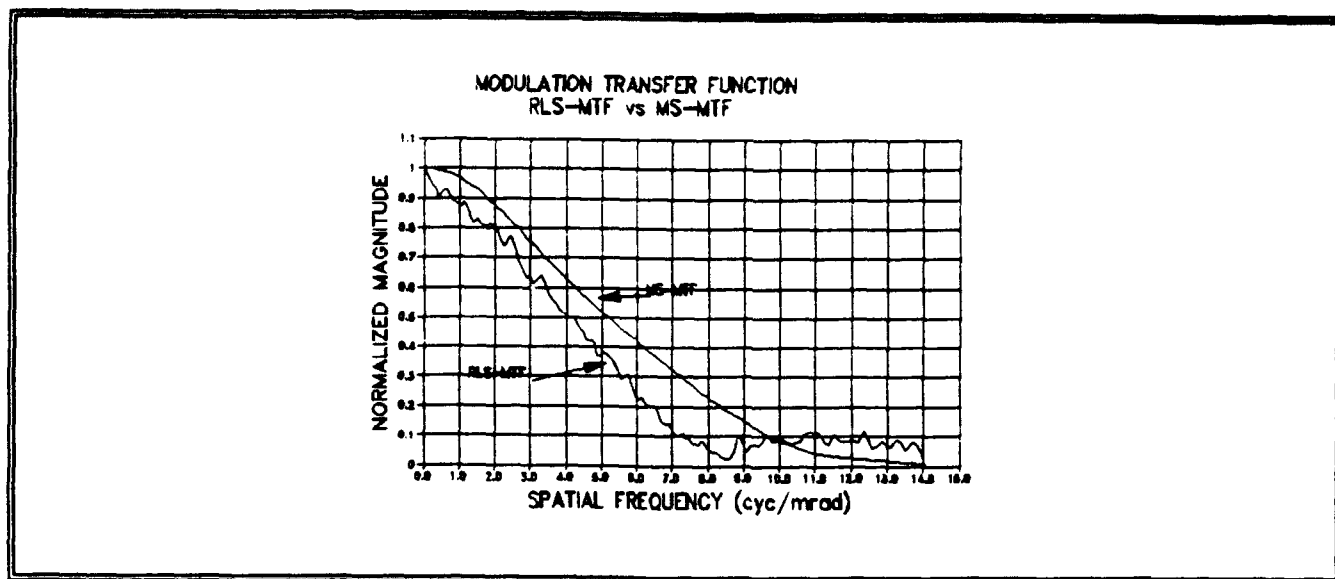
Figure 6 Comparison of MTF from MS-LSF and RLS-LSF Methods.

PHASE TRANSFER FUNCTION
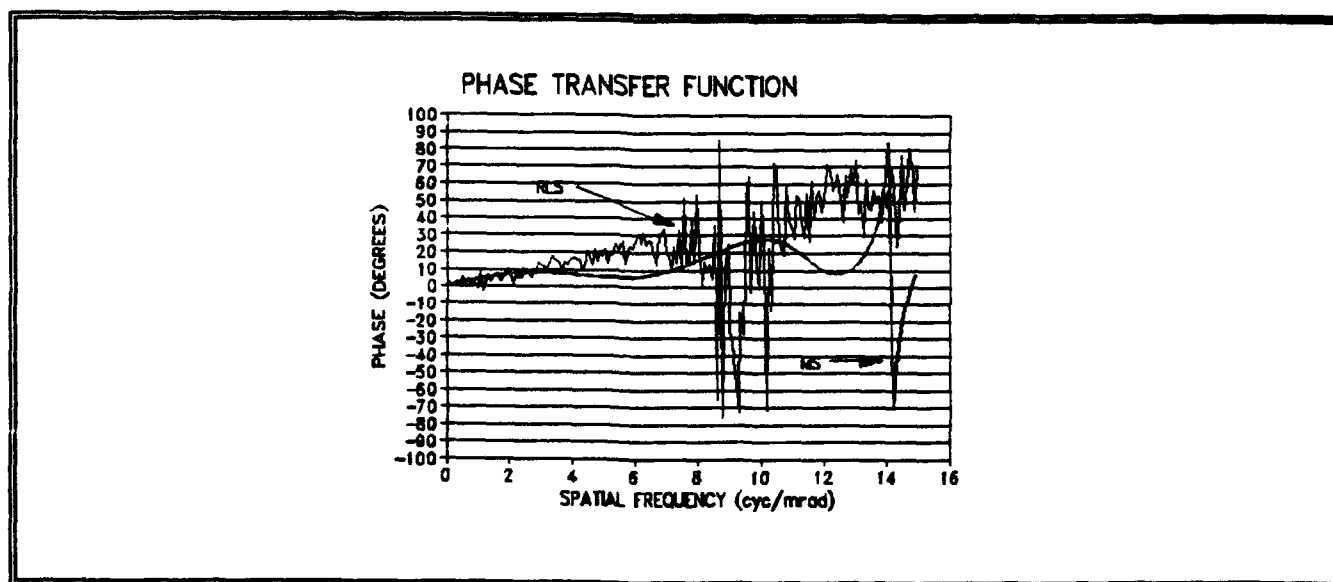
Figure 7 Comparison of OTF Phase Transfer Function
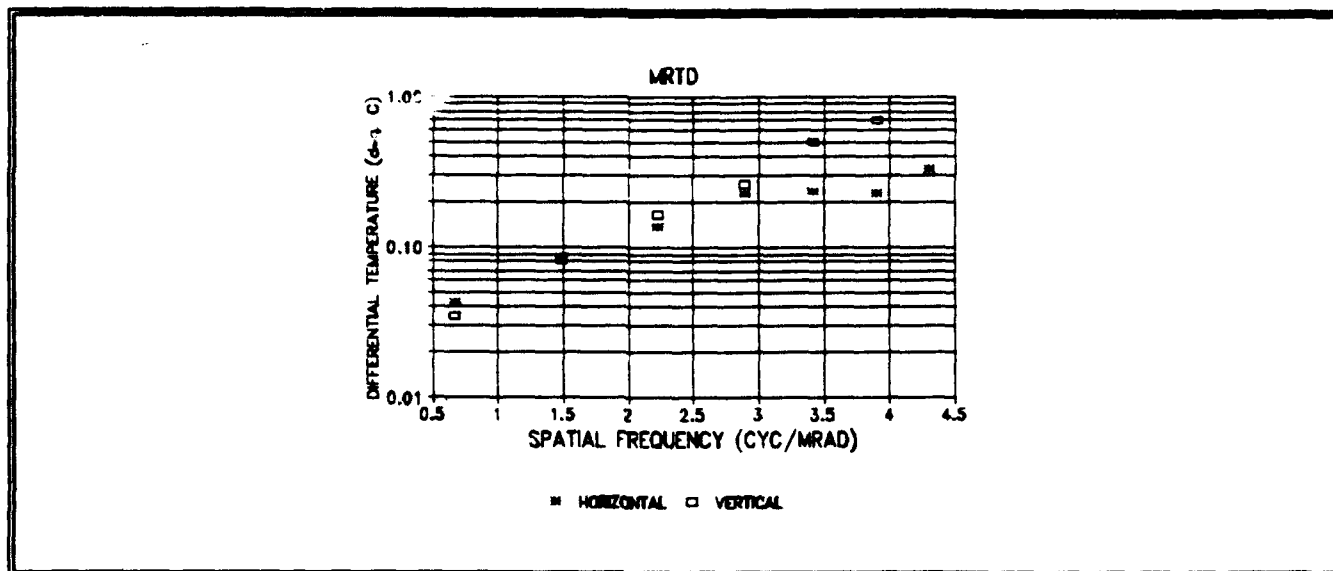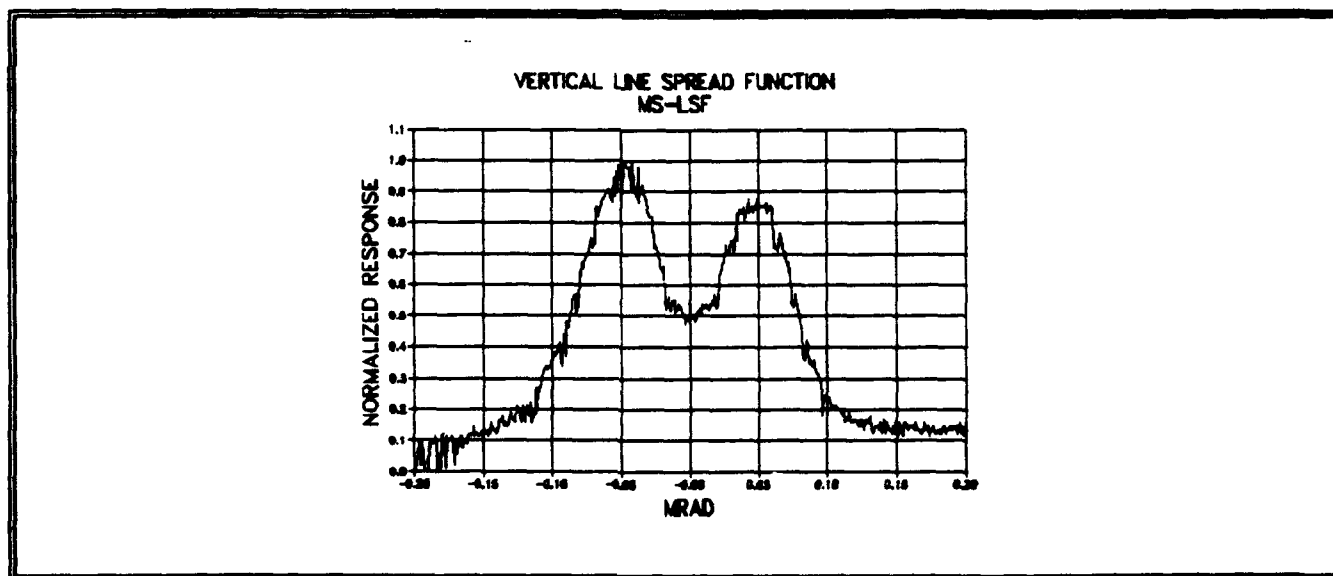from RLS-LSF and MS-LSF Methods.

10

Figure 8 Measured MRTD Results

Figure 9 LSF for Vertical MTF using MS-LSF method