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## **STREAK CAMERA BASED SLR RECEIVER FOR TWO COLOR ATMOSPHERIC MEASUREMENTS**

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### *Abstract.*

To realize accurate two-color differential measurements, an image digitizing system with variable spatial resolution was designed, built and integrated to a photon-counting picosecond streak camera, yielding a temporal scan resolution better than 300 femtosecond/pixel. The streak camera is configured to operate with 3 spatial channels; two of these support green (532 nm) and uv (355 nm) while the third accommodates reference pulses (764 nm) for real-time calibration. Critical parameters affecting differential timing accuracy such as pulse width and shape, number of received photons, streak camera/imaging system nonlinearities, dynamic range, and noise characteristics were investigated to optimize the system for accurate differential delay measurements.

The streak camera output image consists of three image fields, each field is 1024 pixels along the time axis and 16 pixels across the spatial axis. Each of the image fields may be independently positioned across the spatial axis. Two of the image fields are used for the two wavelengths used in the experiment, the third window measures the temporal separation of a pair of diode laser pulses which verify the streak camera sweep speed for each data frame. The sum of the 16 pixel intensities across each of the 1024 temporal positions for the three data windows is used to extract the three waveforms. The waveform data is processed using an iterative three-point running average filter (10 to 30 iterations are used) to remove high-frequency structure. The pulse pair separations are determined using the half-max and centroid type analysis. Rigorous experimental verification has demonstrated that this simplified process provides the best measurement accuracy. To calibrate the receiver system sweep, two laser pulses with precisely known temporal separation are scanned along the full length of the sweep axis. The experimental measurements are then modelled using polynomial regression to obtain a best fit to the data. Data aggregation using normal point approach has provided accurate data fitting techniques and is found to be much more convenient than using the full rate single shot data. The systematic errors from this model has been found to be less than 3 ps for normal points.

## TWO COLOR ATMOSPHERIC MEASUREMENTS

### Objectives:

- Measure atmospheric velocity dispersion difference between 532 and 355 nm using short ( $\leq 30$  ps) pulses, very accurately (2-3 ps).
- Compute atmospheric refraction correction (RC) directly from the differential range.
- Compare this correction with the theoretical one obtained from surface meteorological measurements for agreement/refinement.

### Issues of Importance:

- Is there true hydrostatic equilibrium in the troposphere on a local scale ?
- What are the diurnal and seasonal effects ?
- What effect does the local/global temperature gradient have on RC ?

## STREAK CAMERA SLR RECEIVER SYSTEM

### Desirable Features:

- High Temporal Resolution (ps).
- Good temporal sweep stability.
- High quantum efficiency ( $> 10\%$ )
- Single photoelectron sensitivity.
- High resolution spatial imaging ( $< 1$  ps/pixel).
- Repetition Rate  $\geq 10$  Hz.
- Optical calibration source with temporal and amplitude stability.
- Spectral filtering and wavelength isolation.

## STREAK CAMERA CHARACTERISTICS

### Streak Tube

- Manufactured by Hamamatsu; model C2909, streak tube N2666.
- Sweep: linear
- Maximum MCP gain  $\approx 10^6$
- Spectral response: 200 - 850 nm
- Phosphor Screen: P20
- Effective Photocathode size:  $\approx 6$ mm

### Input Optics

- Spectral transmission: 200 - 1600 nm
- Transmission efficiency: 65% (350 - 1100 nm)
- Image magnification: 1:1
- Effective F-value: F/4.5

### Output Optics

- Image magnification: 1:1
- Effective F-value: F/1.2

### Photocathode gating characteristics

- Duration: 0.3 - 100  $\mu$ s
- Extinction:  $10^3$

### Timing Characteristics

- Maximum sweep  $\approx 250$  ps/12 mm
- Trigger jitter < 10 ps
- Temporal resolution: 1.4 ps (MCP gain = 1)
- Dynamic range: (30:1 at high gain)

## READOUT CHARACTERISTICS

- Vidicon - Plumbicon (North American Phillips model 88 X Q)
- Preamp gain:  $\leq 80$  dB
- Raster Control: flexible, current operation 1024 (time) X 128 (horizontal)
- Sampling rate: 1 M sample/second (max = 16 Msample/second)
- Maximum data transfer to computer:  $\approx 700$  Kbytes/second (MC-DIO-32)
- Maximum rate (currently) limited by interface card 9.4 Hz
- Maximum Temporal Resolution/pixel: 250 fs
- Data windowing: 3 windows for 3 wavelengths, each operating with 1024 X 16 pixels

**TWO COLOR DIFFERENTIAL MEASUREMENT  
THEORETICAL AND EXPERIMENTAL LIMITS OF ACCURACY**

$$R_0 = R(\lambda_1) - \frac{c}{2} \left\{ \left[ \frac{f(\lambda_1)}{f(\lambda_2) - f(\lambda_1)} \right] \left[ (T_0 + T(\lambda_2)) - (T_0 + T(\lambda_1)) \right] \right\} \quad (1)$$

$$\sigma_{R_0}^2 = \sigma_{R(\lambda_1)}^2 + \left\{ \left[ \frac{c}{2} \right] \frac{f(\lambda_1)}{f(\lambda_2) - f(\lambda_1)} \right\}^2 \sigma_{\delta T(\lambda_1, \lambda_2)}^2 \quad (2)$$

Where

$$\delta T(\lambda_1, \lambda_2) \triangleq T(\lambda_2) - T(\lambda_1)$$

$$\sigma_{\delta T(\lambda_1, \lambda_2)} = \sqrt{\sum_{i=1}^2 \left( \frac{\Delta T^2(\lambda_i) \cdot S(\lambda_i)}{n_{ph}(\lambda_i) \cdot \eta_{QE}(\lambda_i) \cdot A} \right) + \left[ \sigma_{MCP}^2 + \sigma_{sweep}^2 \right]} \quad (3)$$

|                     |   |   |
|---------------------|---|---|
| $R_0$               | = | Absolute range to the satellite                                       |
| $R(\lambda)$        | = | Measured range at wavelength $\lambda$                                |
| $f(\lambda)$        | = | Dispersion factor   |
| $T_0$               | = | Absolute time of flight   |
| $T(\lambda)$        | = | Increase in time of flight through atmosphere at wavelength $\lambda$ |
| $S(\lambda)$        | = | Pulse profile factor  |
| $\eta_{ph}$         | = | Number of photons   |
| $\eta_{QE}$         | = | Photocathode quantum efficiency                                       |
| $A$                 | = | Microchannel coupling factor  |
| $\delta T$          | = | Differential time of flight   |
| $\sigma$            | = | Standard deviation  |
| $\Delta T(\lambda)$ | = | Pulse width at $\lambda$  |

## DATA ANALYSIS TECHNIQUES

### SMOOTHING (3 POINT) ALGORITHM

$$\langle I_p \rangle^{(m)} = \frac{[ a \langle I_{p-1} \rangle^{(m-1)} + b \langle I_p \rangle^{(m-1)} + c \langle I_{p+1} \rangle^{(m-1)} ]}{( a + b + c )} \quad (4)$$

$$\langle I_0 \rangle^{(m)} = \frac{[ b \langle I_{1022} \rangle^{(m-1)} + c \langle I_1 \rangle^{(m-1)} ]}{( b + c )} \quad (5)$$

$$\langle I_{1023} \rangle^{(m)} = \frac{[ a \langle I_{1022} \rangle^{(m-1)} + b \langle I_{1023} \rangle^{(m-1)} ]}{( a + b )} \quad (6)$$

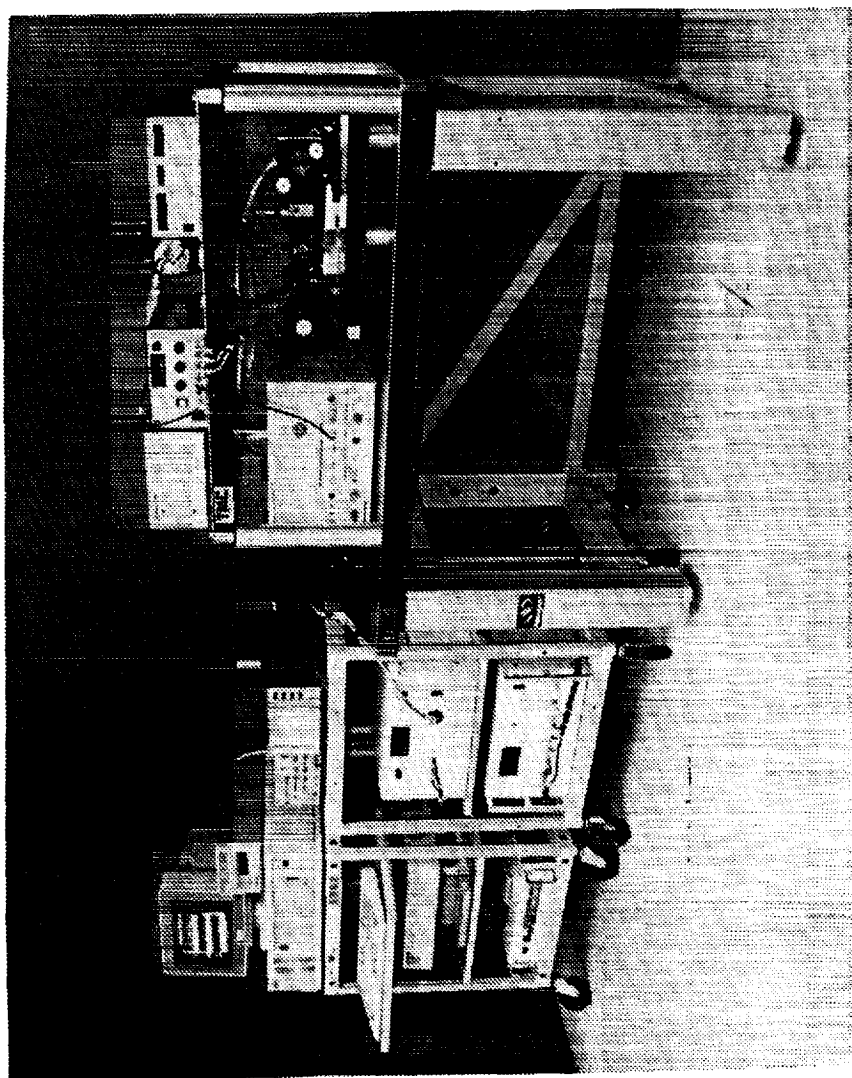
$\langle I_p \rangle^m$  = Mean intensity of the pixel at location p after "m" iterations

a,b,c = Weighting coefficients

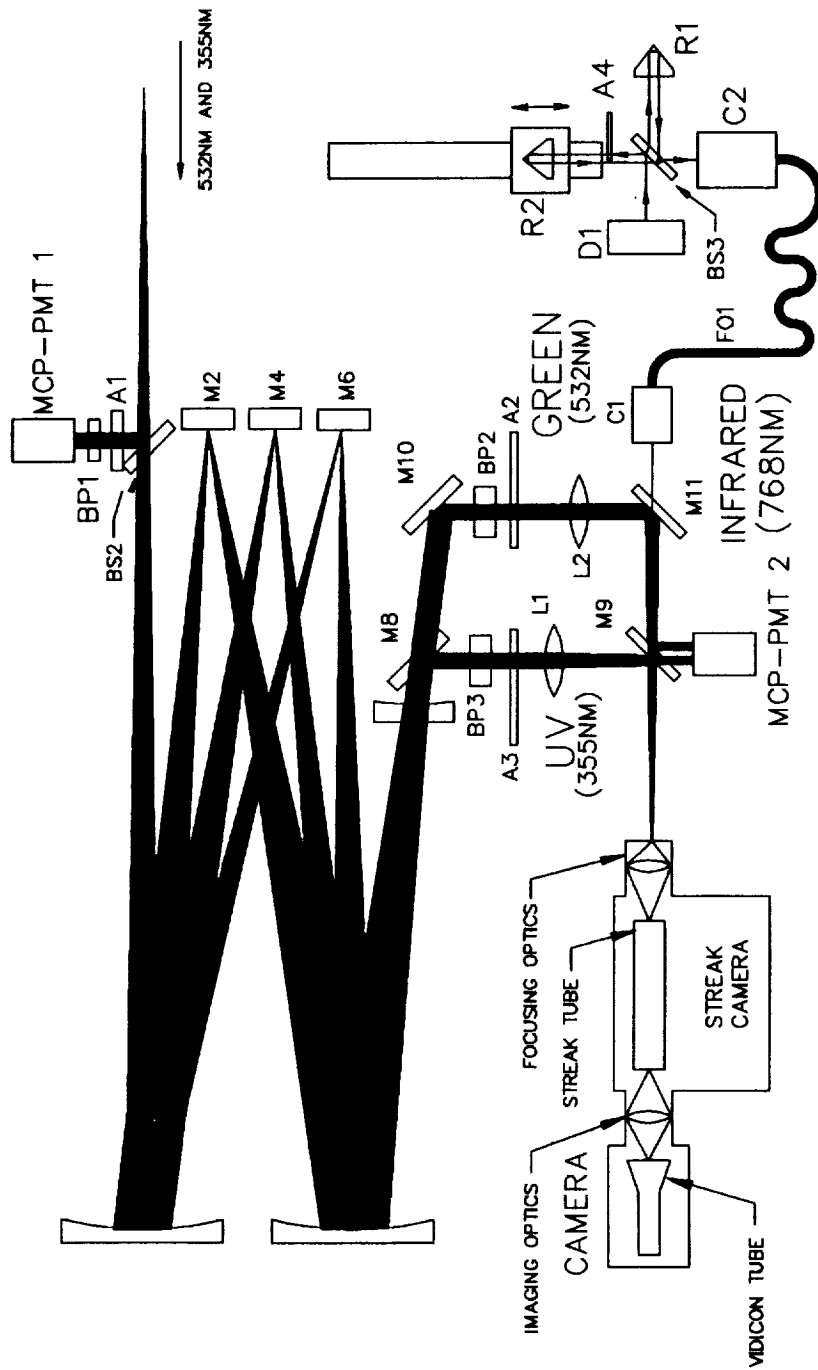
### DETECTION:

- Peak
- Half Maximum (Mean Value)
- Centroid

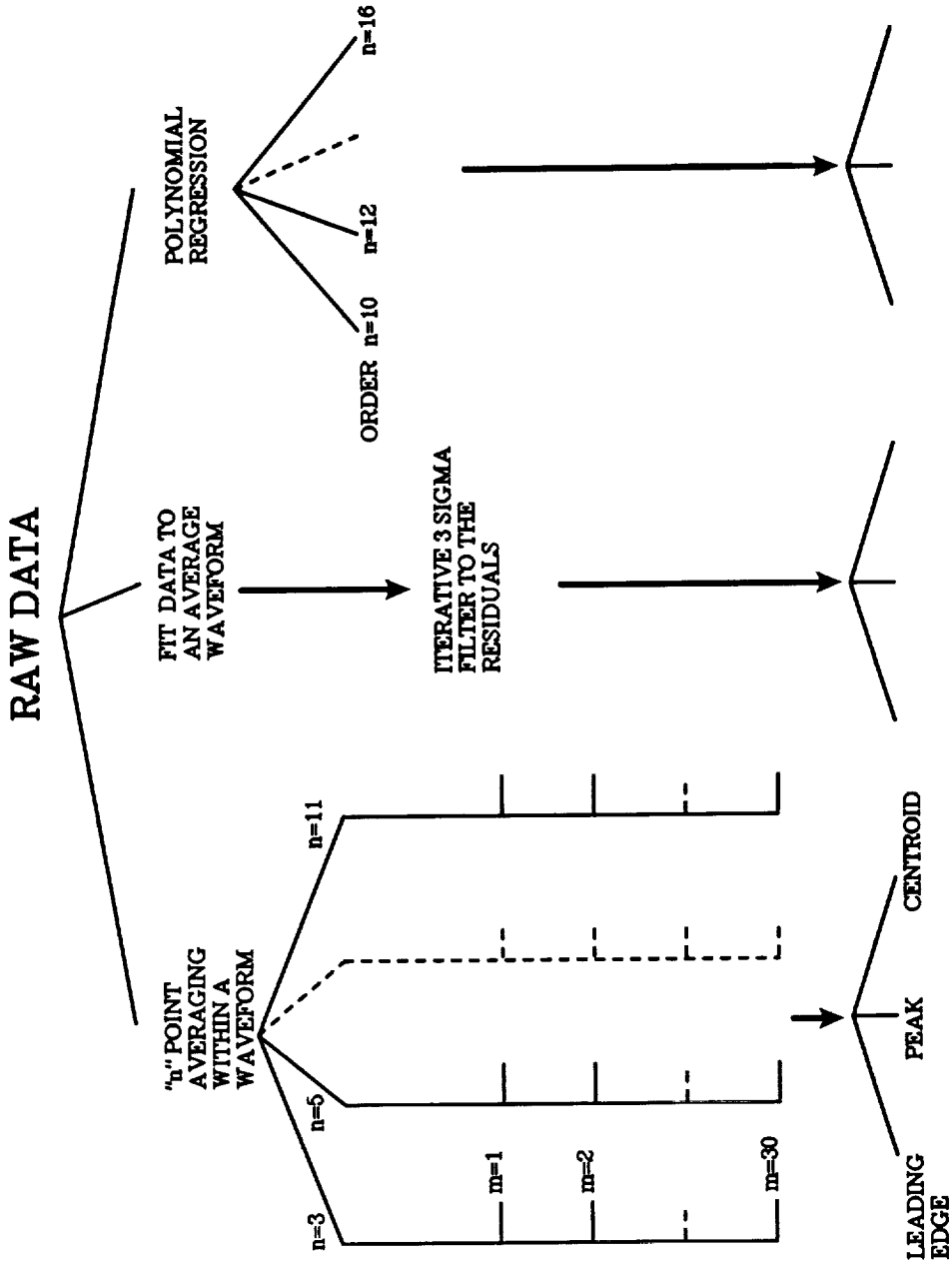
ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH



PHOTOGRAPH OF THE STREAK CAMERA BASED SLR RECEIVE SYSTEM.



OPTICAL SCHEME OF THE STREAK CAMERA RECEIVER SYSTEM, CURRENTLY USED FOR TWO COLOR MEASUREMENT WITH THE NASA GSFC 1.2 METER TELESCOPE.



Tree structure illustrating different types of data processing techniques investigated for determination of pulse pair separation. The best results were obtained for data smoothing with  $n=3$  and  $n=5$  while using centroid/leading edge analysis.



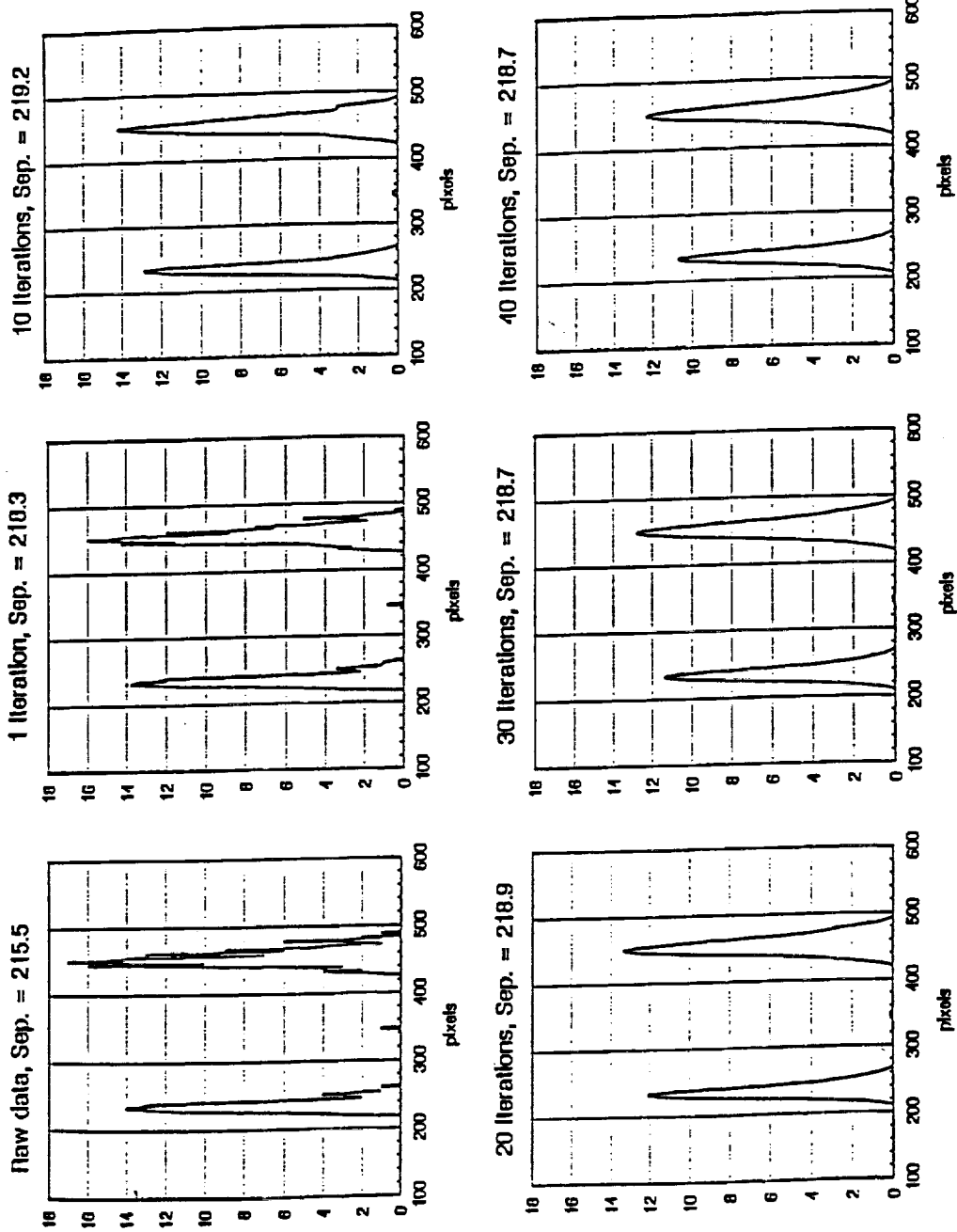
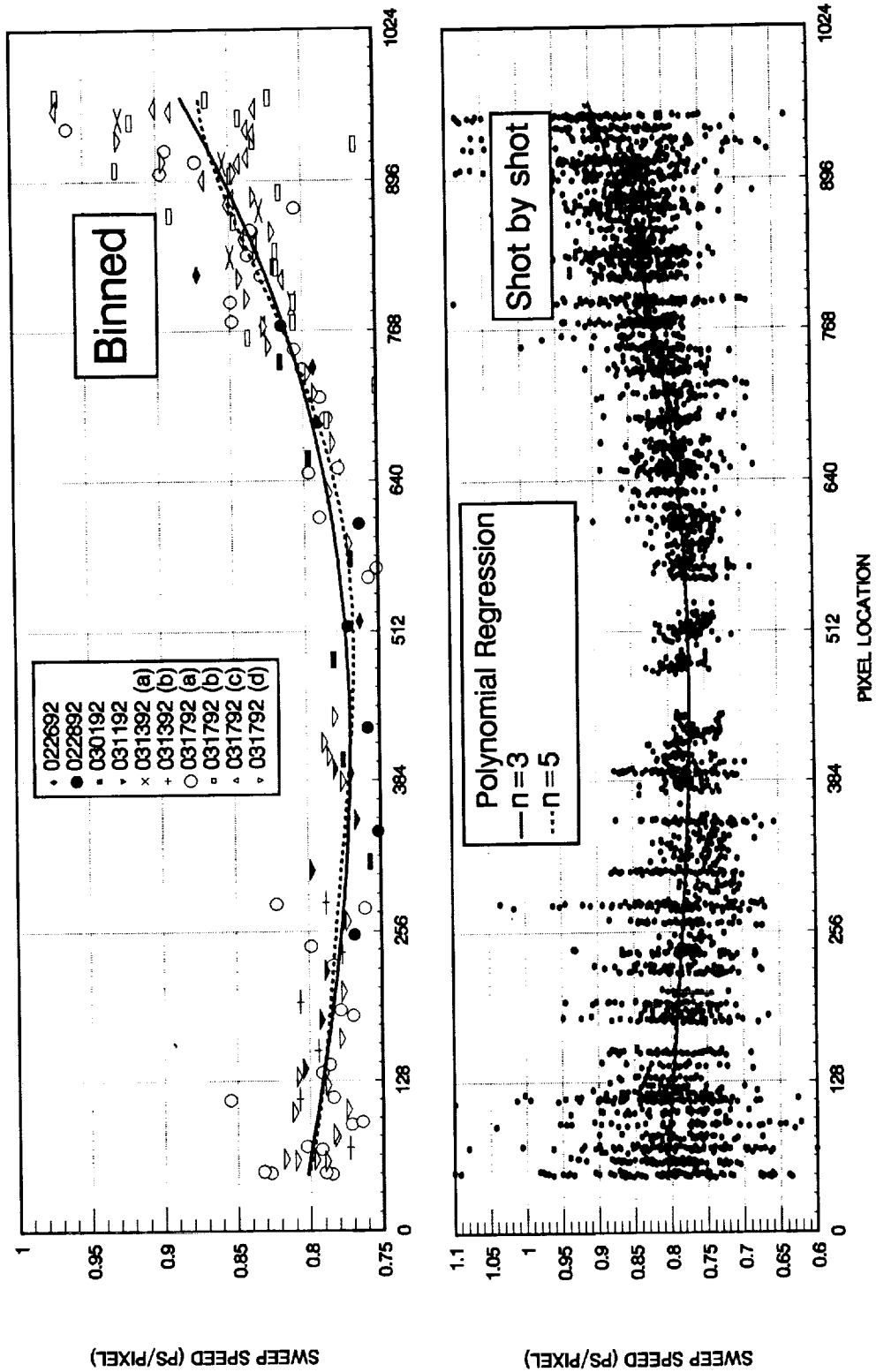


ILLUSTRATION OF THE EVOLUTION OF THE NOISY PULSE PROFILE AS A FUNCTION OF NUMBER OF ITERATIONS OF SMOOTHING (3-POINT). THE PULSE SEPARATION IS STABLE AFTER ABOUT 20 ITERATIONS.



ANALYSIS OF THE NONLINEARITY OF THE SWEEP AS A FUNCTION OF SPATIAL LOCATION. THE TOP PLOT SHOWS NORMAL POINT ANALYSIS FOR A POLYNOMIAL REGRESSION OF  $N=3$  AND  $N=5$  WHILE THE BOTTOM PLOT SHOWS FULL RATE (SINGLE SHOT) ANALYSIS.

## **SUMMARY**

- Single photoelectron sensitive streak camera SLR receive system has been configured with a resolution approaching 250 fs/pixel for high accuracy atmospheric dispersion measurements.
- It has been verified that the streak camera timing characteristics are profoundly impacted by the sweep voltage. The sweep voltage is intrinsically nonlinear in the leading and trailing edges and must be corrected using optical calibration to achieve picosecond timing accuracy. Centroid and half maxima (mean) analyses were found to be superior to peak detection.
- Real-time calibration has been found to be very effective in monitoring the timing performance and would be very advantageous for critical timing measurements.