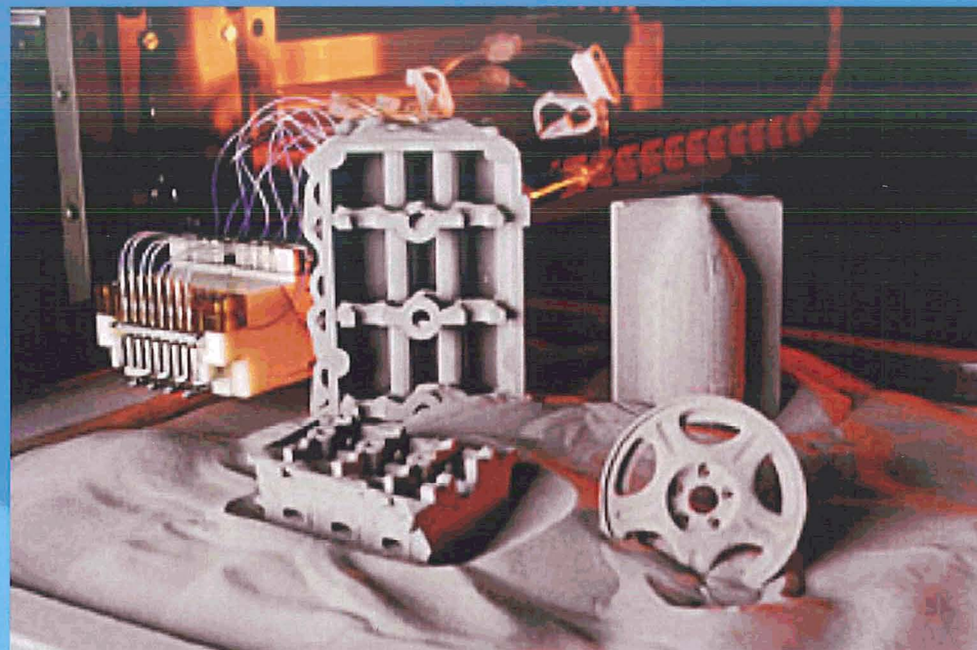
National Aeronautics and Space Administration
Marshall Space Flight Center



In Situ Fabrication Technologies

Technical Interchange Meeting

University of California - Berkeley • May 16-18

Explore. Discover. Understand.

ISFR-Fabrication Technologies: Introduction

Goals:

Purpose of visit

- Introduce the In Situ Fabrication and Repair (ISFR) Element, specifically the Electronics Fabricator
- Understand your strengths/capabilities
- Outline high-level strategies for potential collaboration

ISFR-Fabrication Technologies: Description

Fabrication Technologies is a sub element of the In Situ Fabrication & Repair (ISFR) element

— Supports long duration spaceflights by providing contingency manufacturing capabilities for the moon and Mars exploration missions

— Fabrication Technologies provide fabrication of tools, parts and structural components using in situ, recycled and provisioned resources (via a Multi-Material Fabricator)

— Materials investigated will include metals, plastics, composite and ceramics, through use of additive and/or subtractive techniques

— Trade Studies completed in FY05 identify leading technologies for further development in FY06

— Electronics Fabricator is a stand alone effort with some synergy with the Multi-Material Fabricator

— Dr. Terry D. Rolin has been assigned project lead on the Electronics Fabricator effort to initiate early activities in order to aggressively approach technology development activities in FY06

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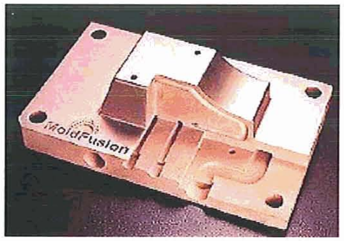
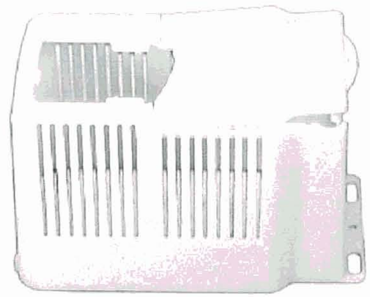
In Situ Fabrication and Repair Fabrication Technologies: Overview

Metals

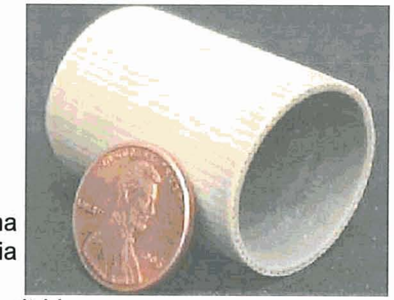


• Replacement Parts
• Unforeseen Tools
• Conformal Repair Patches
• Habitat Fittings

Plastics

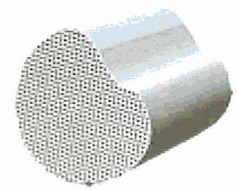


Ceramics



• Alumina
• Zirconia
• Silica
• Silicon nitride
• Misc. oxides

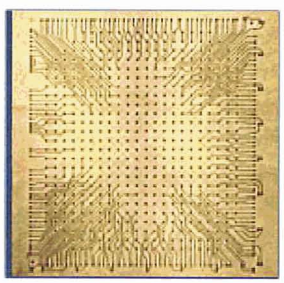
Biological



• Biodegradable bone supports
• Tissue, skin, dental & organ applications

Electronics

• PC Boards
• Discrete Components
• Crew Displays
• Area Lighting



ISFR-Fabrication

- In-Transit Tools & Parts
-On-Surface Tools & Parts

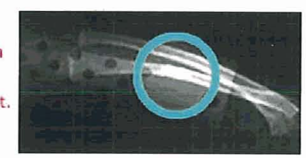
-Trade Study of Processes: Additive, Subtractive, Hybrid

Manufacturing Processes ⟷

•Three Dimensional Printing
•Computer Numerical Control
•Direct Metal Process
•Electron Beam Freeform Fabrication
•Electron Beam Melting: Distributed by Vendor "Arcam"
•Fused Deposition Modeling
•Kinetic Metallization
•Laser Engineered Net Shaping
•Laminated Object Manufacturing
•Precision Metal Deposition
•Stereolithography
•Selective Inhibition of Sintering
•Selective Laser Melting
•Selective Laser Sintering
•Ultrasonic Object Consolidation

⟷ **Products**

The first eight weeks include a controlled rate of bone overgrowth and rate of implant breakdown while using an outer supporting cast.



6.) First 8 Weeks

7.) 8 Weeks Growth

After eight weeks the implant has bonded well to the natural bone ends and the supporting cast can be removed.

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Fabrication Technologies – Scope

ISFR – Fabrication Technologies

- In-Transit & Surface Products
- Replacement Parts
- Unforeseen Tools
- Conformal Repair Patches
- Habitat Fittings
- ECLSS Parts
- Exercise Equipment
- Elastomer Seals

Metals

- Aluminum Alloys
- Titanium Alloys
- Stainless Steels
- Super alloys
- Others TBD

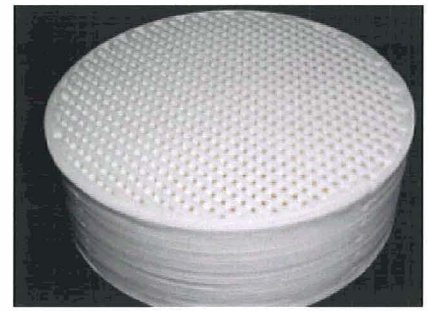
Stainless/Bronze Gear

Aluminum Gear

ECLSS Vapor Compression Distillation System

Ceramics

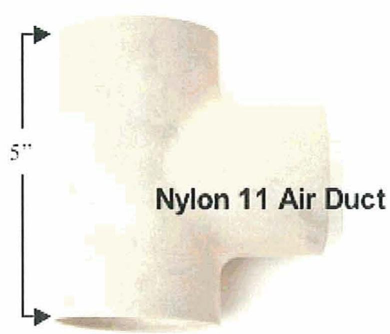
- Alumina
- Zirconia
- Silica
- Silicon nitride
- Others TBD



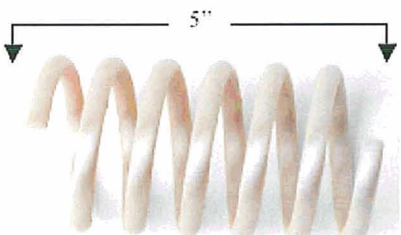
Alumina Filter

Plastics

- ABS Plastics
- Poly Carbonate
- Polyphenylsulfone
- Others TBD



Nylon 11 Air Duct



Polyphenylsulfone Spring

Composites

- Fiber/Resins
- Amalgams
- Infiltrated Structures
- Others TBD

Alumina/Molybdenum Cermet Traces on Alumina Rod Integral Heater Element

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Core Capability: Fabrication of Multi-Material Parts Up To 18" x 18" x 18" in Hypo-G & Micro-G
Sub-Capabilities: Metal, Plastic, Ceramic & Composite Parts; Integral NDE for QA & Process Control

Capability Description

- Manufacturing system internal to controlled cabin environment to produce functional parts to net shape with sufficient tolerances, strength and integrity to meet application specific needs such as CEV ECLS components, robotic arm or rover components, EVA suit items, unforeseen tools, conformal repair patches, and habitat fittings among others.
- Except for start-up and shut-down, fabrication will be automatic without crew intervention under nominal scenarios. Off-nominal scenarios may require crew and/or Earth control intervention.
- Parts build processing files may be loaded from in-situ library or from Earth.
- Integral NDE functions will provide QA & process control as well as ability to scan in existing part surface geometry for modifications or repair.
- System will have ability to fabricate using both provisioned feedstock materials and feedstock refined from in situ regolith.
- Furnace station will provide post build heat treatment, sintering and porous part infiltration functions.

Assumptions

- Power will be available up to 48 hours continuously from carrier or habitat to perform complete build cycle.
- Crew will be available to exchange feedstock, transfer parts to heat treatment furnace, perform parts cleaning, and remove parts.
- Crew will be available to provide support for off-nominal operation scenarios.

Spiral Applicability

Spiral 3, 4, 5: System will be plug and play once landed using power from carrier vehicle, cargo transfer module or habitat module. Once powered up and feedstock is loaded, system will be ready to fabricate hardware. Spiral 5 system will add Mars regolith products to materials processing set compared to Spiral 3 Lunar system.

Metals

Electronics

Plastics

Ceramics

- Replacement Parts
- Unforeseen Tools
- Conformal Patches
- Habitat Fittings
- ECLS Parts
- Robotic Rover Components
- Thermal Management Parts
- Radiation Shielding Panels

Composites

Product Performance Characteristics

Product Materials	
Metal	Ti6Al4V, Al2219, Al6061,SS304, SS316, W
Polymer	Polycarbonate, PPS, Polyimide
Ceramic	Oxides, Nitrides (e.g. Alumina)
Composite	Resins, Cermets, FGMs
Exclusions	Materials w/M.P. > 2,500 C may require bulk feedstock machining
Product Environ. (IVA, EVA)	Application Specific
Product Strength	≥ 70% of Wrought Values
Product Geometry	3D Contours, Internal Channels, Overhangs, Undercuts, etc.
Product Tolerances (inches)	L ≤ 6: ±0.005; L > 6: ± 0.005 in/in
Product Surface Finish	≥ 32 μ-in RMS
Product Life; Restrictions	Application Specific; None
Product Availability Time	Less than 48 Hours

Capability Infrastructure Characteristics

Operational Gravity	Hypo-g & Micro-g
Operational Environment	Cabin IVA; T=10-35 C, P=10-15psia
Shelf Life; Operating Life	5 years; 5 years
Operating Mode	Crew Tended
System Reliability	≥ 95% Uptime

In-Situ Fabrication of Electronics: Phase I

Instrument and Payload Systems Department— Dr. Terry D. Rolin, Project Lead

Objectives:

- Understand current state of the art techniques and technology levels of 3-D electronic design and prototyping to accomplish art to part for electronic components and assemblies
- Understand the feasibility of producing electronic boards with both internal components (embeddeds) and/or piece parts (resistors, capacitors, diodes, etc.)
- Understand materials available on lunar surface for feedstock (iron, silicon, aluminum, etc.) as well as novel material concepts (conductive inks and polymers)
- Layout requirements for approach to Phase II

Approach:

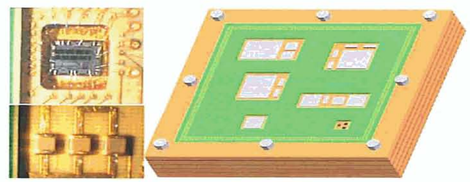
- Capture current knowledge base by research, conference participation, and travel as necessary
- Current understanding and test data indicate that passives are more prevalent and have higher fail rates therefore we must pursue fabricating them first
- Perform initial evaluation testing and fabrication of passives using current onsite technology
- Establish teaming relationships that will aid in faster Spiral development

Challenges:

- Transforming terrestrial processes to microgravity processes
- Power
- Fabrication of piece parts that are multi-material and assemblies that are multi-material and multi-component

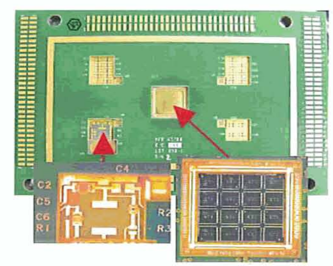
Benefits:

- Lower mass and volume for terrestrial launch
- Repair or replacement of failed parts onsite and on time
- Potential for future injection of novel fabrication techniques into commercial sector



MSFC Model of Stacked Substrate Embedded Component (solderless box-less cube) 400-600% size reduction

Embedded Subassembly



Why Instrument and Payload Systems Department?

- Rapid prototyping technologies are present at the center to serve as a first phase test bed
- Our packaging team alone has over 150 years of combined experience working electronic fabrication issues and problems both in-house and at contractor facilities
- We have authored or co-authored numerous MSFC, NASA and industry process standards for fabrication of electronics
- Extensive experience and capabilities in assembly, thermal test and failure analysis

Electronic Fabricator Capability Evolution Roadmap

Current State of the Art: Rapid prototyping technologies are advancing but....

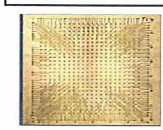
- Currently not possible to build complex circuits on substrates through automated process
- Currently no standards for design, test, and FA of the piece parts
- Currently no push to move capability from terrestrial to microgravity environment

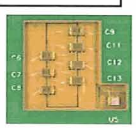
Phase I - FY05

- Conduct trade study to determine; what electronic fabricator technologies are out there; what level they stand; and where are they located
- Work with NCAM at MSFC to understand rapid prototyping techniques (materials, designs, etc.)
- Visit research facilities to establish potential teaming relationship

FTE: 2.5
Materials Eng (1)
Rapid Proto. Spec. (1)
Project Eng. (.5)

WYE (Partner): 2
Ph.D. EE (1)
Post Doc Materials/Chemist (1)





Initial focus must be on passives due to their high percentage of failure rate combined with large volume needed for electronic assemblies

Phase II –FY06

-Technology at TRL 3
- Work with packaging design team to design passives
-Work with partner to initialize building of passives
- Perform full testing and failure analysis on passives
- TRL-3 at completion of Phase II

FTE: 8
Materials (1)
Rapid Prototyping (1)
EEE Packaging (1)
EEE Failure Analyst (2)
EEE Parts (1)
Technician (1)
Project Eng. (1)

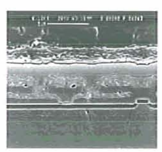
WYE (Partner): 2
Ph.D. EE (1)
Post Doc Mat./Chem. (1)

Phase III – FY07/FY08

- Begin investigation of multi-materials for passives and closed loop control
- Conduct trade analysis to push more viable process as lead technology
- Begin building of MSFC prototype that mimics partners technology
- TRL-4 at completion of Phase III

FTE: 10.5
Materials (1)
Rapid Prototyping (1)
EEE Packaging (1)
Software Designer (1)
EEE Failure Analyst (1)
EEE Parts (1)
Mechanical Design (.75)
Mechanical Fab (1)
Technician (1)
Project Eng. (1)
Robotics Eng. (.75)

WYE (Partner): 3
Ph.D. EE (1)
Post Doc Mat./Chem. (2)

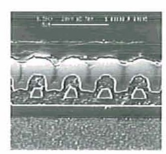


Phase IV – FY09

- Increase materials to include refined regolith products where applicable
- Test MSFC prototype under relevant conditions
- Begin investigation of passives deposited directly on substrate and embeddeds
- Fabrication prototype for passives and some discretes will be at TRL-5 at completion of Phase IV

FTE: 11
Materials (2)
Rapid Prototyping (1)
Software Designer (.75)
Space Environments (.75)
EEE Packaging (1)
EEE Failure Analyst (1)
Mechanical Design (.5)
Mechanical Fab (1)
Project Eng. (1)
Technician (1)
Test Eng. (1)

WYE (Partner): 3
Ph.D. EE (1)
Post Doc Mat./Chem. (2)

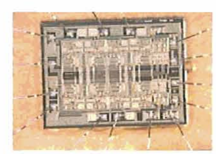


Phase V – FY10

- Characterize and redesign based on prototype tests
- Optimize functionality for lunar environment
-Test and optimize under relevant conditions (vibration, thermal extremes, etc.)

FTE: 11.75
Materials (1)
Rapid Prototyping (1)
EEE Packaging (1)
Software Designer (.5)
Space Environments (.5)
EEE Failure Analyst (1)
Mechanical Design (1)
Mechanical Fab (2)
Robotics Eng. (.75)
Project Eng. (1)
Technician (2)

WYE (Partner): 3
Ph.D. EE (1)
Post Doc Mat./Chem. (2)

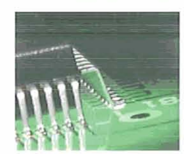


Phase VI – FY11/FY12

- Begin building MSFC fabricator that is positioned for flight qualification
-Test flight applicable prototype components (ink jets) in a microgravity environment (KC-135?)
- Perform full DPA on samples fabricated in microgravity environment
-Prototype at robust TRL-6

FTE: 14
Materials (1)
Rapid Prototyping (1)
EEE Packaging (1)
Software Designer (.5)
Space Environments (.5)
Test Eng. (2)
EEE Failure Analyst (2)
Mechanical Design (1)
Mechanical Fab (2)
Technician (2)
Project Eng. (1)

WYE (Partner): 2
Ph.D. EE (1)
Post Doc Mat./Chem. (1)



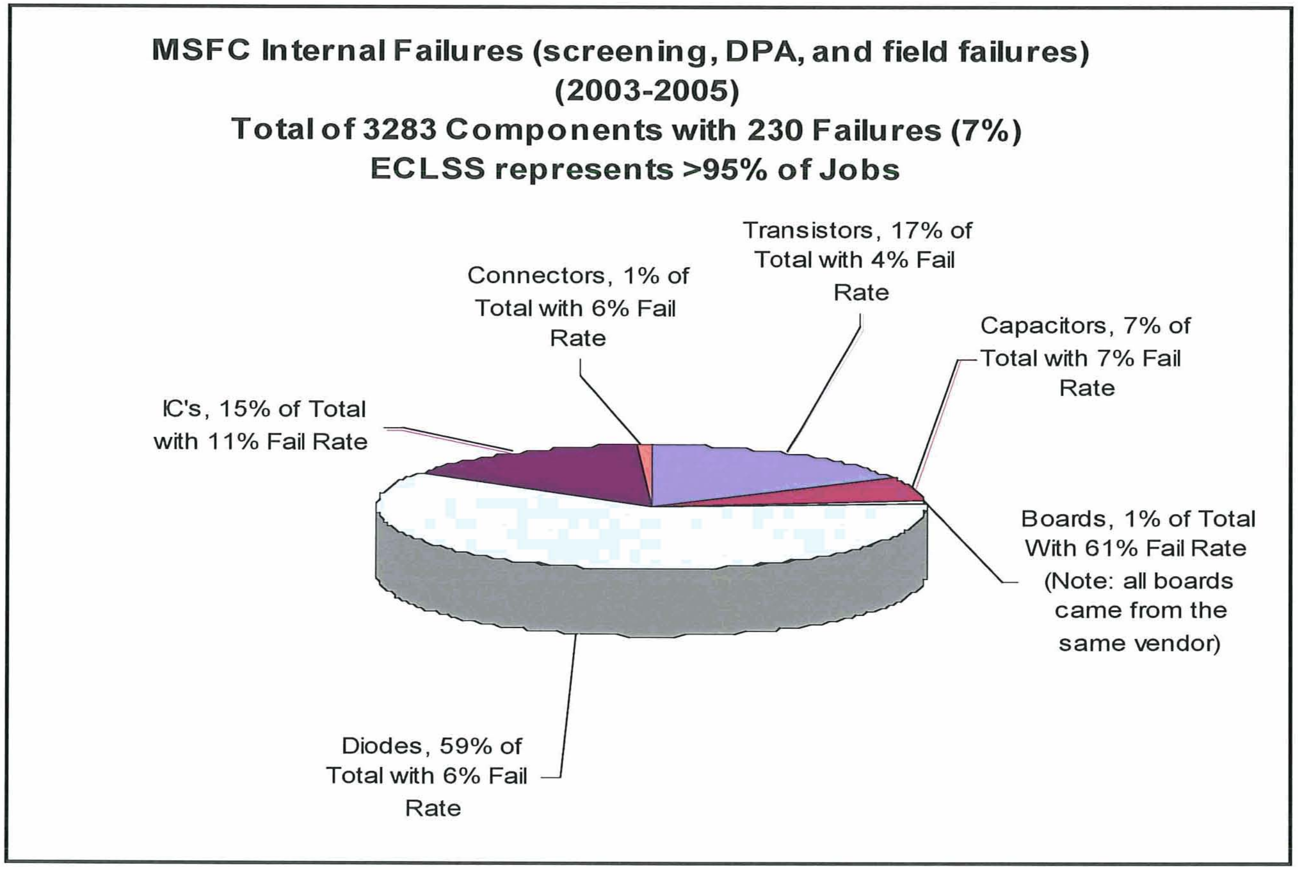
DATA FROM A RECENT PAPER BY LLOYD CONDRA OF
BOEING AEROSPACE PHANTOM WORKS

- **PROJECTED PIECE PART REQUIREMENTS 2003-2010**

• **MICROPROCESSORS**	**444,000**
• **MEMORIES**	**668,000**
• **OTHER ICs**	**11,200,000**
• **DISCRETES**	**20,000,000**
• **PASSIVES**	**114,000,000**
• **MISCELLANEOUS**	**84,000**

Clearly the bulk of electronics failures will come from passives

MSFC Screening and FA Results



Typical Failure Mechanisms

Note: Most failures came from manufacturer, not during use in the field

Transistors: ESD, EOS, thermal runaway, failure to meet spec
Capacitors: Dielectric leakage, failure to meet specs
Boards: Workmanship, failure to meet specs

Diodes: ESD, EOS, failure to meet specs
IC's: ESD, EOS, failure to meet specs
Connectors: Workmanship, failure to meet specs

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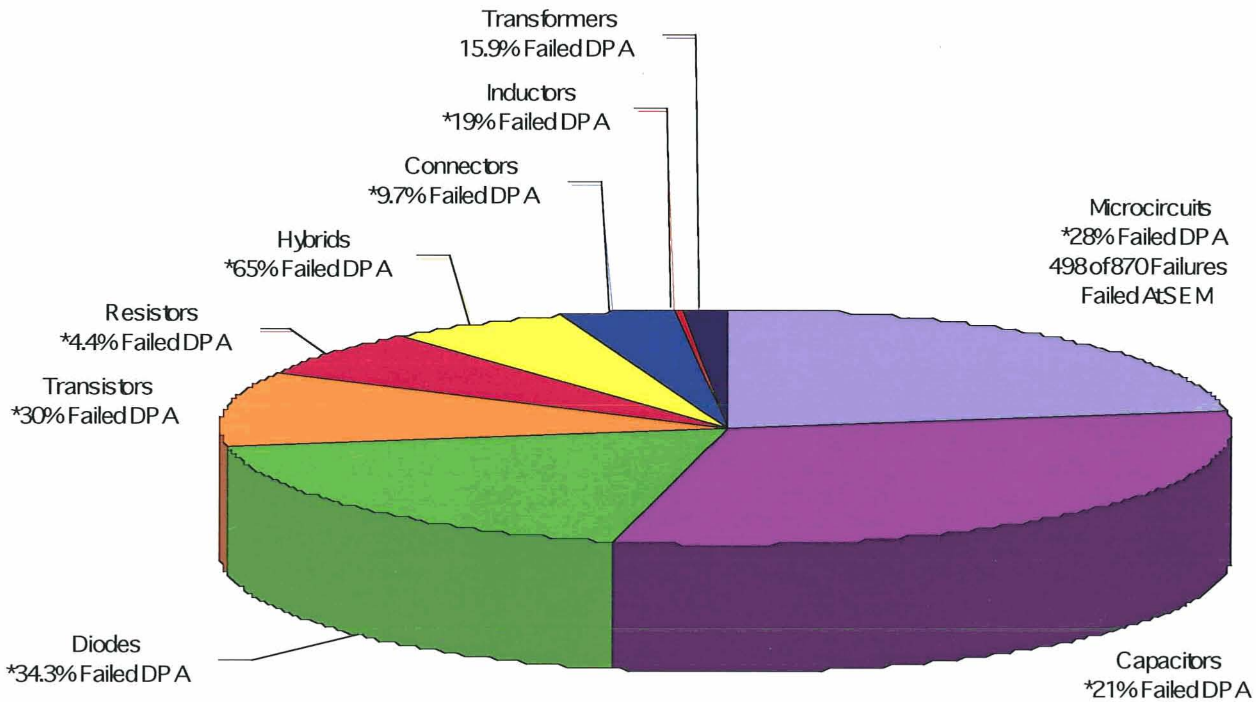
DPA (Destructive Physical Analysis) Results Within Part Type Distribution For 1989-90, 97-99 (11,442 DPA's Performed) Overall DPA Failure Rate Was 25.4%

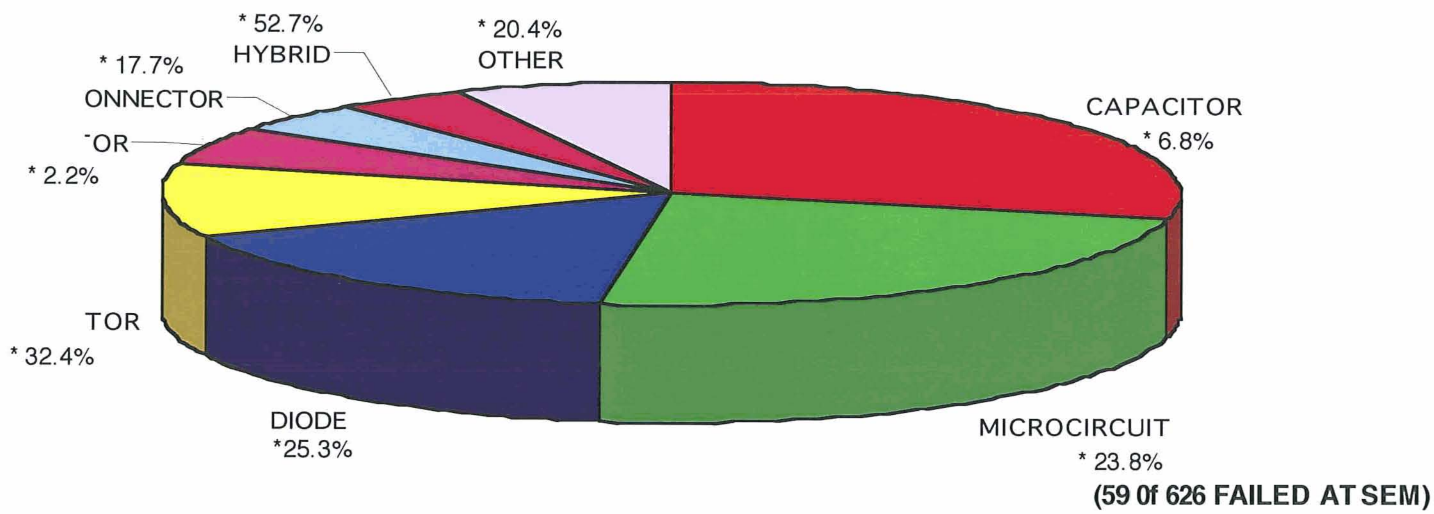


*Denotes DPA Failure Rate per DPA's performed

Diodes and capacitors represent approximately 50% of the 11,442 DPA's performed

Note: Passives represent the largest percentage of total failures

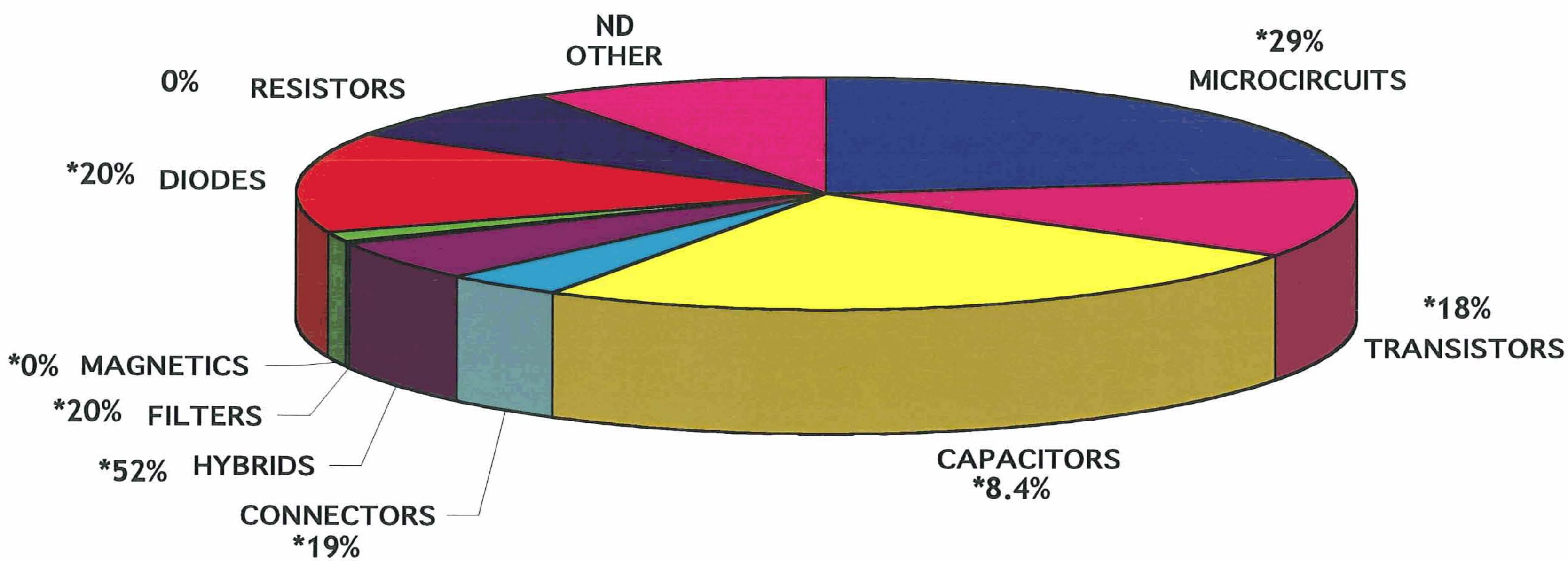
DESTRUCTIVE PHYSICAL ANALYSIS (DPA) RESULTS WITHIN PART TYPE DISTRIBUTIONS FOR 01/2001 – 01/2002 TOTAL DPA FAILURE RATE WAS 19.7% (2633 DPA'S PERFORMED)



*Denotes DPA Failure Rate

CAPACITOR	MICROCIRCUIT	DIODE	TRANSISTOR
RESISTOR	CONNECTOR	HYBRID	OTHER

2003 DPA RESULTS



*** DPA FAILURE RATE WITHIN PART TYPE DISTRIBUTIONS FOR YEAR 2003 (2240 DPAs PERFORMED). 18% OVERALL FAILURE RATE OBSERVED.**

ISFR-Fabrication Technologies Summary

- **Based on recent failure analyses, NASA recognizes the need to use novel/cutting edge technologies for electronics fabrication**
- **Electronic Fabricator is a complement of the Fabrication Technologies Program Operating Plan FY06 baseline budget submit**
- **Additional "out year" funding is contingent on relevancy to program objectives, with a development process current with the technology development spirals phased to support the fundamental spirals defined for Human Exploration of Space Program**
- **What we desire is:**
  - Expertise in developing the materials/feedstock for electronic fabricator concept/application
  - Initiate hardware development activities, to include breadboard fabrication and integration

ISFR-Fabrication Technologies: Contacts

- Monica Hammond/SY10 Project Manager

  544-7141

- Richard Hagood/SP33 Systems Engineer

  544-4922

- Dr. Terry D. Rolin/EI42 Electronics Fabrication Lead

  544-5579

For more information…http://est.msfc.nasa.gov/ISFR/fab.html

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