Miniature Instruments for Probe Missions

Richard Dissly

Ball Aerospace & Technologies Corp

Introduction

Strong desire to minimize the mass of
future planetary entry probes

Instruments are a large lever on system mass
(2x - 3x scaling); but they are only a part of the issue

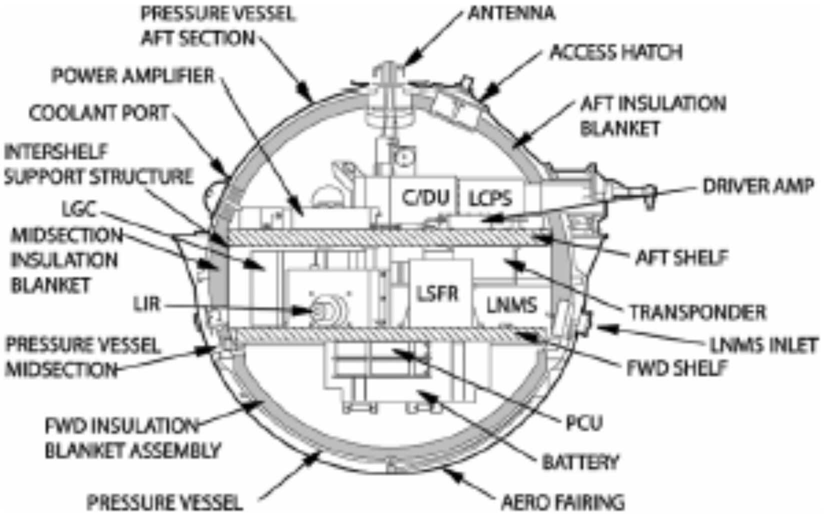
System-level look at what drives probe mass,
and overview of trends in key areas

Presentation Outline

- Historical context – PV and Huygens examples
- Instruments and sensors
- Electronics packaging/integration
- Summary

Context - Pioneer Venus Large Probe

Launch: 5/78
LP mass: 315kg
256 bps DTE
40 A-hr Ag-Zn battery, 28V



Instrument Resources

- Atmospheric Structure Exp **2.3kg, 4.9W**
- Nephelometer **1.1 kg, 2.4 W**
- Cloud Particle Size Spectrometer **4.4kg, 20W**
- Gas Chromatograph **6.3kg, 42W**
- Infrared Radiometer **2.6kg, 5.5W**
- Neutral Particle Mass Spectrometer **10.9kg, 14W**
- Solar Flux Radiometer **1.6kg, 4W**

Total inst mass: **29.2kg**

"Box-level" Architecture

- Each instrument is at least 1 box, often 2
- Stacked on 2 separate shelves
- Cable bundles from power and data busses to each inst
- All inside Ti pressure vessel
- Multiple feedthrus/windows

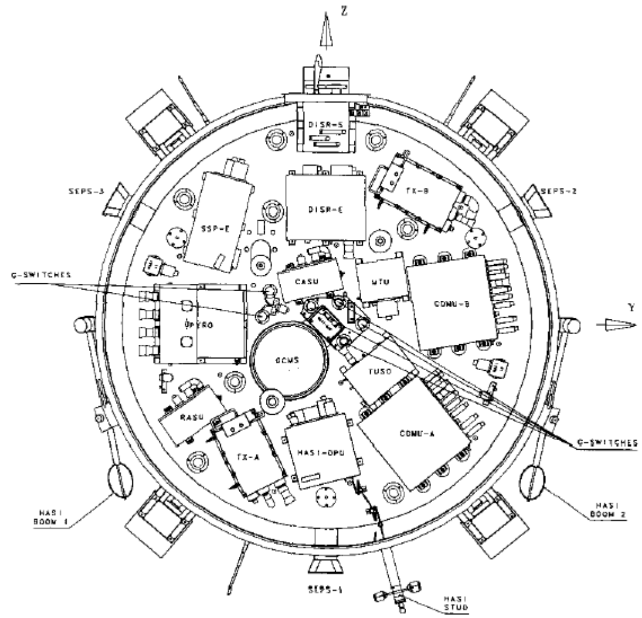
Context - Huygens Probe

Launch: 10/97
Probe mass: 318kg
8 kbps relayed
21A-hr LiSO2 battery, 28V

Instrument Resources

- Atmospheric Structure (HASI): **6.3kg, 15W**
- Doppler Wind (DWE): **1.9kg, 10W**
- Descent Imager/Spectral Radiometer (DISR): **8.1kg, 13W**
- Aerosol Collector and Pyrolyser (ACP): **6.3kg, 3W**
- Gas Chromatograph and Mass Spectrometer (GCMS): **17.3kg, 28W**
- Surface Science Package (SSP): **3.9kg, 10W**

Total inst mass: **43.8kg**



"Box-level" Architecture

- Each instrument is at least 1 box, often 2
- Attached to both sides of single shelf
- Cable bundles from power and data busses to each inst
- Vented to atmosphere
- Multiple feedthrus/windows

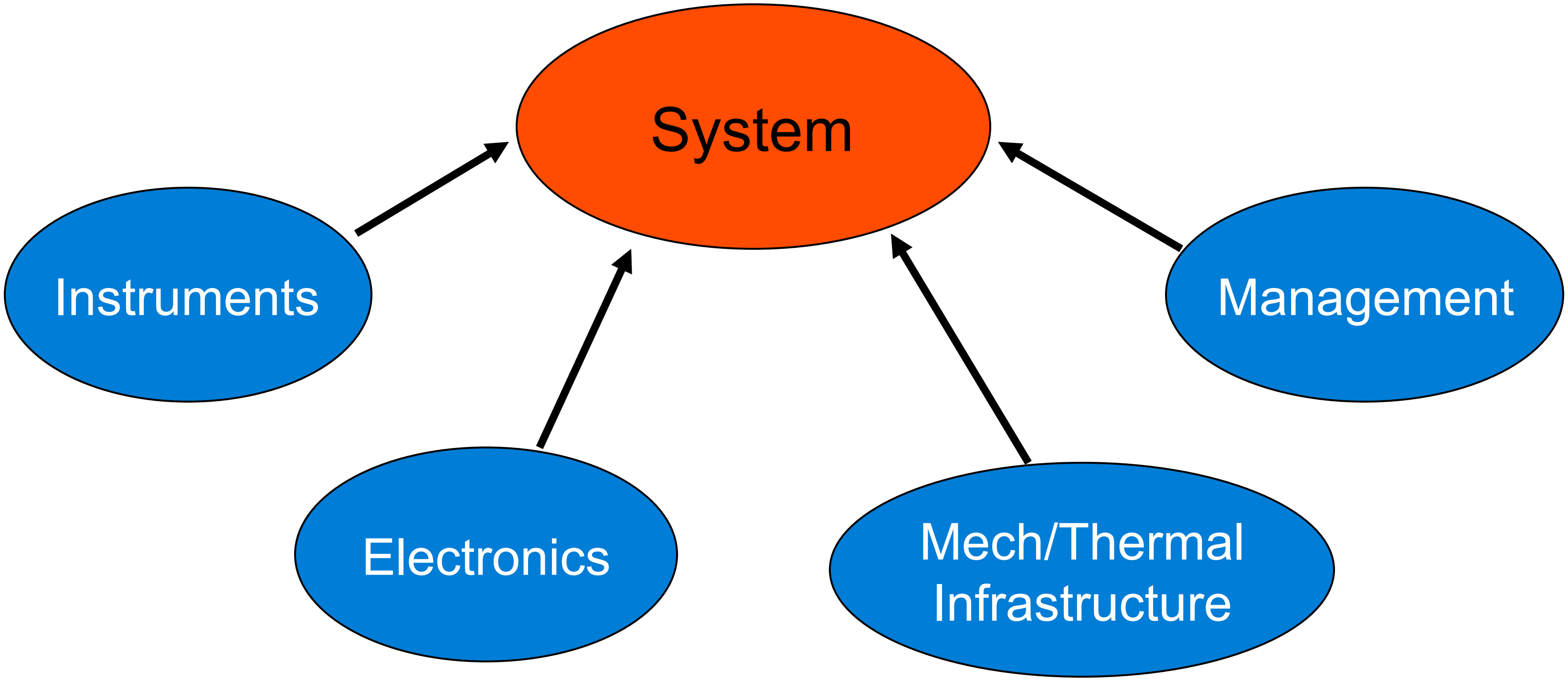
Summary of “where we’ve been”

Previous descent probes were designed as *classical* flight systems

- Designed to be manipulated at the scale of hand-held tools
- Box-level, modular architecture for instruments and subsystems
- Macroscopic cable runs
- Power bus at 28V

Probe miniaturization is a SYSTEM issue

To effectively miniaturize future probes, need to push from several directions:

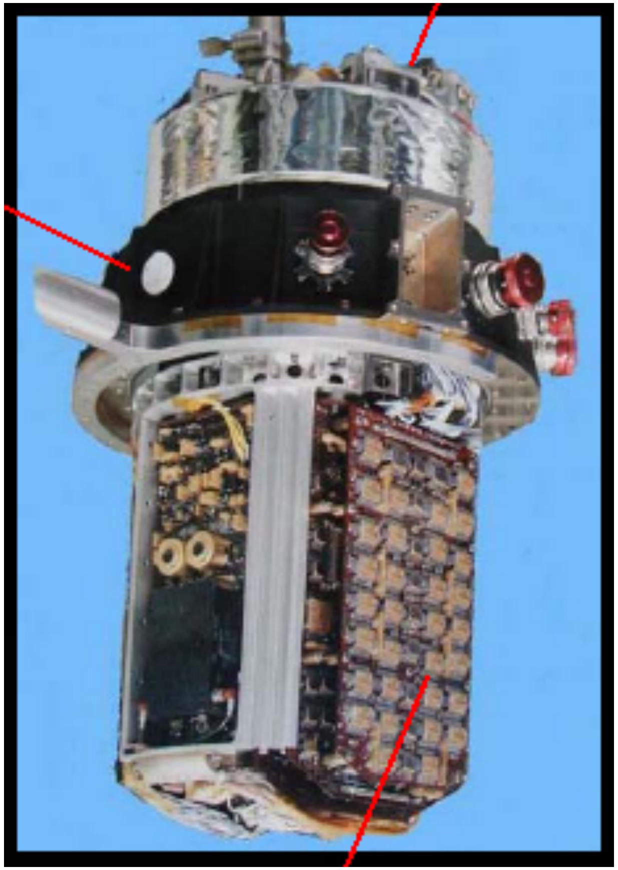


Instrument Miniaturization

Specific Case: Mass spectrometers

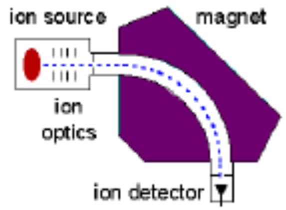
Huygens GCMS

- Quadrupole w/ 3 GC columns
- Mass:17.3 kg mass
- Power (avg): 41 W
- Mass range 2-141 amu
- ~10ppb sensitivity
- Redundant detectors, ion sources
- Multiple ion pumps / getters
- Dynamic range $>10^8$
- Resolution 10^{-6} for adjacent half masses up to 60 u, less for higher masses
- 960 bps



Types of mass spectrometers

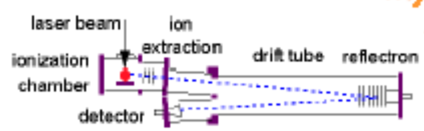
- *Magnetic Deflection* –
  B↑ as r ↓



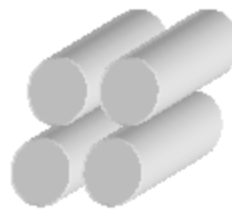
$$m/z = \frac{B^2 r^2}{2V}$$

- *Time of Flight* –
  t ↓ and V ↓ as r ↓

$$m/z = \frac{2Vt^2}{L^2}$$



- *Linear Quadrupole* –
  f ↑ and V_{rf} ↓ as r ↓



$$m/z = \frac{7E6 V_{rf}}{f^2 r_0^2}$$

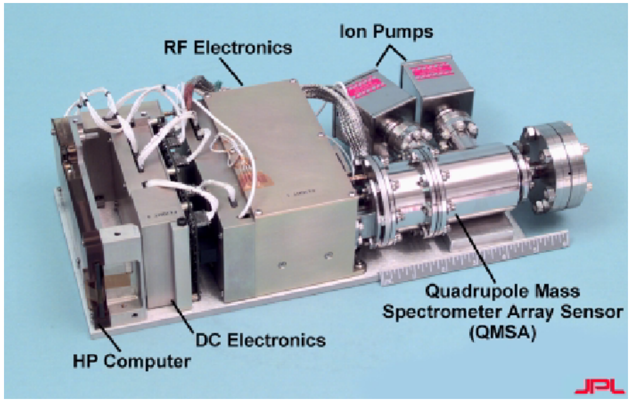
- *Quadrupole Ion Trap* –
  f ↑ and V_{rf} ↓ as r ↓

$$m/z = \frac{8V_{rf}}{q_z (r_0^2 + 2z_0^2)\Omega^2}$$

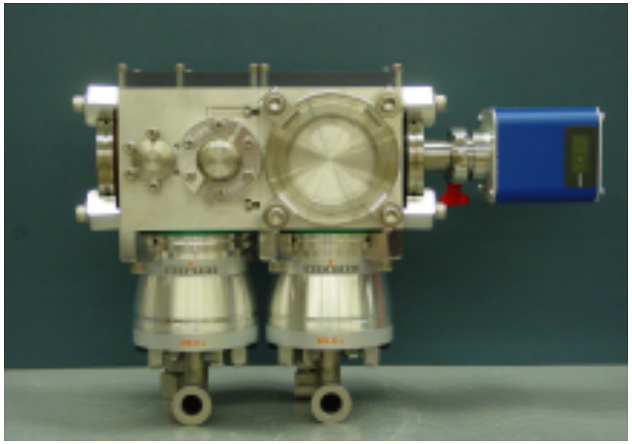
B. Farmer, NJIT, 2003

Compact, rugged mass spectrometers are available in many types

IonWerks Ortho-TOF

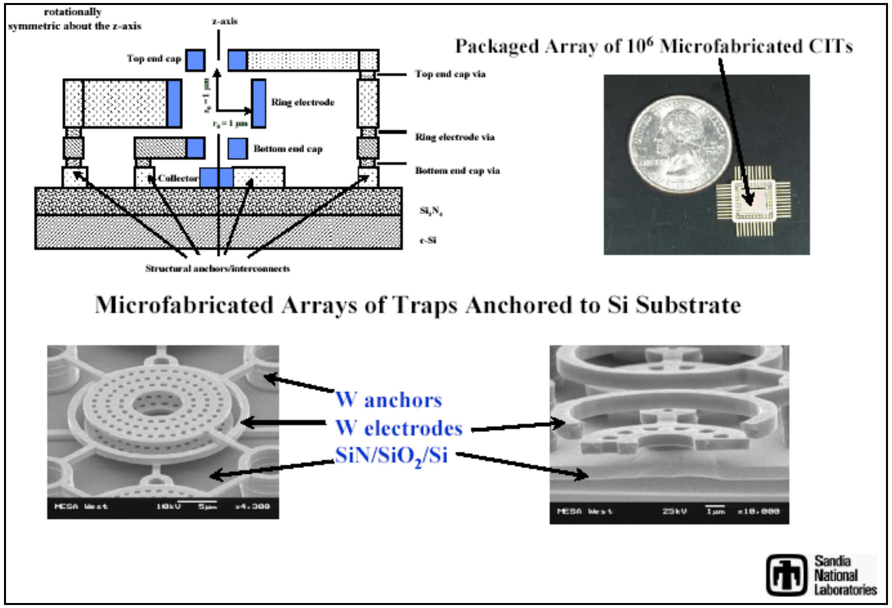


JPL Quad Array (Chutjian, et al)

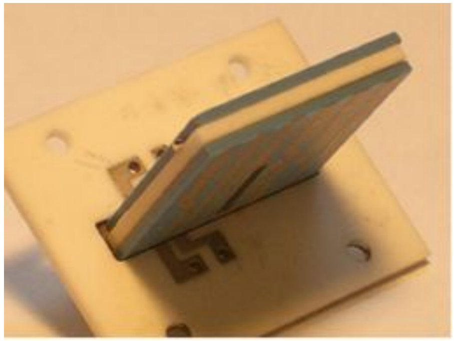


Aston Labs (Purdue) Cylindrical Ion Trap

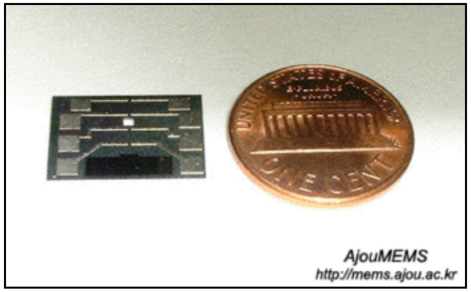
Extreme miniaturization of mass spectrometers



Sandia Nat'l Labs Ion Trap Arrays



Ceramitron double-focusing mag sector



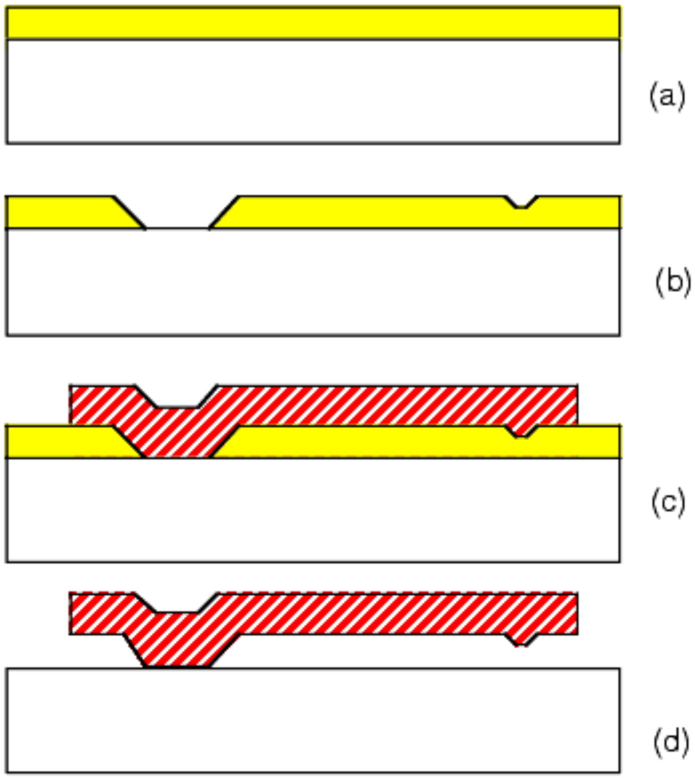
Ajou MEMS TOF

Zyvex MEMS TOF

Technology showing promise, but mass resolution, sensitivity both much less than flight-proven systems

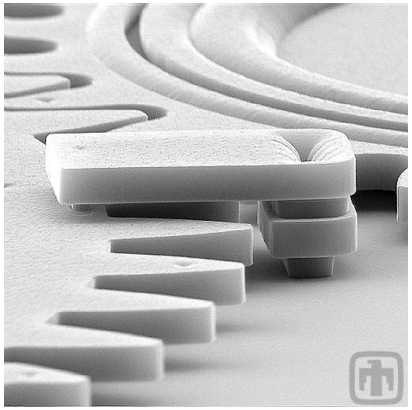
More on MEMS (Micro-Electromechanical Systems)

How MEMS are built



Typical surface micromachining steps: (a) Sacrificial layer deposition, (b) etching of anchor and bushing regions, (c) structural layer patterning, and (d) free-standing microstructure after release

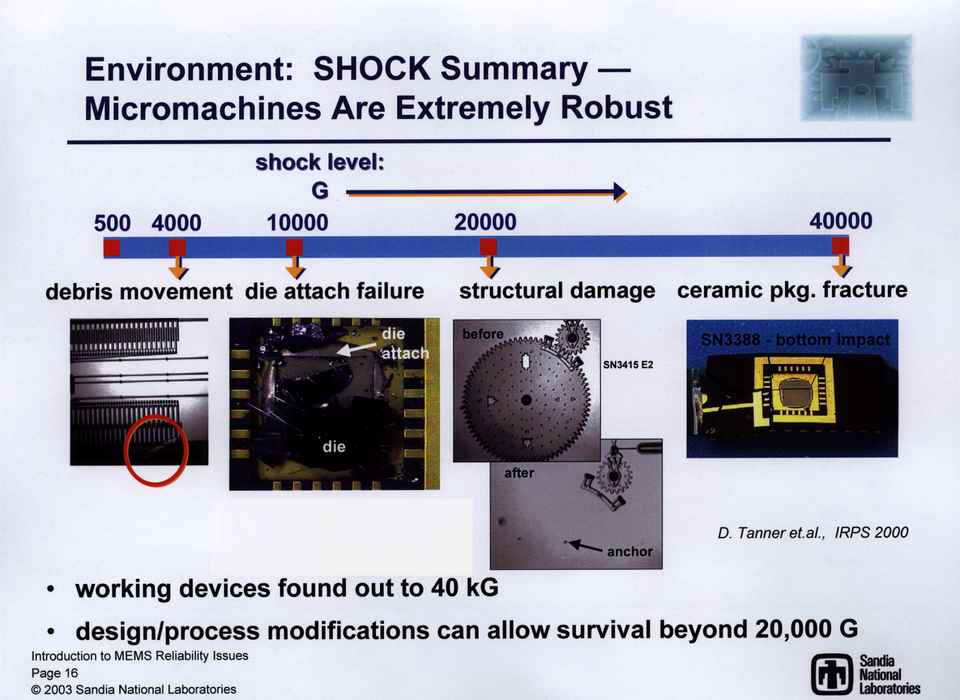
- Micrometer scale machines built using same technology developed in the semi-conductor industry
  - Surface processes using photolithography, plating, etching and electro-mechanical planarization



Sandia National Laboratories

Attributes of MEMS devices - optimal for planetary probe environments

- Very small mass and size
- Very low power
- Functionality over broad pressure and temperature regimes
  - Vacuum to >1000 bar
  - Temperatures from 10s – many 100s K
- High impact, shock, and vibration tolerance
- Tight dimensional control
- Repeatability
- Relatively low cost
- Very high reliability
- Long lifetimes (10^{10} operations w/o degradation)
- Redundancy
- Allows integrated miniaturized instrumentation, multiple measurements, redundancy, and integrated electronics



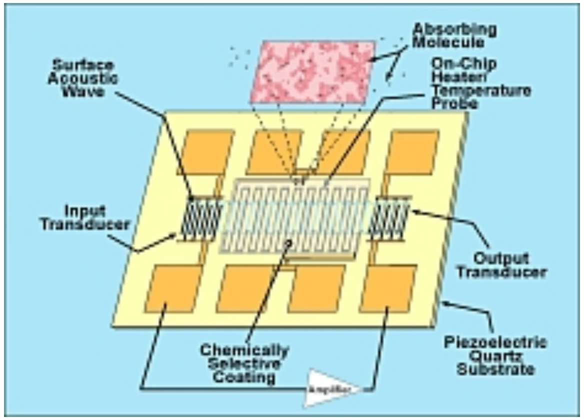
Example MEMS Sensors

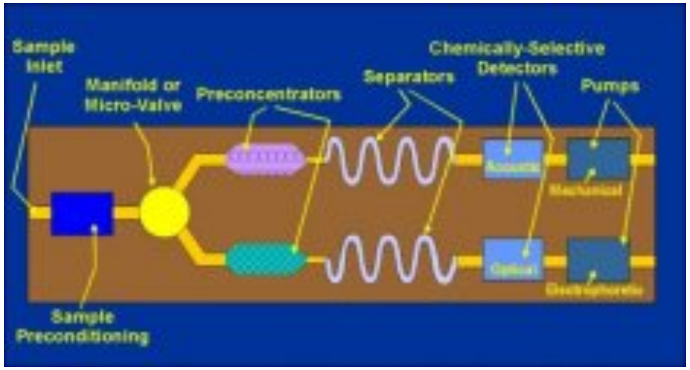
Name	Description	Measurement Range
Atomic Magnetometer	Uses coherent population trapping resonance to probe interaction of atoms' magnetic moment with external magnetic field. Bulk etched wafers to create gas cell in integrated with micro-laser and photo-diode. Total size about 2 mm^3	Sensitivity ~50 picoTesla
Capacitive pressure sensor	Thin membrane over evacuated volume is deflected by external pressure. Deflection is measured by change in capacitance between membrane and substrate.	Pressures to ~ 5bar
Accelerometers	Cantilevered test mass is displaced when external acceleration is applied. Change in capacitance between test mass and rigid sensing electrode give measure of capacitance.	Can measure accelerations > 100g
Humidity	Non-porous nanostructure whose resistively changes as a function of humidity.	Measures from 10-90% relative humidity
Piezoelectric gas sensor	Sensing surface changes volume when in contact with target gas. Piezoelectric techniques are used to measure change in volume.	Material is chosen based on target gas

From D. McComas, IPPW3

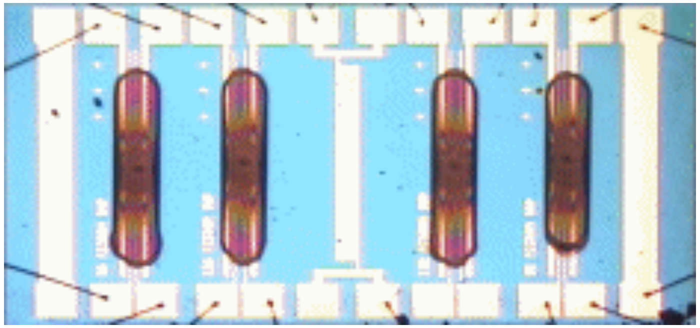
Other miniature chemical sensors

Surface Acoustic Wave (SAW) Sensitive to tiny mass changes (sub monolayer). Coated with a chemically selective thin film. Piezoelectric quartz as a substrate





MEMS Lab-on-a-chip – GC, pumps, detectors at mm-scale



Chemiresistive sensors
Measures resistivity change in chemically selective thin films

Images Courtesy
Sandia Nat’l Labs

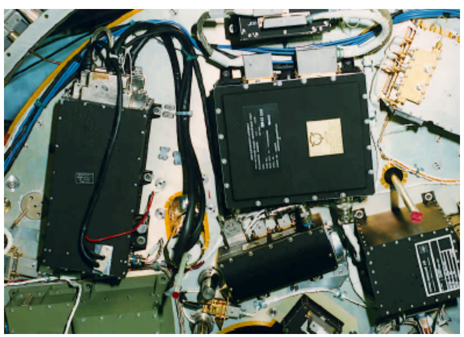
Electronics Miniaturization

Electronics miniaturization – packaging trends

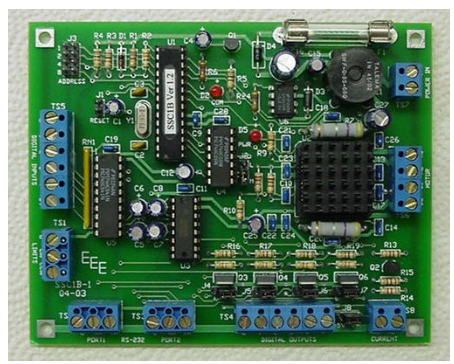
Flight will follow trends in commercial electronics:

Continuous demand for smaller, lighter, more power efficient products

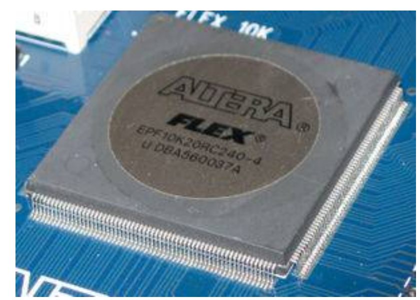
Evolution of Flight Instrument Control



Box-level



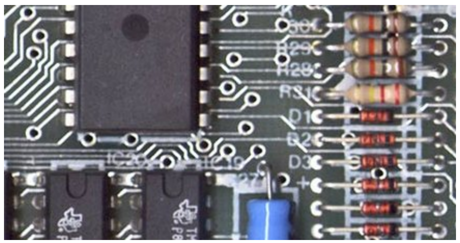
Board-level



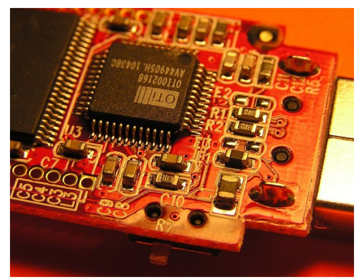
Field Programmable Gate Array
or
Application Specific Integrated Circuit
(System-on-a-Chip)

Electronics miniaturization – circuit design trends

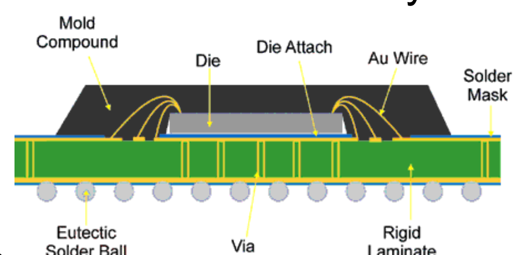
PCB with thru holes



Leaded surface mount



Ball Grid Array



Smaller Packaging, Lower Power

Additional Thoughts

- Smaller instruments and supporting systems are under continuous development
- Probe miniaturization ultimately relies on tighter system integration
  - Maintaining modularity may be difficult
  - Pushing integration to the limit can be difficult programmatically with many different players involved
- The next step in flight miniaturization relies on moving away from macroscopic scales