Space Qualification Plan of Optoelectronic and Photonic Devices for Optical Communication Systems

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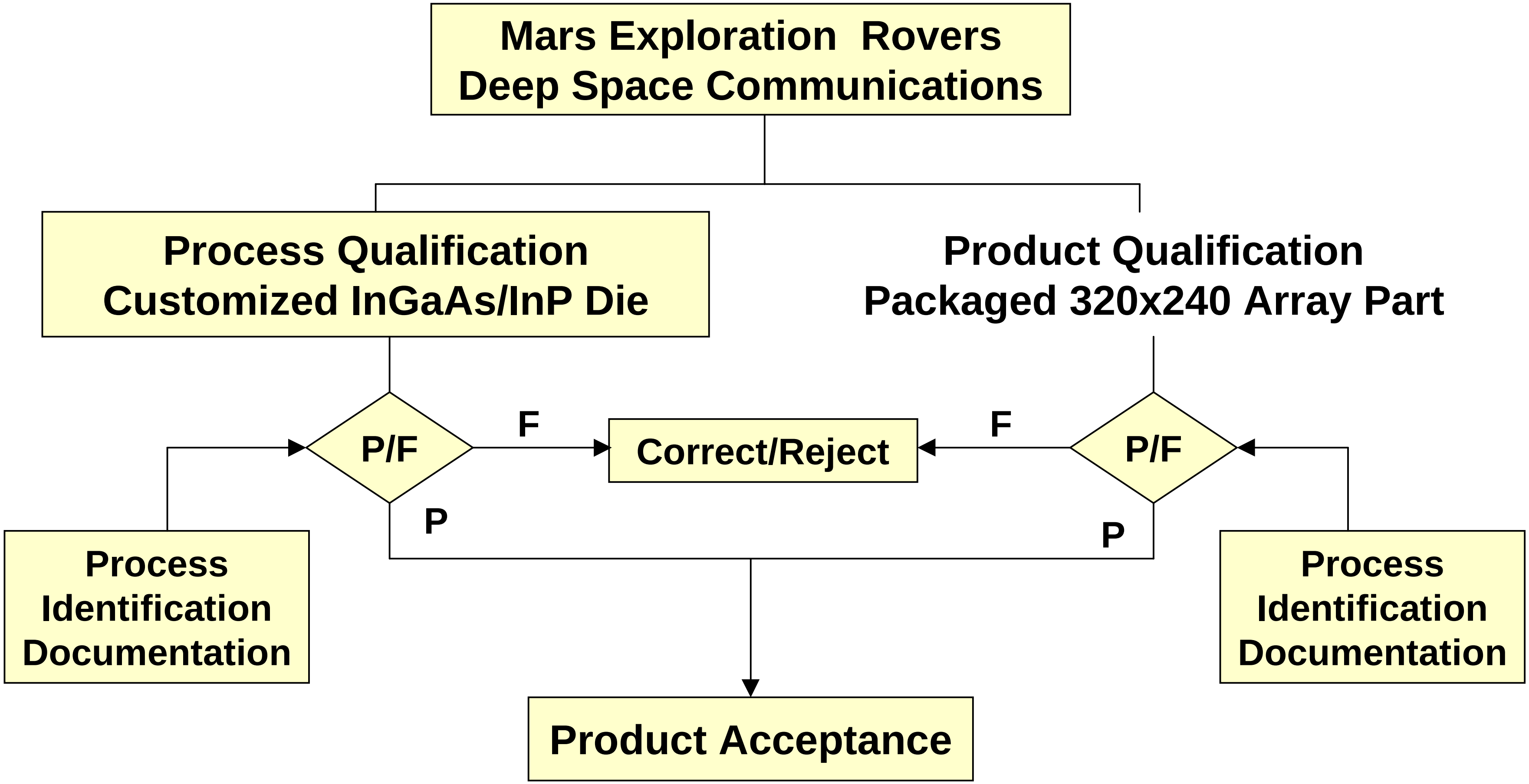
Purpose

- To characterize newly available photonic devices needed for the future space missions (optical communications with spacecrafts (i.e. International Space Station)/ spectrometers) and develop space qualification guidelines
- To establish a space qualification plan of a newly developed InGaAs Active Pixel PIN Receiver devices, and identify the advantages over the existing state-of-the-art photonic receiver devices

Presentation outline

- Purpose
- Qualification Methodology
- Receivers
- Qualification Variables
- Space Qualification Plan
- Conclusions
- Recommendations

Methodology: Space Qualification of InGaAs/InP Active Pixel Receivers



Mars Exploration Rovers
Deep Space Communications

Process Qualification
Customized InGaAs/InP Die

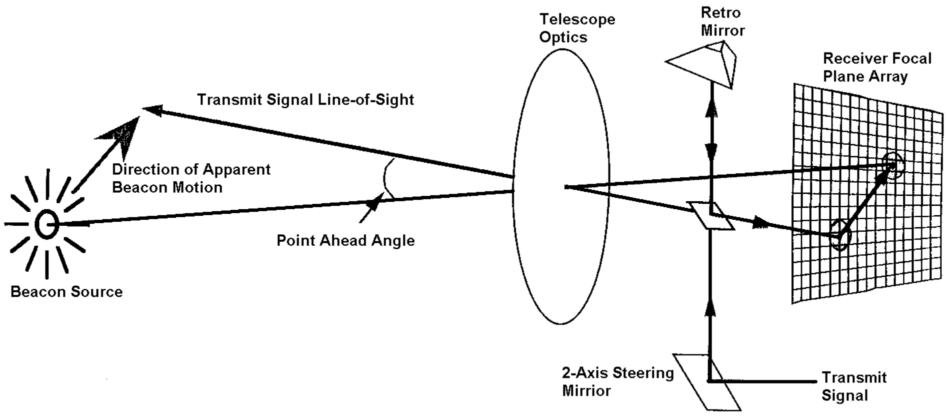
Product Qualification
Packaged 320x240 Array Part

Process Identification Documentation

Process Identification Documentation

Product Acceptance

Applications

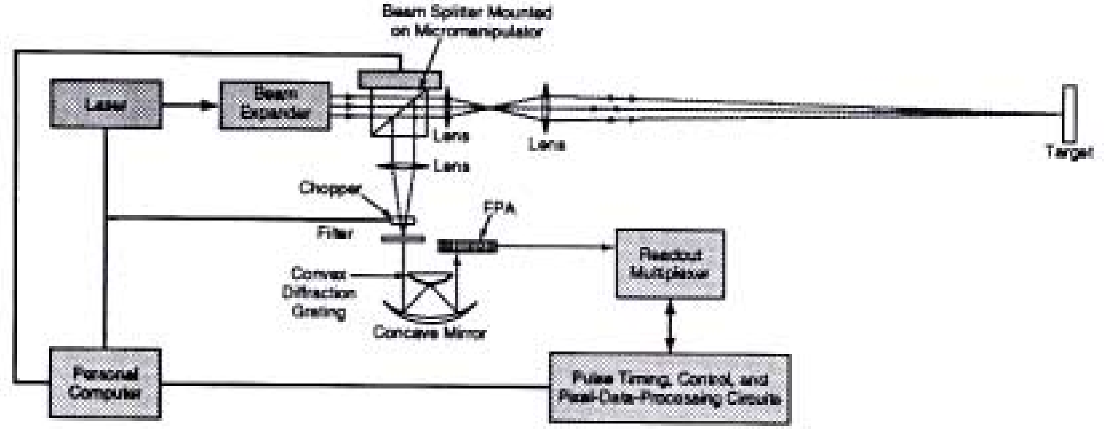


Tracking System

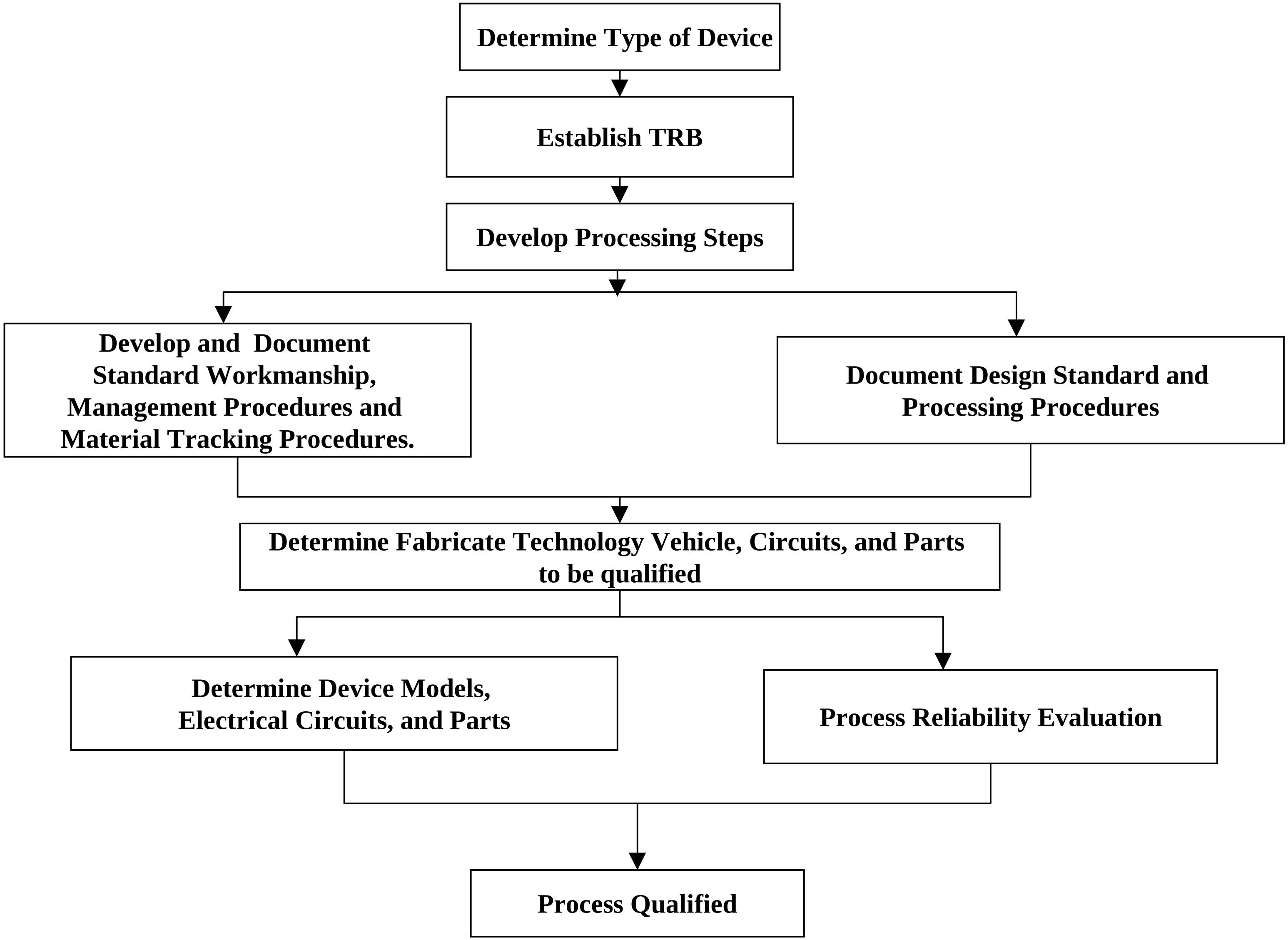
- Proper Orientation Relative to the Arriving Optical Field.
- Closed Loop tracking Control Systems (Azimuth, Elevation).

Multifunctional Active Spectral Analyzer (MAESA)

- Obtain a wavelength-resolved characteristic spectrum of the target for its identification.
- Obtain temporal and spatial multifunctional information of the same target



Process Qualification



Determine Type of Device

Establish TRB

Develop Processing Steps

Develop and Document Standard Workmanship, Management Procedures and Material Tracking Procedures.

Document Design Standard and Processing Procedures

Determine Fabricate Technology Vehicle, Circuits, and Parts to be qualified

Determine Device Models, Electrical Circuits, and Parts

Process Reliability Evaluation

Process Qualified

Product Qualification

- External Visual Inspection
- Lot Acceptance Test for Die
- Die mounting and Wire Bonding
- Nondestructive Bond Pull Test
- Pre-ca Visual Inspection
- Serialization and Marking
- Infrared Scan
- Seal Test
- Temperature Cycle/Shock Test
- Vibration/Sock Test
- Particle Impact Noise Detection
- Electrical/Optical Test at High/Low Temperature
- Pre Electrical/Optical
- Burn-in
- Hermetic Seal Test
- Radiographic Inspection
- Final Electrical/Optical

Typical Packaged Device Screening

Test	Reference
Nondestructive bond pull	MIL-STD-883, Method 2023
Internal visual inspection	MIL-STD-883, Method 2017
IR-scan (prior to seal)	JEDEC Document JES2 [7]
Temperature cycling/	MIL-STD-883, Method 1010/
Thermal shock	MIL-STD-883, Method I 01 I
Mechanical shock/	MIL-STD-883, Method 2002/
Constant acceleration	MIL-STD-883 Method 2001
Particle impact noise detection	MIL-STD-883, Method 2020
Electrical	Customer's specification
Burn-in	MIL-STD-883, Method 1015
Electrical (high/low temp)	Customer's specification
Fine leak	MIL-STD-883, Method 1014
Gross leak	MIL-STD-883, Method 1014
Radiographic	MIL-STD-883, Method 2012
External visual	MIL-STD-883, Method 2009

Space Qualification Plan

- **This qualification plan covers the general provisions for photonic devices intended for use in in-situ material analyses/detector system applications.**

- **The qualification plan should include optical as well as electrical for all the photonic devices such as:**
  - **laser diodes (single/multiple modes)**
  - **PIN receiver diodes and transistors**
  - **fibers (single/multiple mode)**
  - **Index guides: p-InP/n-InGaAs/p-InP**
  - **Opto-couplers**
  - **Optical amplifiers**
  - **Optical switches**

Optical Receivers

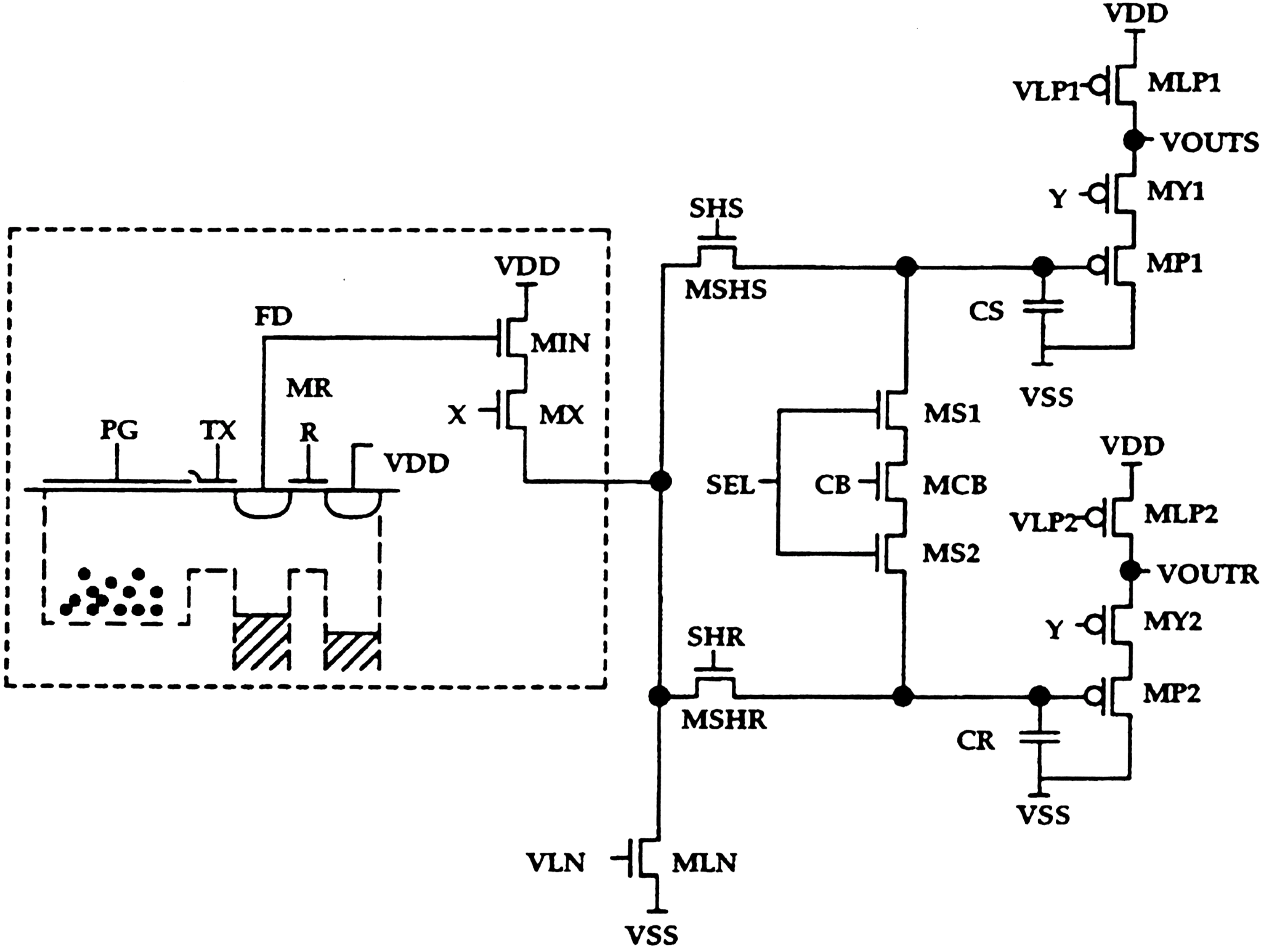
- Devices
  - Photo-gate
  - Photodiode
  - Avalanche Photodiodes

- Readout Circuits
  - Amplify
  - Switching
  - 2-D Data processes

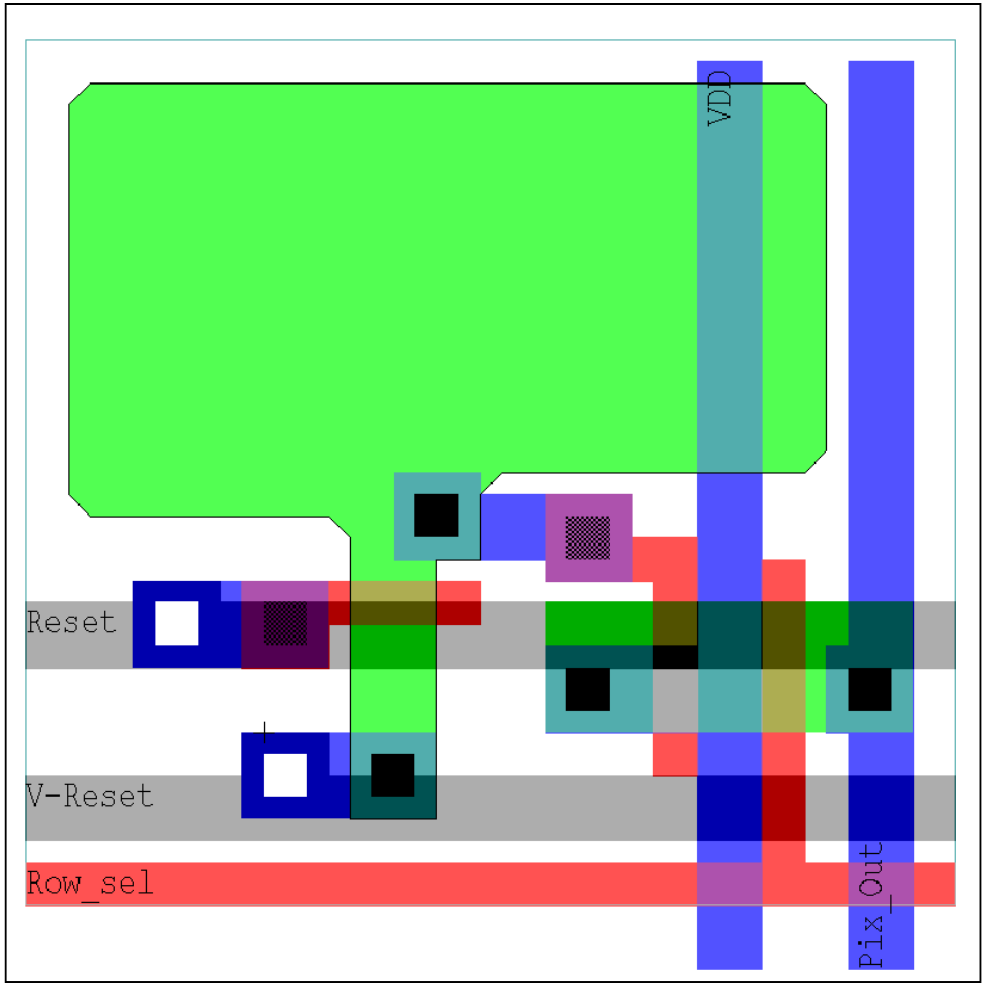
The State-of-the-Art Detectors

	Si APD	**Ge-APD**	**InGaA/InP APD**	**InGaAs-PD/FET**
λ (microns)	0.5-1.0	0.8 - 1.5	1.25	1.0 -1.7
η max	0.8	0.8	0.8	0.8
i d (A)	1.00E-11	1.00E-06	1.00E-09	1.00E-09
Cj (pF)	1	1	1	2
F	300	70	30	
τ_r (ns)	0.15		0.16	0.06

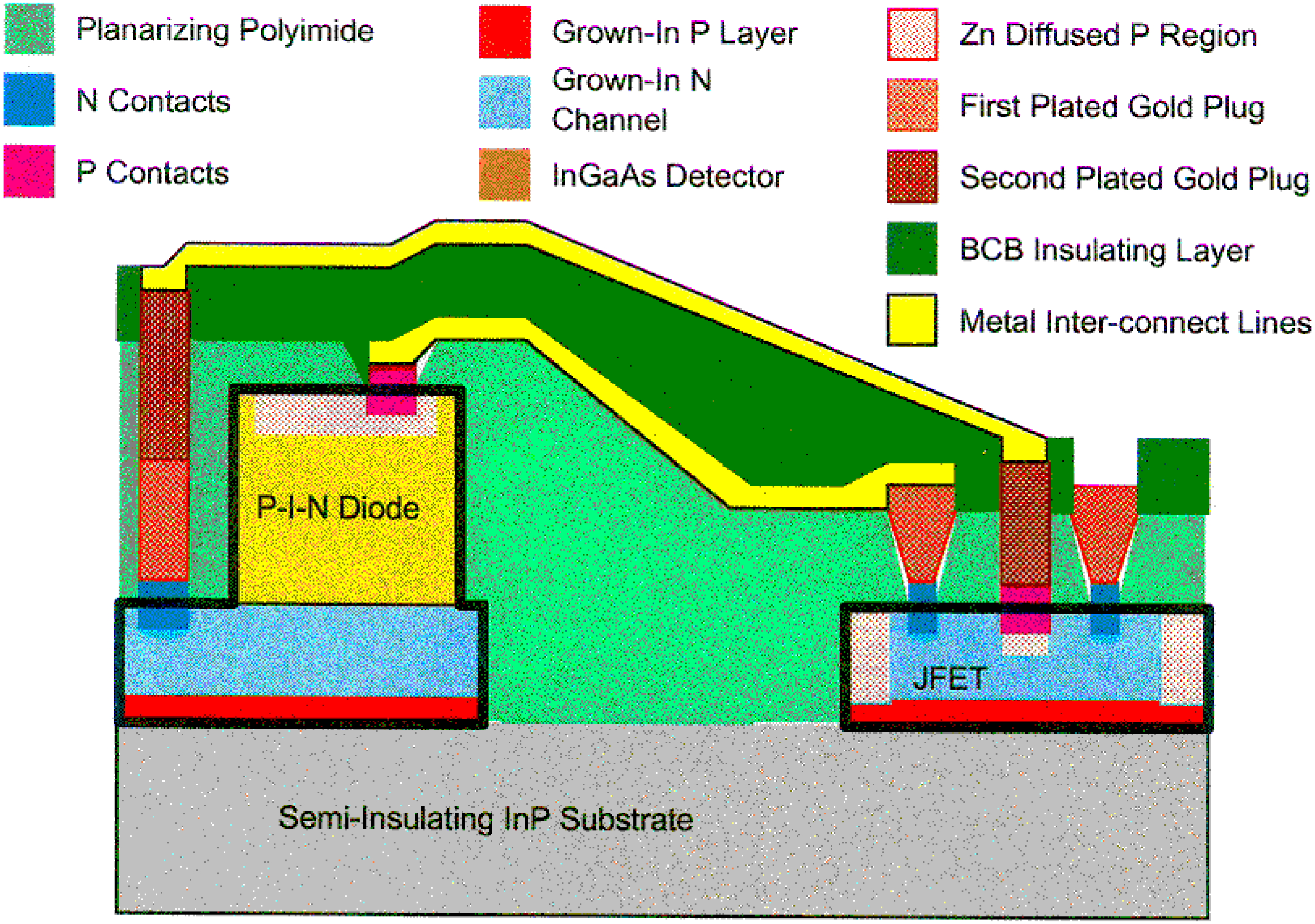
Active Pixel Sensor (APS)
Single Stage Buried Channel Junction CCD



Active Pixel Sensors



A Typical Monolithic Integration



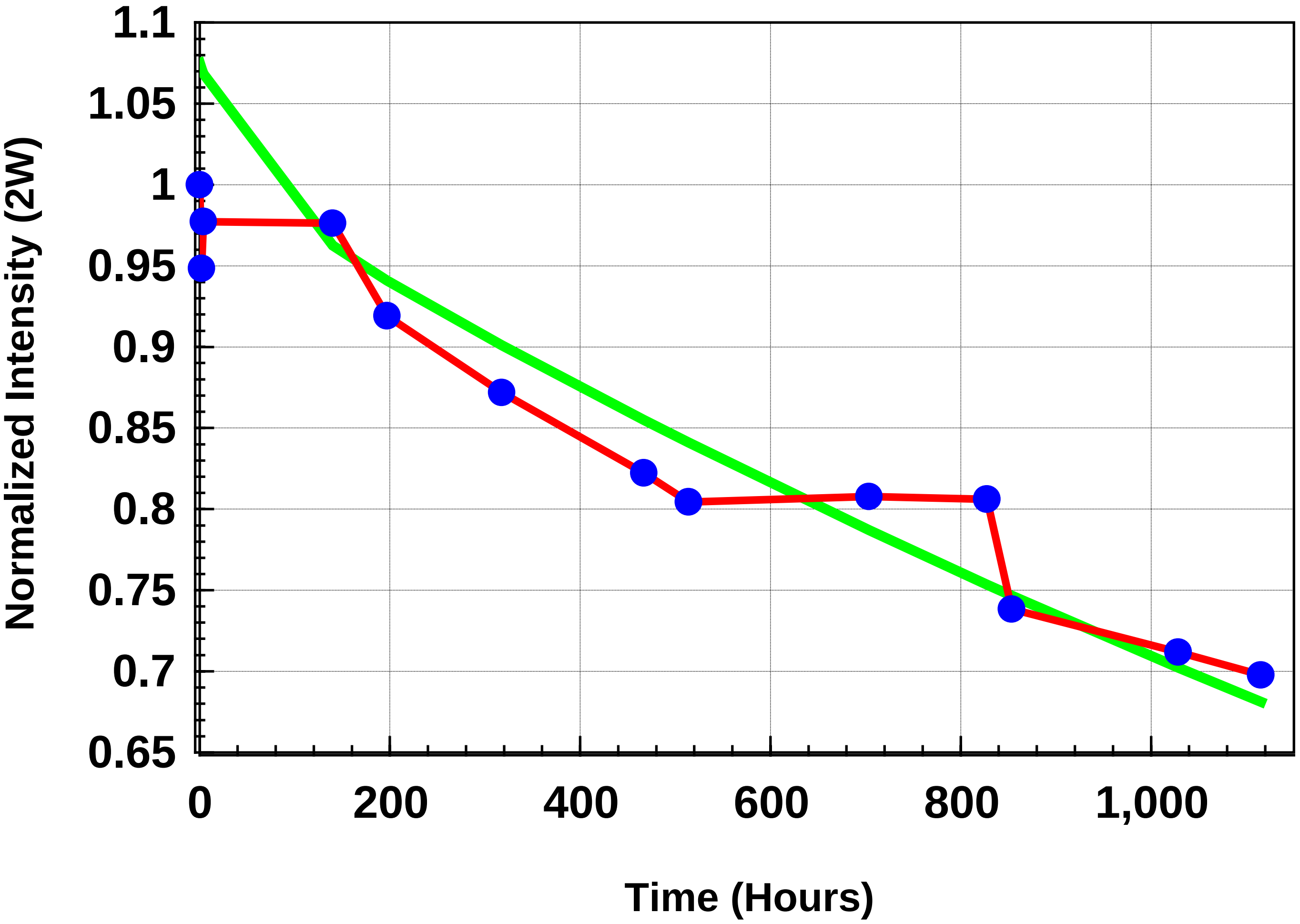
Key Reliability Factors

- Major critical variables to qualify the receiver are:
  - Detectivity ($D^* = 10^{12}$cm(Hz)$^{1/2}$/W at a temperature of 200K)
  - Lifetime
  - Operating Temperature (-100 ~125 ^{o}C,10^o C/half life)
  - Bias Current/Voltage
  - Output power
  - Data Rates: 50Mb/s
  - Spectral width (0.5 ~ 2.5 µm)

- Dislocations
- Metal diffusion
- Inner material Degradations
- Point Defects
- Crystal structures vacancies
- AlGaAs/GaAs>InGaAs(P)/InP
- 110 Crystal axis
- Impurity level of the material
- Workmanship/reproducibility
- Radiation Damages
- Total Ionizing Dose (25K Rad)
- Replacement Damage (>25K Rad)
- Single Event Upsets (75MeV/mg/cm^2)
- Single Event Latch ups
- Single Event Burn outs
- Modulation Transfer Functions

- Surface Degradations
- Facet oxidation/slow
- Aluminum/inhibit diffusion: AlGaAs/GaAs
- Output power: 200mW
- Catastrophic optical damage/fast
- Facet melting: AlGaAs>InGaAs/InP
- Bandgap shrinking: non-absorbing mirror (<0.1 MW/cm^2)
- Alloy electrodes
- Metal diffusion
- AuZnNi: Dark spot defects
- Schottky type electrode: TiPtAu
- Bonding parts
- Soft solders: In, Sn, and Au rich solders/sudden failures
- Hard solders: Au rich solders/reduce instability
- Optical degradation/Modes
- Lifetime

Lifetime


1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0
200
400
600
800
1,000
Normalized Intensity (2W)
Time (Hours)

Summary of Lifetime

- **Monolithic Integration**
  - **Front Illumination Possible**
  - **Remove the Hybridization**
  - **Low-power, Low-cost, and Miniaturization Possible**
- **Active Pixel Smart Control**
  - **Direct Addressing**
  - **Remove the Needs of Multiplexers**
  - **Fast Data Processing**
- **Two-dimensional APS**
  - **Dual Function Imaging Possible**
  - **Spectrometer/Laser Image Detection and Ranging**
  - **Real-time Data Processing Possible**

Modulation Transfer Function

- In-situ evaluation of advanced active pixel focal plane arrays by Modulation Transfer Function in different stages of imager system developments is necessary for an ideal design of different sensors and their signal processing.
- Understanding the tradeoff between different figures of merit will enable designers to achieve the most efficient array design for specific missions.

Modulation Transfer Functions

- Modulation Transfer Function
- Active Imaging Focal Plane Arrays
- Cross talks
- Advanced Photodiode Active Pixel Test Chip
- Optical probing system
- Results

Modulation Transfer Function (MTF)

$$\mathrm{MTF} = \mathrm{MTF}_{\mathrm{optical}} \times \mathrm{MTF}_{\mathrm{pixel}}\,.$$

Ideal imaging system MTF is given by the product of the optical diffraction limited MTF of the optics and the ideal MTF of the pixel.

For circular aperture, the diffraction-limited MTF of the optics is circular symmetric. Its one dimensional profile can be given as:

$$\mathrm{MTF}_{\mathrm{optical}}(f/f_c) = 2/\pi \, \{ \cos^{-1}(f/f_c) - f/f_c[1 - (f/f_c)^2]^{1/2} \},$$

for all f_c =< f and

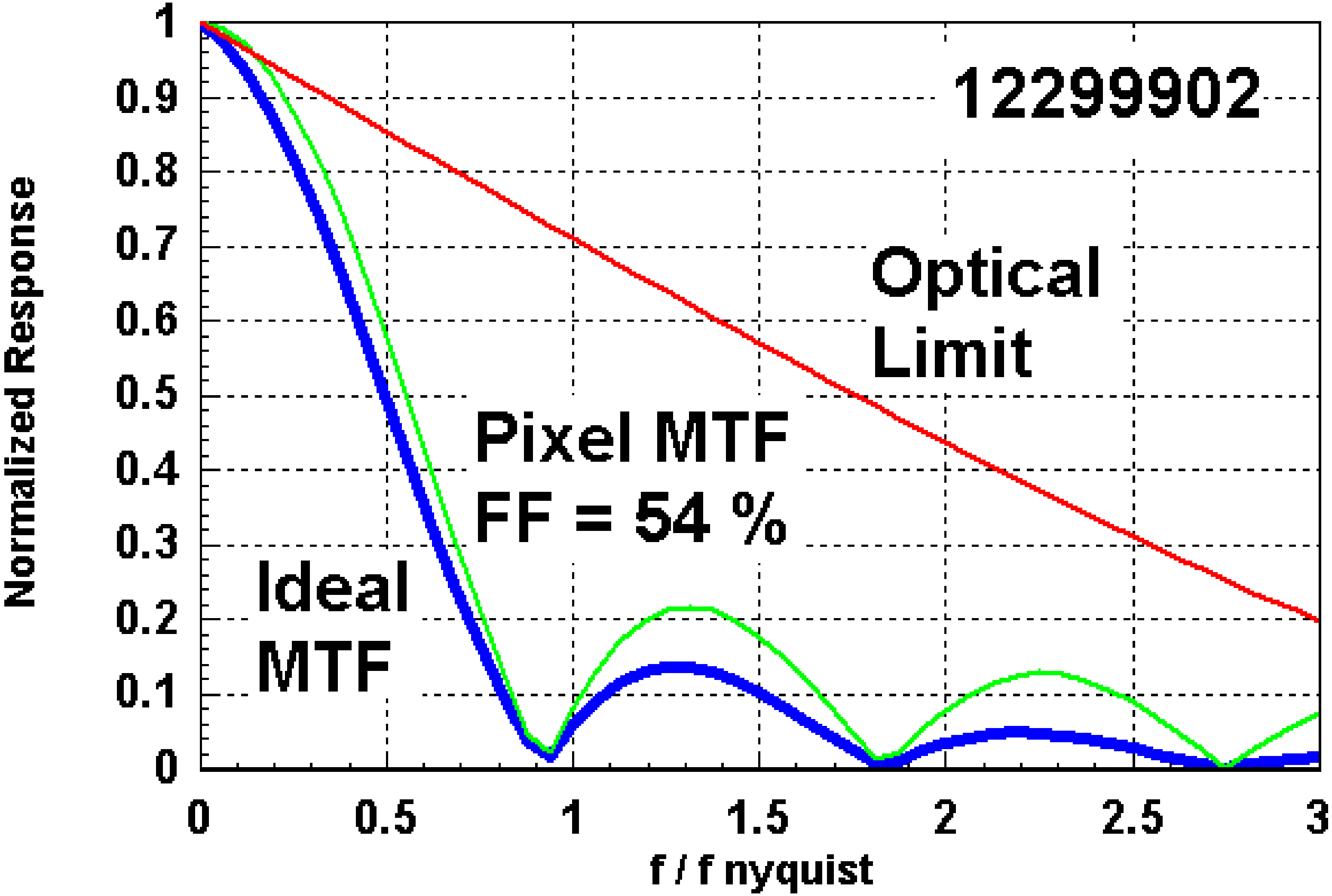
zero otherwise.

The cutoff frequency f_c is related as 1/(f/#). The ideal pixel MTF is the magnitude of the Fourier transform of the a rectangular function of width W or height of the active area of the pixel can be expressed as:

$$\mathrm{MTF}_{\mathrm{pixel}}(f) = |\sin(\pi f W)/ \pi f W|.$$

The real pixel MTF is depend upon many variables such as charge transfer efficiency (CTE), cross talk, pixel fill factor, pixel shape, and readout electronics including time delay integration (TDI) techniques.

Ideal MTF


12299902
Optical Limit
Pixel MTF FF = 54 %
Ideal MTF
Normalized Response
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
f / f nyquist

Discrete Fourier Transformations for Modulation Transfer Function (MTF)

$$Xd(k \Delta f) = \Delta t \Sigma_{n=0}^{N-1} x(n \Delta t) \exp\{-j 2\pi k \Delta f n \Delta t\}$$

where

N: number of samples being considered,

Δt: the time between samples,

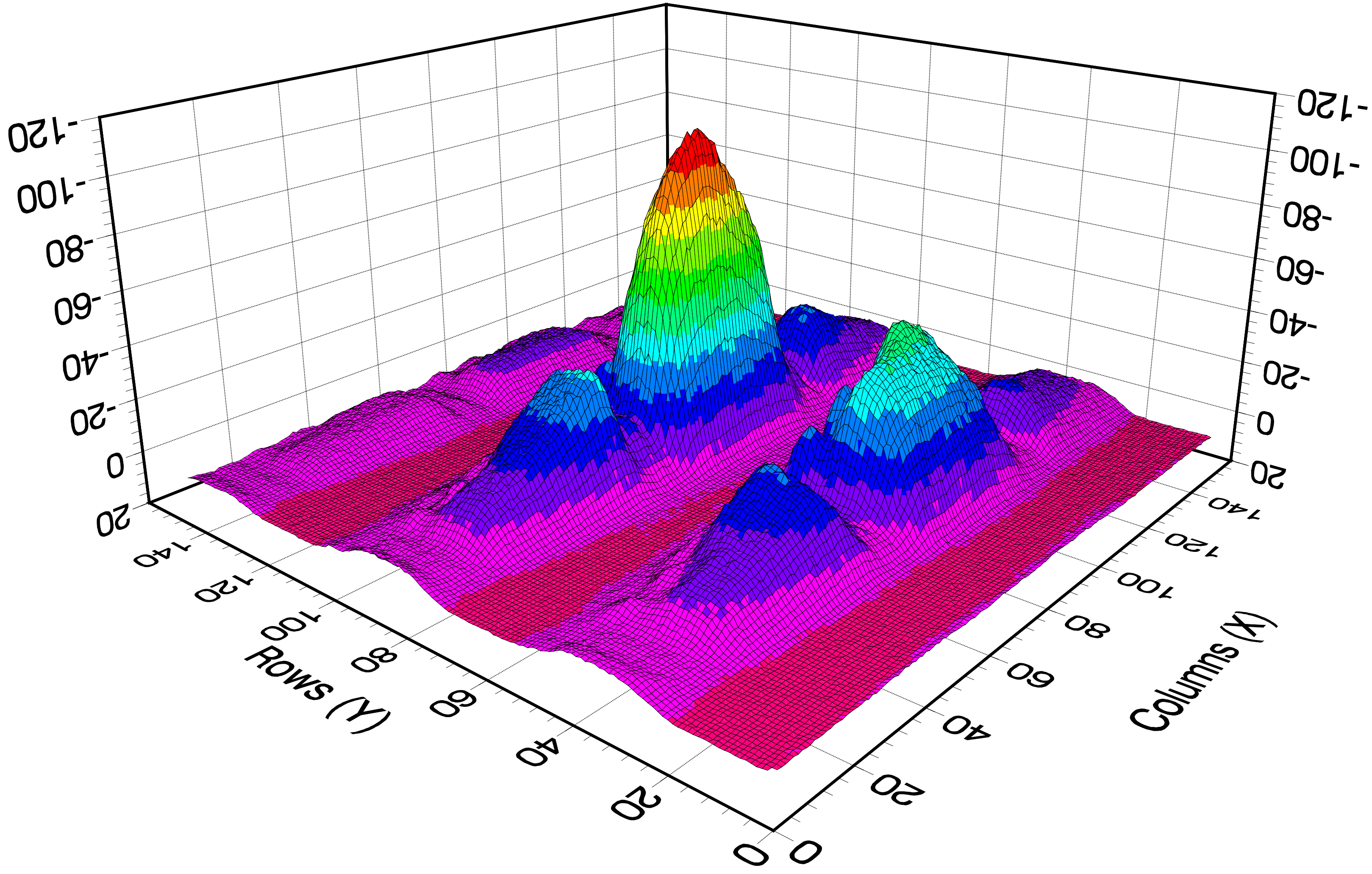
Δf: the sample interval in the frequency domain,

n: the time sample index,

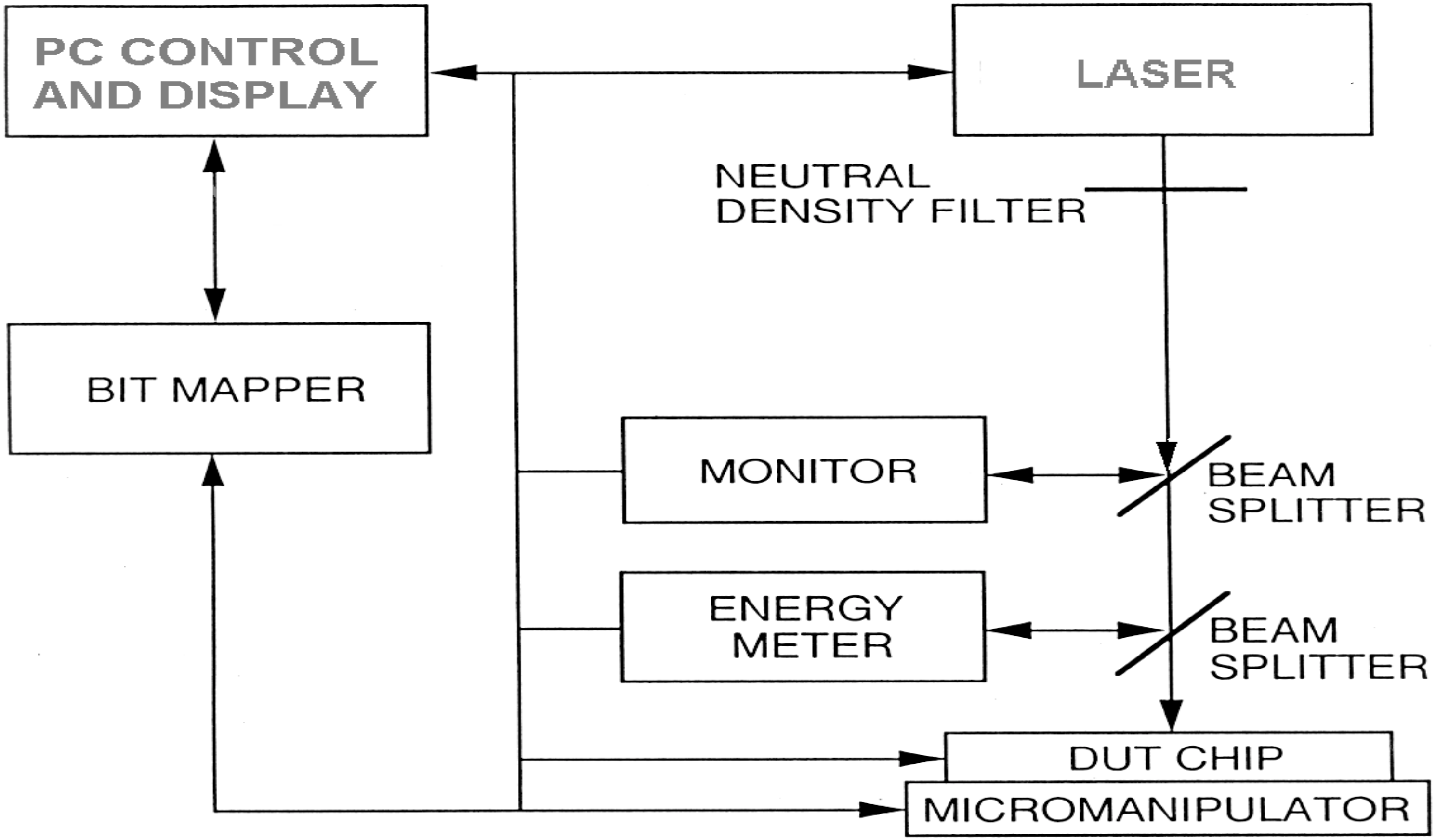
k: the index for the computed set of discrete frequency domain,

j: $(-1)^{1/2}$.

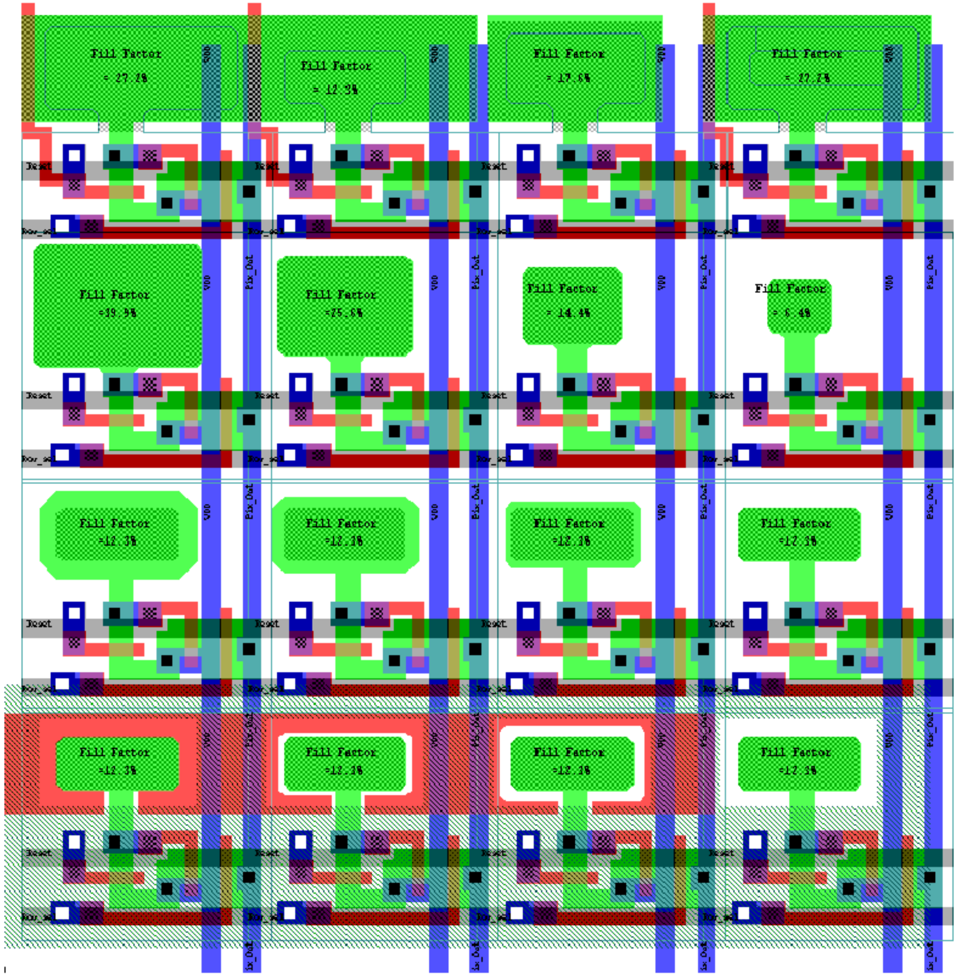
Typical crosstalk among the eight nearest neighbor pixels is 5.1%



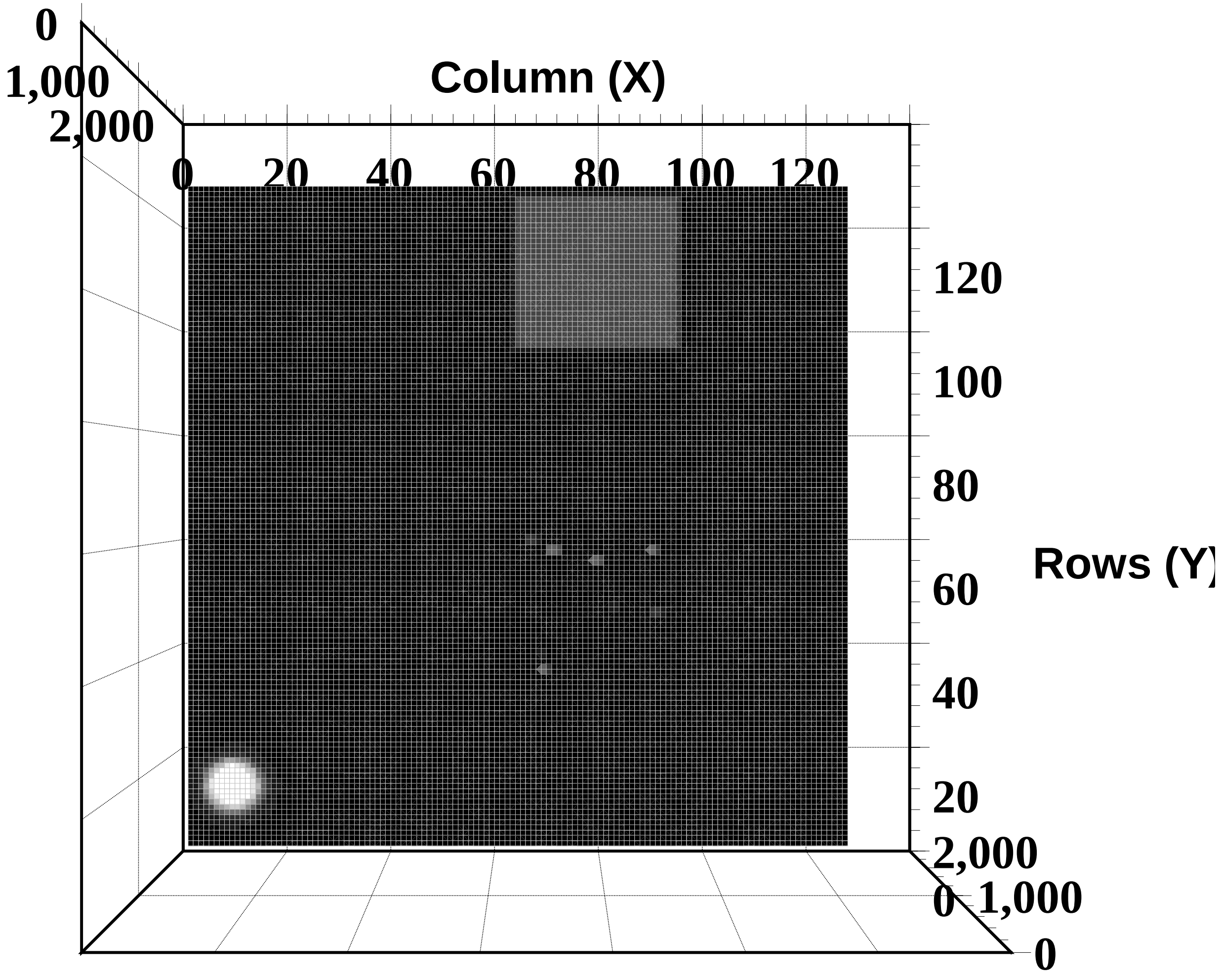
Block diagram of the Microelectronic Advanced Laser Scanner



DICE APD CHIP PIXEL ARRAY



Active test pixel arrays used for the MTF measurements



Procedure of the MTF Measurements

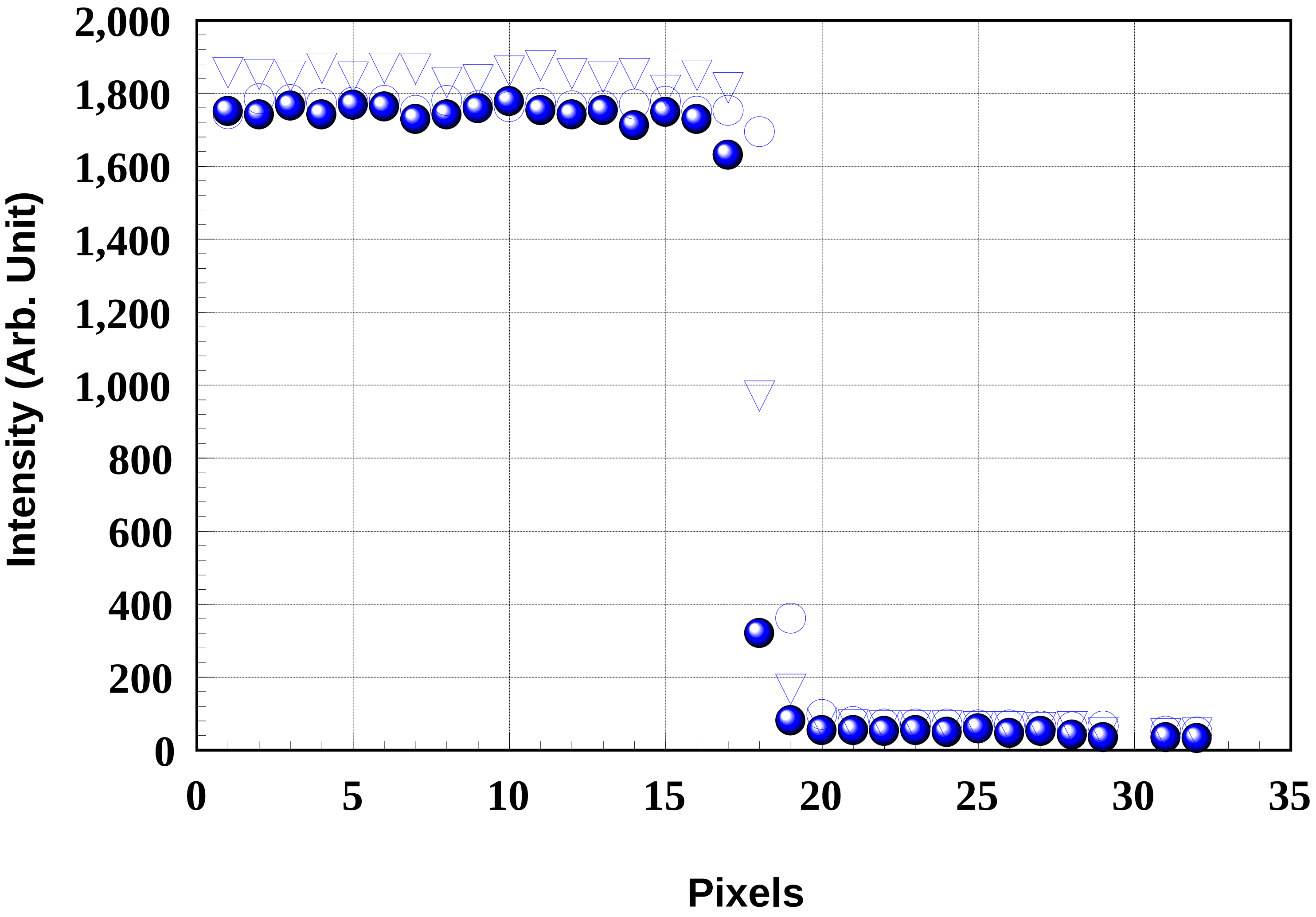
- **A Single image containing an edge was stored for location of the edge.**
- **Utilizing the linear regression line fitting, the edge spread function (ESF) was determined as:**

$$F(x) = D + A / [\exp\{(B-x)/C\} + 1]$$

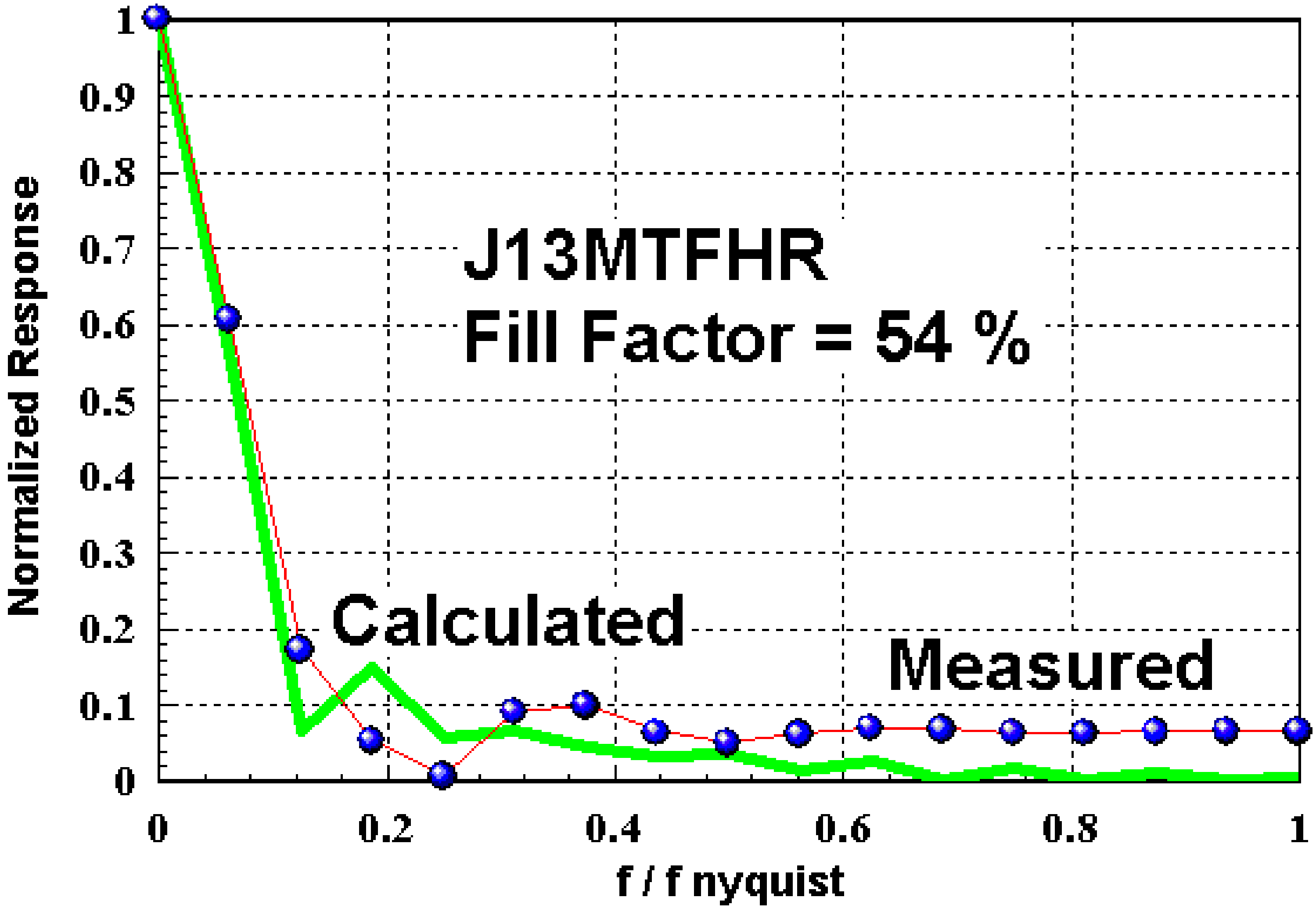
where A, B, C, and D are constants.

- **Calculate the line spread function (LSF) by differentiate the ESF.**
- **Perform the discrete Fourier transformation (DFT) of the LSF for MTF of the one-dimensional focal plane array. The real part of the DFT is the MTF.**

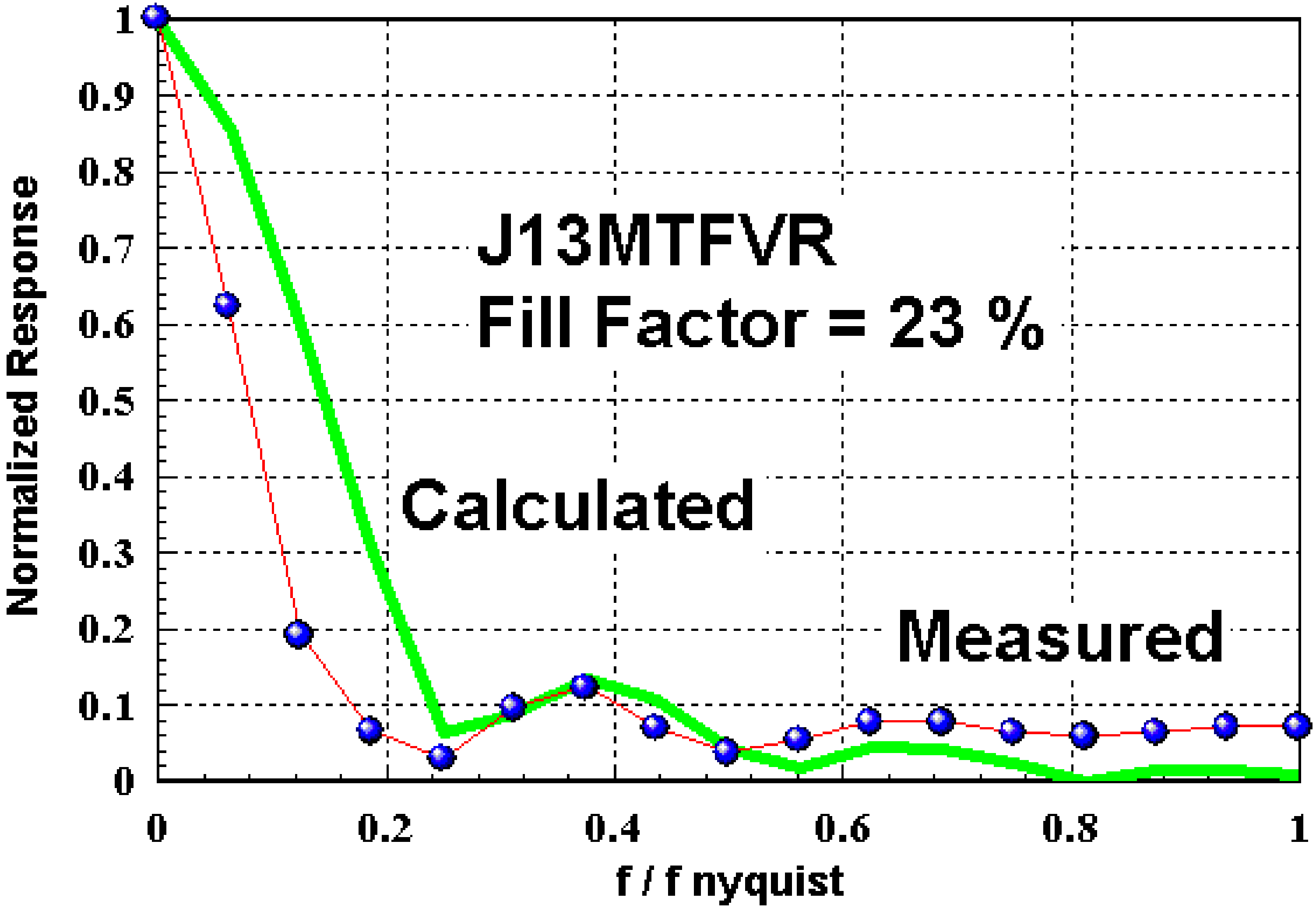
Edge Spread Function



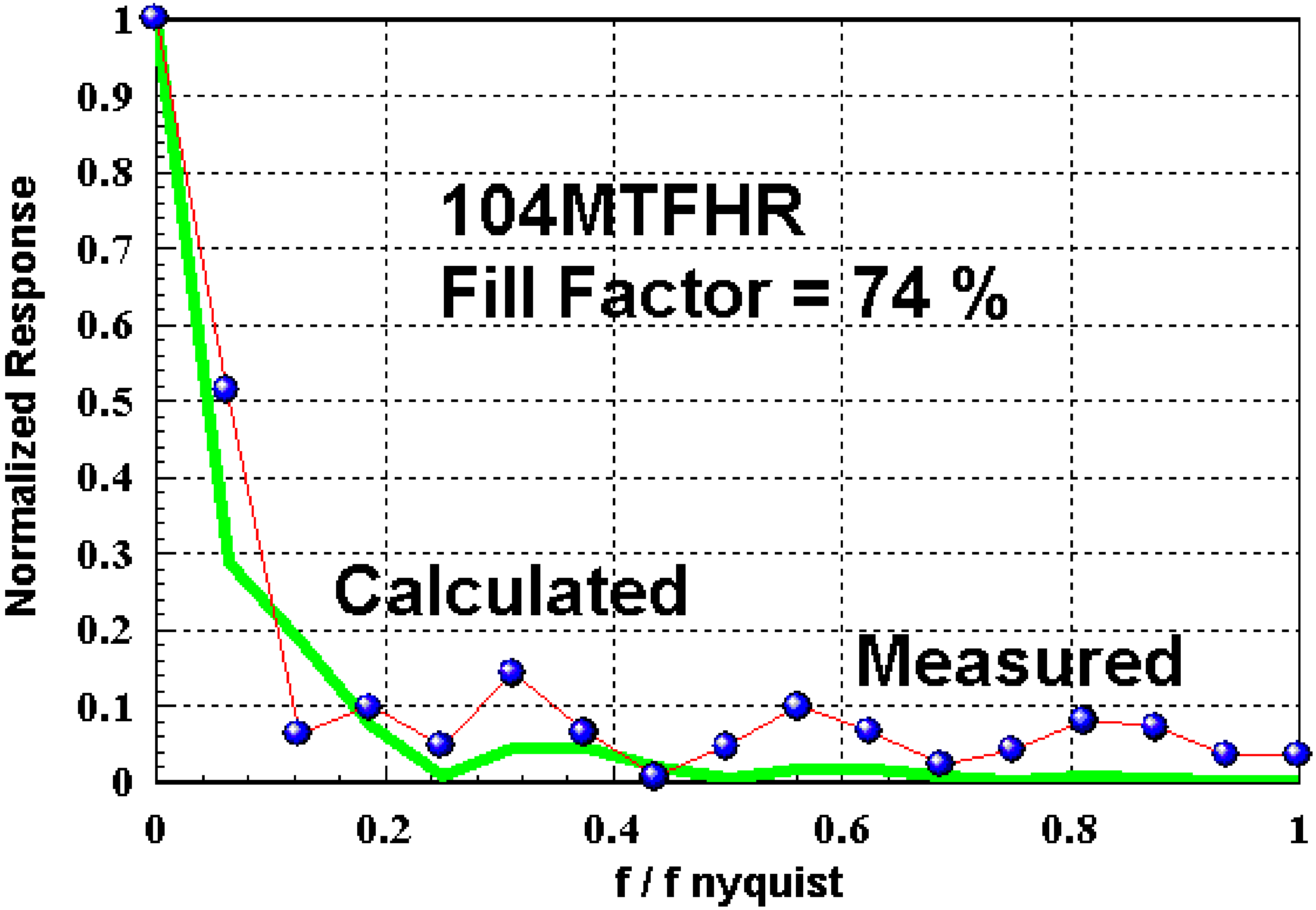
Modulation Transfer Function



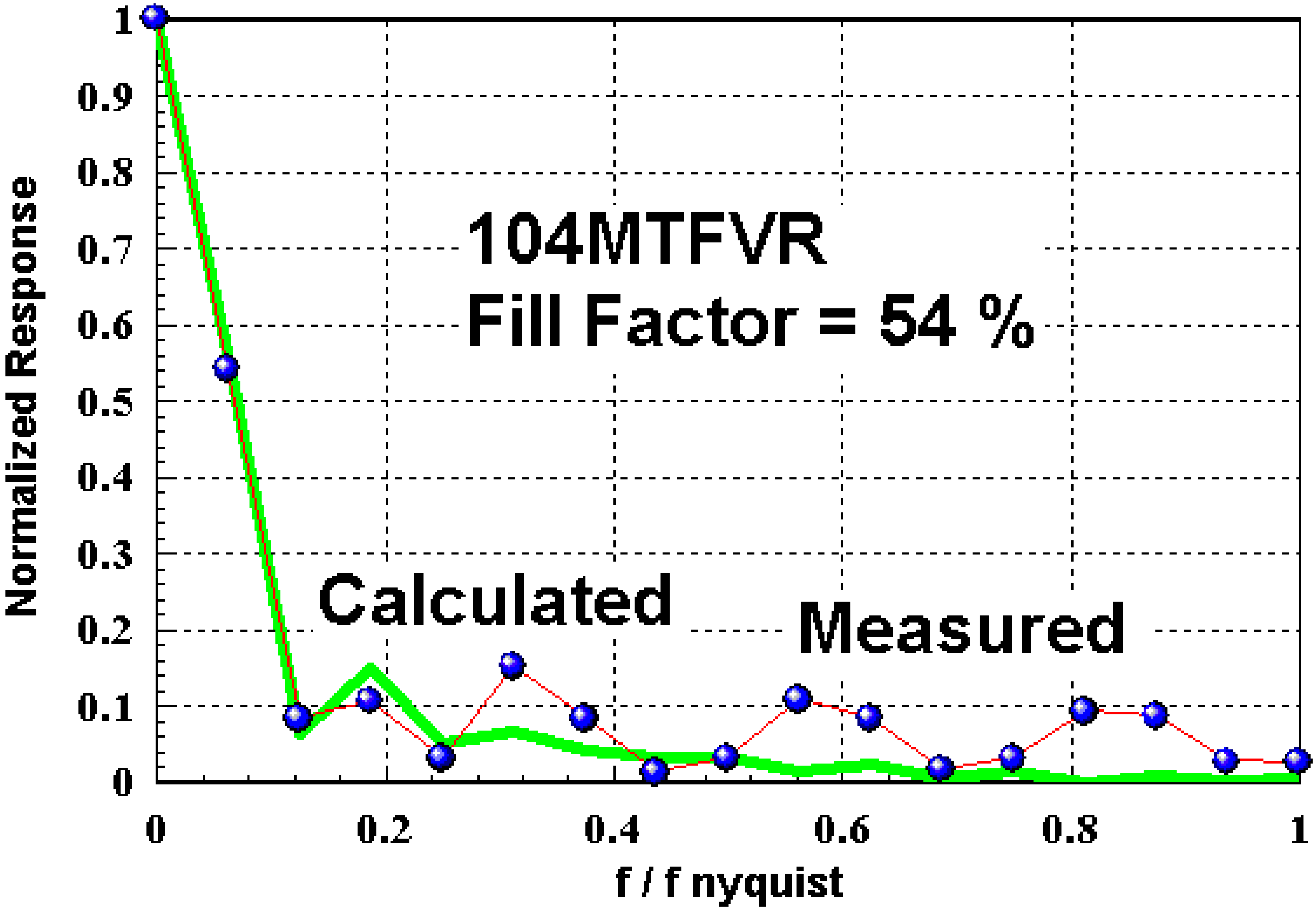
Modulation Transfer Function



Modulation Transfer Function



Modulation Transfer Function



Summary of the MTF

- The performance of active pixel focal plane arrays is characterized by estimating their spatial frequency responses. A modified knife-edge technique that estimates 1-dimensional system MTF profiles is used.
- Advantages of the technique include the need for only a single image to perform the measurement in each direction and the fact that moving parts and high-precision alignment are not necessary.
- Various silicon active pixel sensor array responses that are not affected by the charge transfer efficiency (CTE) were measured and compared with calculated MTF profiles in both the horizontal and vertical directions.
- Calculated ideal pixel MTF of the different fill factor was compared with measured MTF and overall pixel crosstalk effects. Furthermore, it was demonstrated that the technique can be utilized as a timely evaluation technique of the focal plane array pixel design.

Conclusions

- General overview of Space qualification of Optoelectronic and Photonic Devices for space optical communications/Spectrometer was described.
- Efforts were concentrated to generate the needed general guideline of the optical reliability concerns.
- Ultimate goal for this effort is to gradually establish enough data to develop a space qualification plan of newly developed photonic specific parts.
- A numerical model to assess the lifetime and MTF as qualification variables

Acknowledgements

The author is grateful to their numerous colleagues including John S. Koehler, Charles H. Ho and Chris Wrigley of JPL for providing technical assistance for this paper.

The study described in this report was carried out by the Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.