An Overview of Advanced Technologies for Instruments and Spacecraft on Several NASA Missions

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Particles and Fields

Fast Plasma,
Plasma Composition (MMS)
Energetic Particle Analyzers (Messenger, PLUTO, JUNO, RBSP, MMS, SP+)
High Energy Particles (Cassini)
Electric Fields, Magnetic Fields, Waves
Remote Sensing Experiments
In red flight missions with these instrument technologies

Passive remote Sensing
Neutral Atoms (Cassini, Image, Bepi-Colombo)
High, Medium and Low Energy
UV spectrographic Imagers
Visible multi-spectral imagers
IR imaging cameras
X-ray, gamma ray and neutron instruments

Active Remote Sensing
Laser altimeters (Messenger)
LIDAR imagers

High Energy ENA of storm phases (left), and FUV wide-band imaging of the aurora from molecular nitrogen (middle), taken by the IMAGE satellite – passive remote sensing examples. Laser imaging altimeter of the Near mission (right) – active remote sensing.

Figure 1. NEAR will place a spacecraft into orbit about the elliptical asteroid 433 Eros. The asteroid’s dimensions have been estimated at \(36 \times 15 \times 13\) km. NEAR’s optical instruments, including the laser radar, are continuously pointed toward the asteroid’s
Miniaturization of Spacecraft Poses Constraints to Instrument Resources

REVOLUTIONIZING SPACECRAFT MASS: TOWARD A "SPACECRAFT ON A CHIP"

1000 kg

100 kg

10 kg

PAST

PRESENT

FUTURE

CASSINI

MARS PATHFINDER

MARS '98 LANDER

NEAR

SSTI / DISCOVERY

"NEW MILLENNIUM SPACECRAFT"

PLUTO FLYBY

-NPP - 4
New Horizons PEPSSI
Time of Flight vs Energy Particle Spectrometer

Energy range: \(~20\text{KeV} \text{ to } ~1\text{MeV}\) ions and electrons

Mass and Power: \(~1.5\text{ Kg and } ~2.5\text{W}\
Before Miniaturization: >10\text{Kgr, } >10\text{Watts}

FOV: \(160^\circ \times 12^\circ\) solid angle divided into 12 sectors
Bursts of Energetic Ions Stream Down the Tail

Sulfur and oxygen from Io’s volcanic activity
Simplified block diagram of APL’s energetic particle sensor (EPS) on Messenger, Pluto, MMS, etc.

- Energy range: ~5 keV/nuc to ~20 MeV total
- Energy resolution ~2 keV FWHM
- Time of flight range: 0 ns to ~300 ns
- TOF resolution: ~1 ns sensor plus electronics
- FOV: 160 deg @ 6 sectors x 12 deg
- Front end counting rates: >1 meg cps

- Start and stop thin foils and single MCP
- Six start anodes and 6 stop anodes
- Note: start and stop anodes are replaced with 1D delay lines in the new versions for integral time and position sensing

- Six SSD blocks, each block includes one large and one small ion pixel, and one small and one large electron pixel: total 24 channels.

- Simulated TOF vs E ion species tracks
- Note: not fully accurate for actual foil and SSD loses

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The High Energy Neutral Atom Imager on the IMAGE S/C

TOF versus Energy ENA imaging analyzer
Micro – Channel Plate Detectors
  1D and 2D detectors

Solid State Detectors (SSDs)
  Single pixels and multi pixel
  Strip Detectors
  APD detectors
  Pixelated Detectors

ASICs – Time of Flight Chips
TOF chips for precise time and position sensing at low power
Includes: CFDs, TDC, Valid Event Logic, PLL and I/O
Time resolutions as low as 20ps and time span up to 10us

ASICs- Energy chip
Multi channel SSD read out, each channel includes: CSA- Shaper- Active Baseline Restorer – output buffer
Low noise ~1 FWHM with small detectors, ~4keV with large detectors 10pf
Extra wide Energy Dynamic Range 10,000
ASICS- TRIO Smart sensor Chip
16 inputs multiplexed ADC
32 location memory
On chip voltage reference
Serial and parallel read outs
Used in instrument and spacecraft housekeeping such temperature, voltage and current monitoring
Aluminates lots of conventional electronic and wire harness

FPGA Based Even Classification and Memory Mapping
Time of Flight vs Energy processing
Species separation, energy binning and spectra accumulations
Science product generation
Compression and telemetry
**Brief Specifications:**

- Digitizes a Start–Stop time difference in one chip
- Two Constant Fraction Discrs (CFDs), one for start and one for stop
- One 11-bit Time to Digital Converter (TDC), 32-bit also available
- Analog input-digital output with CFD-TDC mode
- Digital Input–Digital output with TDC mode only
- CFD time walk <50ps at 40db input dynamic range
- CFD current dissipation 1.7mA/channel @3.3V
- TDC time digitization adjustable with external clock
- 50ps or 25ps with 40MHz clock, 500ps or 250ps with 4MHz clock
- TDC DNL <0.5LSB and INL <2LSB
- Current 0.5mA @10Kc/sec, 1mA @100kc/sec, 5mA @1Mc/sec
- Vdd 3.0V to 5.5V, Temp –70C to +150C, Rad Hard, no latch-up
- Package 84-pin flat-pack or PGA, also 20-pin
- Qualification u-electronics MIL-STD-883

**Missions**

- **NASA/IMAGE** launched 03/00
  - HENA neutral atoms
- **MESSENGER** launch 05/04
  - MLA laser altimeter, EPS particles, FIPS plasma, XRS X-rays
- **PLUTO/NH** launch 2006
  - EPS particles

**Near Feature Funded Missions**

- MMS
- IBEX
- JUNO
- Several instrument grants
SSD-CSA-Shaper
Amercium source ~60KeV gamma-rays
Standard deviation ~2.5 KeV

Mean: 86.7mV
Standard Deviation: 3.85mV
• 16 analog inputs (extendable to 32 with external MUX)
• 32 10-bit memory locations
• Temperature mode with passive or active sensors
• Voltage mode with single ended voltage sources
• Programmable front-end delay from 1us to 5msecs
• 10-bit ADC up to 100KSamples/sec (internal or external clock)
• ADC Vref+ and Vref- controllable (internal reference or user defined)
• ADC in voltage range 0.5V below GND and 0.5V above Vdd
• Built-in band-gap voltage reference and amplifier
• Standard parallel interface with 10-bit DB and 8-bit AB
• Standard I2C serial interface with 7-bit hard address select
• Built-in time out protection circuit in the serial interface on/off option
• Fixed mode or scanning mode of operation
• 2.8-5.5V PS operation; power dissipation <10mW at all Vdds
• Technology: CMOS 0.8u, Class S qualification, 4 Mrad TID
• Latch-up free, SEU thresholds >120 LET MeV/(mg/cm2)

Some Space Missions
• CONTOUR
• MESSENGER
• STEREO
• PLUTO/ NEW HORIZ
• IBEX_LO
• MMS
• JUNO
• RBSP

Applications
• TVI measurements
• Muxed ADC in instr
Micro-channel plates (MCP), two-stack or three-stack, with flexible active area, geometry and size.

A variety of 1D and 2D delay lines with active areas matching the MCP

- Option of a photo cathode to enhance the efficiency of photon detection
- Option of front foil(s) to increase the efficiency of particle detection.

TOF chip electronics for time of hit and position
Energy Chip Electronics for Charge Measurements
FPGA for data acquisition
Matlab SW for data analysis and visualization

2D Delay Line anode
- active area 8cm x 8cm
- Position resolution ~0.1mm rms
- Time resolution <50ps rms

Front focal plane and back components / preamplifiers
X-Y position measurements
Spacing of mask Holes 1mm

2-D Time, Position and PHA Detector of single particles/photons with: MCP-Cross Delay Line Anode - pair of TOF chips for X-Y and time of hit

General Specs: 4-column data X and Y @ 10umics up to 10-bits per, Time of hit @ 10pico-sec from trigger, 8-bit PHA @ 10MHz

X and Y 35um/bin or 100bins ~ 3.5 hole spacing
Z number of counts

Experiment: 25x25 mm mask with ~0.15mm diameter holes at 1 mm separation. Degraded alpha source with x-ray background
Source to mask 16 cm, mask to MCP 2 cm. Electronics dead time 1u-sec. TOF time resolution set @ 50ps --> X-Y position resolution 35um/bin
X-Y position measurements
Spacing of mask Holes 1mm

2-D Time, Position and PHA Detector of single particles/photons with: MCP-Cross Delay Line Anode - pair of TOF chips for X-Y and time of hit

General Specs: 4-colurnn data X and Y @ >= 10 microns up to 10-bits per. Time of hit @ >= 10 pico-sec from trigger, 8-bit PHA, <= 10 MHz

Experiment: 25 x 25 mm mask with ~0.15 mm diameter holes at 1 mm separation. Degraded alpha source with x-ray background
Source to mask 16 cm; mask to MCP 2 cm. Electronics dead time 1 u-sec. TOF time resolution set @ 50 ps -> X-Y position resolution 35 um/bin
X-Y position measurements

Spacing of mask Holes 1mm

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The Smart/HPCA Plasma Instrument
Lead Organization SWRI
Photos of the HPCA Anode / FEE board

Anode Side
Design approach for Micro-systems
- VLSI technologies
- Mixed signal Analog-Digital Processing
- Low Noise analog and fast digital on the same chip
- System on a Chip includes all necessary support circuits for signal processing, interfaces and command/telemetry
- Design for testability
- Chip-on-board implementation of systems

Issues to be addressed
- Total Radiation Dose
- Single Event Upsets
- Single Event latch-up
- Space Qualification
Radiation Effects in Semiconductor Devices and ICs

- Total Ionizing Dose (TID) effects in MOS Devices

  - Transistor level
    - Threshold voltage shifts due to trapped holes in gate SiO2 layers
    - Drive current shifts
    - Carrier mobility reduction
    - Parasitic leakage currents due to NMOS subthreshold, and parasitic field NMOS transistor conduction

  - Circuit level
    - Performance degradation of analog functions
      » Voltage/current offsets, bandwidth, gain, and stability
      » Lost functionality
    - Performance degradation of digital functions
      » I/O parametric and noise margin shifts
      » Data loss and lost functionality