N93-26978

AEROSPACE TECHNOLOGY DIRECTORATE — POWER TECHNOLOGY DIVISION — NASA Lewis Research Center

NUCLEAR PROPULSION

TECHNICAL INTERCHANGE MEETING

OCTOBER 20-23, 1992

Power Management and Distribution Technology

John Ellis Dickman

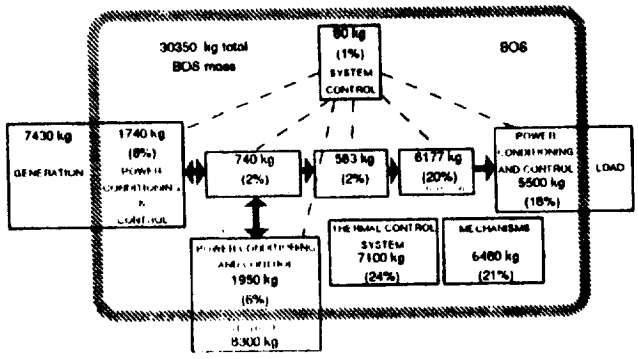
OCTOBER 21, 1992

AEROSPACE TECHNOLOGY DIRECTORATE — POWER TECHNOLOGY DIVISION — NASA Lewis Research Center

APPLICATIONS AND SYSTEMS DEFINITIONS

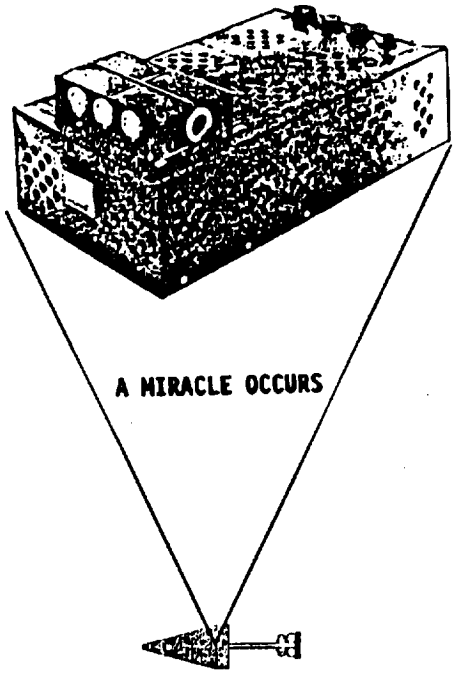
OBJECTIVES:

- DEFINE PMAD TECHNOLOGY REQUIREMENTS FOR ADVANCED SPACE MISSIONS, e. g. SSF EVOLUTION, LUNAR/MARS BASES, ADVANCED SPACECRAFT, PLATFORMS AND VEHICLES.



ACCOMPLISHMENTS:

- DEVELOPED MASS DATABASE OF EXISTING AND SOA SPACE SYSTEMS
  - PMAD MASS RANGES FROM 40 TO > 220 kg/kW
  - NEW CLASS OF "SPACE UTILITY" POWER SYSTEMS EVOLVING
  - "BALANCE OF SYSTEM" (PMAD, THERMAL, MECHANICAL) ARE MAJOR MASS CONTRIBUTORS (e. g. BOS IS 2/3 OF SSF POWER SYSTEM MASS)



POWER PROCESSING, CONTROLS, AND DISTRIBUTION

STATE-OF-THE-ART

25-100 kg/kWe

PILOTED MARS NEP VEHICLE

TOTAL

5-10 kg/kWe

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HIGH PERFORMANCE COMPONENTS

- **TECHNOLOGY DEVELOPMENT CHALLENGES**
  - To establish the technology base in power electronics that will enable or significantly enhance future NASA missions
    - Survive adverse environments
    - Improved performance, mass, and reliability
    - Enable advanced system architectures
- **TECHNOLOGY DEVELOPMENT APPROACH**
  - Assemble complete program out of individual programs focused on customer needs
    - Base R&T: High temperature components
    - Nuclear Propulsion: High temperature components
    - CSTI HCP: Radiation tolerant power switches; Fiber optic sensors
    - OSMQ, T. Standards: NASA Space Wiring
  - Form strategic alliances with other component development efforts
  - Build commercial capability in advanced parts

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HIGH CAPACITY POWER/CSTI (586-01)

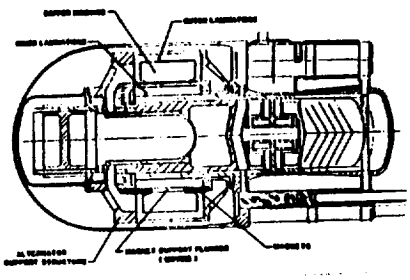
OBJECTIVE:

DEVELOP ENABLING ELECTRIC COMONENT AND CIRCUIT TECHNOLOGY FOR SP-100

- **> 600 K**
- **> 1 mRAD GAMMA, 10^{13} NEUTRON FLUENCE**
- **FAULT TOLERANT**
- **STIRLING LINEAR ALTERNATOR**

SP-100 Thermoelectric configuration

REFERENCE SSE LINEAR ALTERNATOR



APPROACH:

- **INVESTIGATE 10-100 kW INVERTER/CONVERTER CIRCUITS**
  - **MAPHAM SWITCH COMPARISON (IN HOUSE)**
  - **CASCADE SCHWARTZ INVERTER (U. TOLEDO)**
- **COMPONENTS**
  - **DETERMINE DEGRADATION OF H.P. S.S. SWITCHES IN HIGH TEMPERATURE AND NUCLEAR ENVIRONMENTS**
  - **CHARACTERIZE AND DEVELOP TRANSMISSION LINES, CAPACITORS AND TRANSFORMERS/INDUCTORS**

CSTI HIGH CAPACITY POWER

NASA

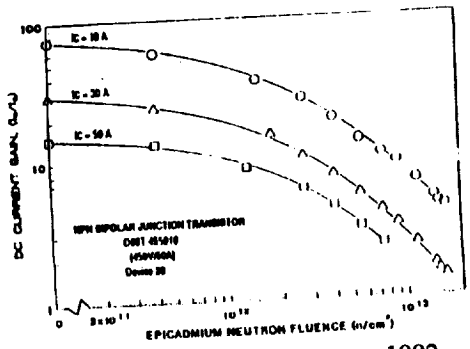
NEUTRON & GAMMA RAY EFFECTS ON SOLID STATE POWER SWITCHES

OBJECTIVE: DETERMINE AND ASSESS THE EFFECTS OF GAMMA RAYS AND NEUTRONS ON COMMERCIAL AND DEVELOPMENTAL-TYPE SOLID STATE SWITCHES

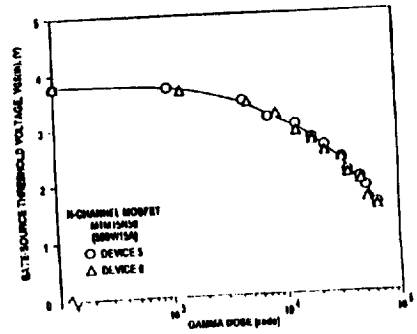
APPROACH: MEASURE SENSITIVITY OF SWITCH PARAMETERS TO GAMMA AND NEUTRON IRRADIATION UNDER IN-SITU CONDITIONS AT ROOM AND ELEVATED TEMPERATURES

STATUS: POWER BJTs, MOSFETs AND SITs TESTED AND EVALUATED TO NEUTRON FLUENCES ≥ 10^{13} n/cm^2 AND GAMMA DOSES ≥ 10^6 rads

CURRENT GAIN @ VCE = 2.5V vs EPICADMIUM NEUTRON FLUENCE
FLUX = 7.8 x 10^8 n/cm^{2}s FLUENCE = 1.7 x 10^{13} n/cm^2



GATE-THRESHOLD VOLTAGE vs GAMMA DOSE
DOSE RATE = 6.8 krad/hr DOSE = 73 krads



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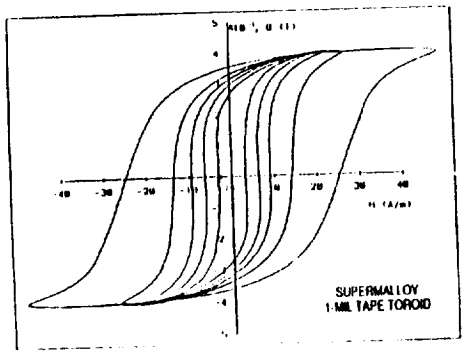
HIGH TEMPERATURE, HIGH FREQUENCY SOFT MAGNETIC MATERIAL'S CHARACTERIZATION

OBJECTIVE: DETERMINE AND ASSESS THE COMBINED EFFECTS OF TEMPERATURE, FREQUENCY AND EXCITATION WAVEFORM ON COMMERCIAL SOFT MAGNETIC MATERIALS

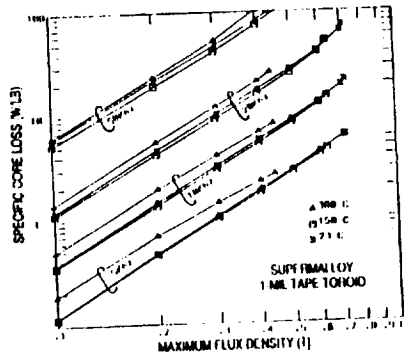
APPROACH: DEVELOP TEST SYSTEM TO ACCURATELY MEASURE, RECORD AND PLOT SPECIFIC CORE LOSS AND DYNAMIC B-H HYSTERESIS LOOPS TO TO 300C AND 50 kHz UNDER SINE- AND SQUARE-WAVE VOLTAGE EXCITATION

STATUS: 80-20 Ni-Fe, 50-50 Ni-Fe, 3% Si-Fe AND AMORPHOUS MAGNETIC ALLOYS TESTED UNDER SINEWAVE VOLTAGE EXCITATION TO 300C AND f ≥ 20 kHz

FREQUENCY-CLUSTER B-H LOOPS AT B_M= 0.4 T AND T = 300C
f = 1 kHz (INNER LOOP), 5, 10, 20 AND 50 KHZ (OUTER LOOP)
SINEWAVE VOLTAGE EXCITATION



SPECIFIC CORE LOSS vs FLUX DENSITY,
FREQUENCY & TEMPERATURE
SINEWAVE VOLTAGE EXCITATION



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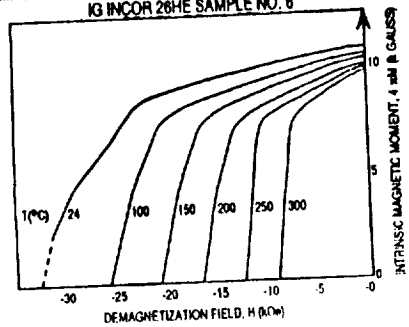
HIGH TEMPERATURE RARE EARTH PERMANENT MAGNET CHARATERISTICS

OBJECTIVE: CHARACTERIZE RARE-EARTH PERMANENT MAGNETS TO 300 °C AND INVESTIGATE LONG-TERM AGING EFFECTS

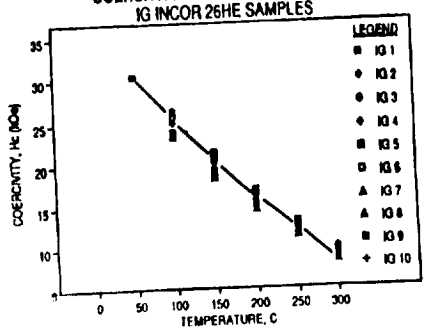
APPROACH: MEASURE REVERSIBLE, IRREVERSIBLE, AND PERMANENT LOSS OF MAGNETIC PROPERTIES DUE TO SHORT AND LONG TERM EXPOSURE TO ELEVATED TEMPERATURES

STATUS: 50 SAMPLES OF Sm_2Co_{17} FROM 5 VENDORS (10 PER VENDOR) TESTED TO 300°C TO INVESTIGATE SHORT-TERM TEMPERATURE EFFECTS

DEMAGNETIZATION CURVES AT SELECTED TEMPERATURES
IG INCOR 26HE SAMPLE NO. 6



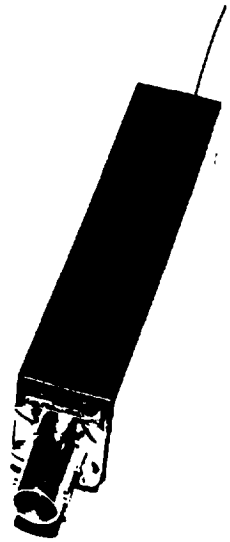
COERCIVITY VERSUS TEMPERATURE
IG INCOR 26HE SAMPLES



FIBER-OPTIC SENSORS FOR POWER DIAGNOSTICS

SHOWN	• Fiber Optic Current Sensor and Voltage Sensor.
OBJECTIVE	• To provide accurate electrical sensors with very high electrical isolation and immunity to electromagnetic interference (EMI).
ACCOMPLISHMENTS	• Developed fiber-optic current sensor with very high EMI immunity and electrical isolation. Operation between - 65 to + 125° C. Survived 17g vibration tests.
	• Developed fiber-optic voltage sensor. Working to reduce sensitivity to vibration for voltage sensor.
BENEFITS	• Accurate electrical measurements at locations somewhat remote from central electronics, such as in aircraft wings or in conjunction with electromechanical actuators. High EMI immunity. Very high isolation with low mass. Very applicable to industrial operations.
APPLICABLE MISSIONS	• Lunar and Mars surface power, aircraft (especially with electro-mechanical actuators), Vehicle Health Management systems, electric utility industry.

FIBER-OPTIC
CURRENT SENSOR



FIBER-OPTIC
VOLTAGE SENSOR

NASA WIRING TECHNOLOGY

GOAL: DEVELOP SAFE AND RELIABLE POWER WIRING SYSTEMS FOR FUTURE NASA SPACE MISSIONS

APPROACH:

- o EVALUATE POSSIBLE METHODS OF ACCOMPLISHING GOAL
  - QUANTIFY/UNDERSTAND BREAKDOWN MECHANISMS IN PRESENT WIRING SYSTEMS
  - ASSESS LIMITATIONS OF PRESENT WIRING SYSTEMS FOR PROPOSED MISSIONS
  - IDENTIFY AND EVALUATE CANDIDATE ADVANCED MATERIALS AND WIRE DESIGNS
  - RESOLVE WIRING SYSTEM ISSUES
- o PRIORITIZE APPROACHES: COST, LIMITATIONS, ETC.
- o IMPLEMENT DEVELOPMENT PROGRAM

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HIGH TEMPERATURE POWER ELECTRONICS

- REQUIREMENTS, TRADE STUDIES AND GOALS DEFINITION:
  - Define system requirements and applications environments for NASA space missions
  - Assess system mass and volume drivers
  - Identify opportunities and benefits of specific technology developments
- HIGH-TEMPERATURE CHARACTERIZATION:
  - Experimentally determine the efficiency, reliability, and upper limit on operating temperature for advanced power electronic components as a function of power level.
- HIGH EFFICIENCY, ELEVATED TEMPERATURE POWER ELECTRONICS:
  - Establish a high efficiency, elevated operating temperature advanced power electronics technology base
  - Build a 95% efficient inverter power circuit operating at 125°C

HIGH TEMPERATURE POWER ELECTRONICS PROGRAM

COMPONENTS R&D:

INDUCTORS

- DESIGNED AND TESTED MOLY-POWDERED-PERMALLOY CORE (MPP) INDUCTORS VERSUS FREQUENCY AND TEMPERATURE.
- INDUCTORS PERFORMED SATISFACTORILY UP TO 200° C, UNDER LOW BIAS @ 50 Hz-100 kHz.
- PROCUREMENT OF LARGE MPP CORES IS COMPLETE.
- TESTING TECHNIQUES UNDER FULL BIAS ARE BEING INVESTIGATED.

TRANSFORMER

- DEVELOPMENT OF 200°C COAXIALLY-WOUND TRANSFORMER IS UNDERWAY AT THE UNIVERSITY OF WISCONSIN.

CAPACITORS

- THERMAL AGING TESTS (200°C, 2000 HOURS) WITHOUT ELECTRICAL BIAS OF CERAMIC, TEFLON CAPACITORS ARE COMPLETED. LIFE TESTING UNDER FULL BIAS IS UNDERWAY.
- MOUNTING OF THERMOCOUPLES ON CAPACITORS IS COMPLETE FOR FUTURE TEMPERATURE RISE MEASUREMENTS.
- PROCUREMENT OF POWER CAPACITORS IS UNDERWAY.

SWITCHES

- DEVELOPMENTAL EFFORTS OF HIGH TEMPERATURE SWITCH TECHNOLOGY ARE BEING MONITORED.

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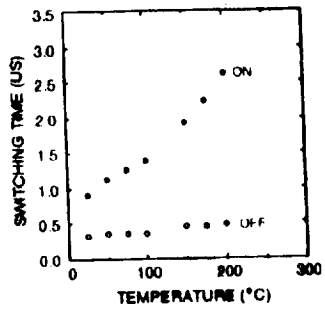
200°C-BASEPLATE ELECTRONICS

SURVIVES SEVERE ENVIRONMENTS AND LIGHTENS RADIATORS

GOAL: BUILD & TEST ASSEMBLY

- **ACHIEVABLE (100°C > SOA)**
- **UNCOVERS MISSING TECHNOLOGY**
- **EXCEEDS LUNAR TEMPERATURE (130°C)**
- **REDUCES RADIATOR AREA > 2**
- **BROAD SPINOFFS**

H. T. TEST LAB



MCT SWITCHING TIMES

- **SUNY/AUBURN GRANTS INITIATED**
- **COMPONENTS TESTED**
  - MCT
  - CAPACITORS
  - INSULATION
- **LABS SET UP**
- **CUSTOM COMPONENTS ORDERED**

H. T. COMPONENT CHARACTERIZATION

SHOWN:	• 200°C inductor, transformer and capacitors
OBJECTIVE:	• Experimentally determine the efficiency, reliability and upper limits on operating temperature for advanced power electronic components as a function of power level
APPROACH:	• Acquire SOTA commercially available and/or developmental power electronic components • Test performance as a function of temperature • Conduct aging studies at maximum acceptable temperature. Repeat performance tests
ACCOMPLISHMENTS:	• Acquired and completed performance testing of three types of capacitors to 200°C. Aging tests are on-going • Built and completed performance test on four types of inductors to 200°C • Completed high temperature characterization of power switching devices
BENEFITS:	• Simplifies and lightens thermal management system • Enhanced tolerance of hostile environments • Improved reliability and efficiency
MISSION:	• Lunar base, advanced platforms; nuclear & solar-dynamic power • Engine integrated electronics

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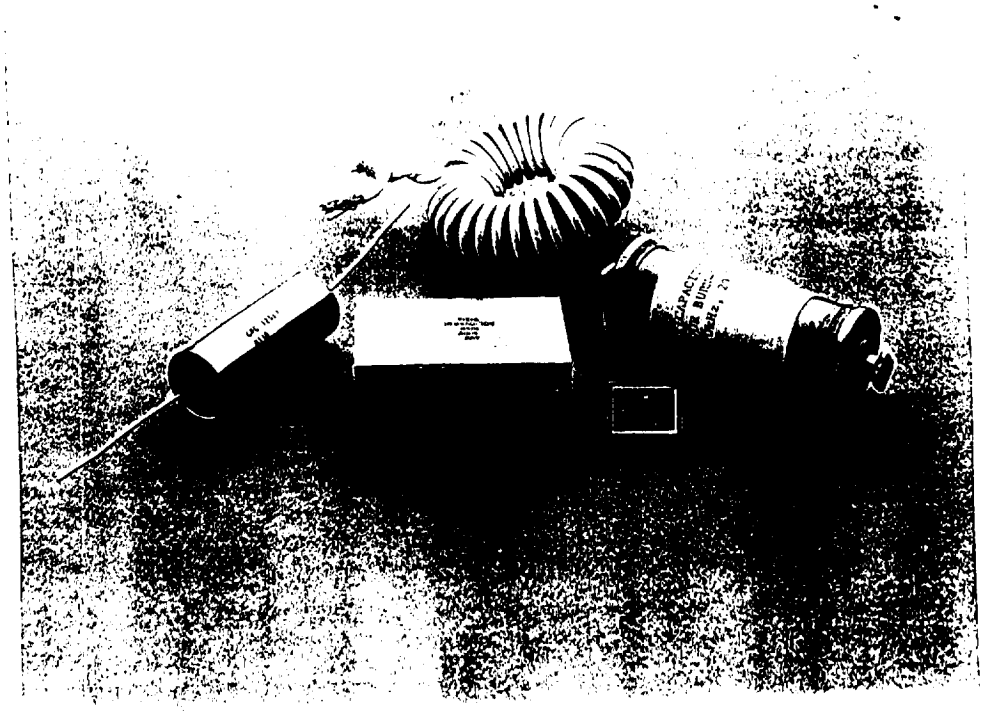

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H.T. COAXIAL TRANSFORMER

SHOWN:
- Coaxially wound transformer for 50 kW converter
- 50 kW soft switched, dc-dc converter

OBJECTIVE:
- Develop very light, very low loss topologies and components for high power space systems (Megawatt Inverter Program)
- Develop high temperature coaxial transformer

APPROACH:
- Grants to U. Wisconsin

ACCOMPLISHMENTS:
- Developed and demonstrated the coaxially wound transformer, a new concept that improves the converter's power density
- Demonstrated 0.24 kg/kW converter
- Grant underway for development of high temperature transformer
- Applied to induction heating on robotic production lines (Miller Electric Co.)
- Applied to zero-force power transfer into μgravity experiment pallet

BENEFITS:
- Lighter weight, higher efficiency power electronics, and simplified thermal management
- Unique features allow design innovations

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National Aeronautics and Space Administration Lewis Research Center

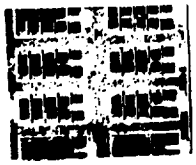
INSTRUMENTATION & CONTROL TECHNOLOGY DIVISION

NASA

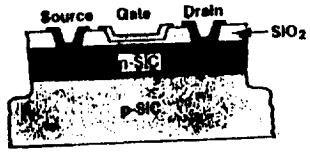
SILICON CARBIDE MOSFET

Milestone: Develop and demonstrate a high temperature, (400 °C), 6H-SiC metal-oxide-semiconductor field effect transistor (MOSFET)

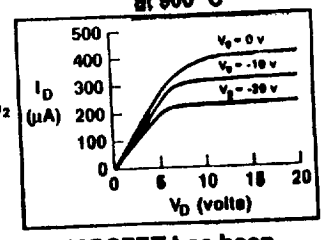
MOSFET Array



SiC MOSFET Structure



I-V Characteristics at 500 °C



Accomplishments: A depletion-mode silicon carbide MOSFET has been developed and successfully demonstrated at an operational temperature of 500 °C.

Benefits: Silicon carbide MOSFETs (switches) provide the most basic active electronic device from which integrated circuits can be developed.

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