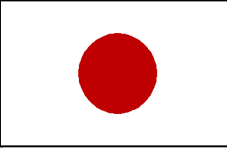
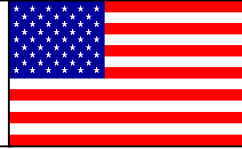




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Kyoto, Japan

13-14 October 1999



# Small-Scale SC Applications: The American Perspective

Paul M. Grant

Science Fellow

Electric Power Research Institute

Palo Alto, California USA

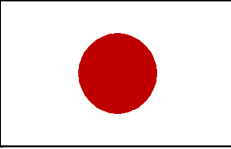


P. M. Grant

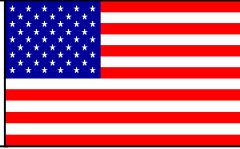
*Small-Scale SC Applications - The American Perspective*



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# Agenda

- Communications

Filters, passive devices relevant to the wireless communications industry

- Sensors

Mostly SQUIDS, applications to topographic mapping, medical scanning, NDA, in vivo physics

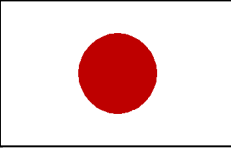
- Digital

Ultra-high performance computation, "the PetaFLOP initiative"

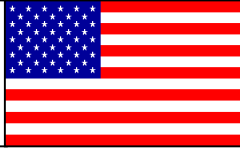
*Special Thanks on all to  
John Rowell*



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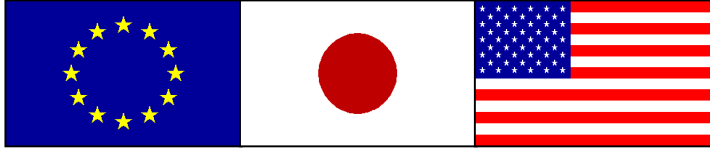
# Communications: Players

## Institutions

- Conductus
- STI
- Northrup - Gruman
- Illinois Superconductor
- Hypres
- TRW

## People

- Randy Simon\*
- Bob Hammond\*
- John Talvacchio\*



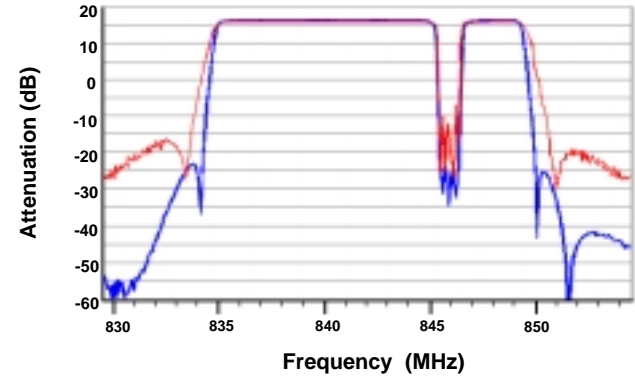
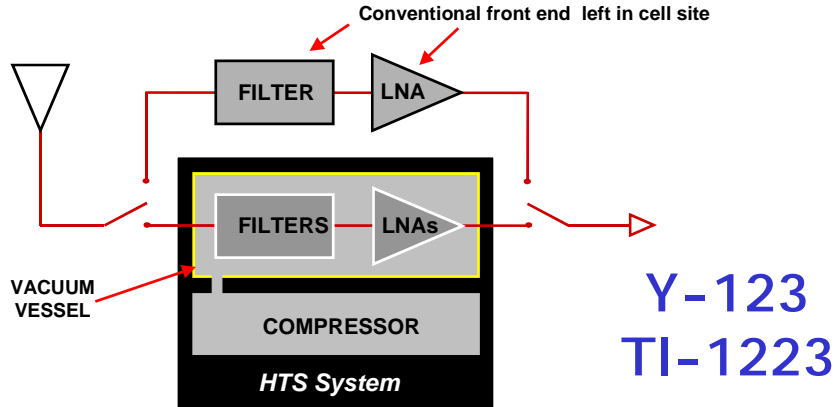
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**ISTEK**

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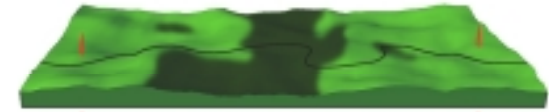
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# Communications: Status



— ClearSite® Thin-Film Superconductor Filter — Conventional Filter

Before HTS



28 Miles Between Cell Sites

HTS Deployed



- Conductus -- ClearSite® (G-M Cryocooler)
- Illinois Superconductor -- RangeMaster®  
 SpectrumMaster®  
 PowerMaster®
- Superconductor Technologies -- SuperFilter® (Stirling Cryocooler)



P. M. Grant

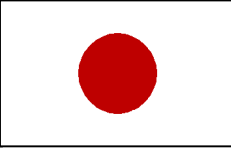
Small-Scale SC Applications - The American Perspective

## Increase Range/Coverage

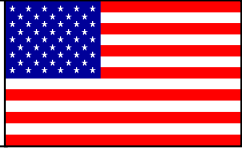




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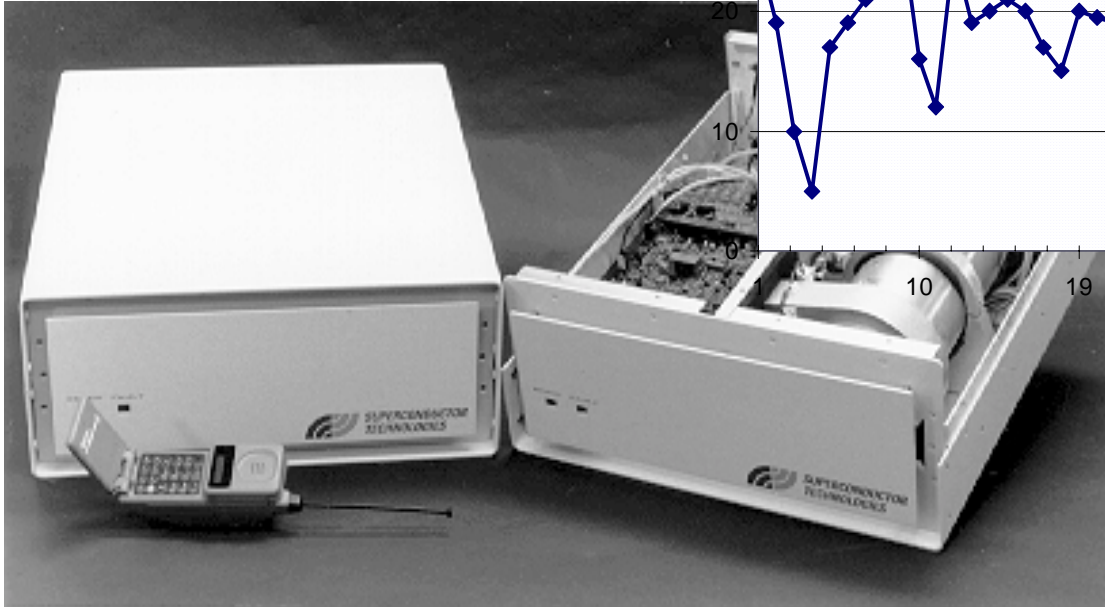
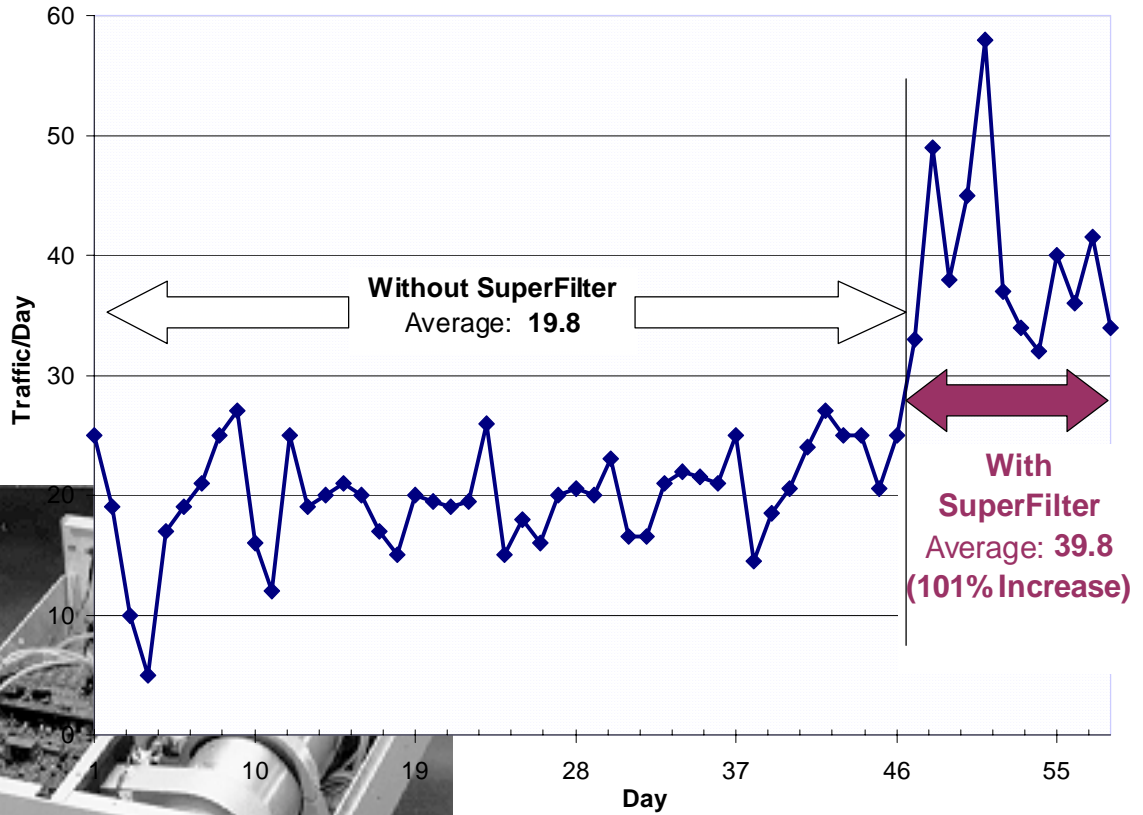


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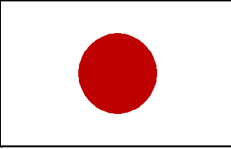
# Communications: Status

*Increase Traffic*

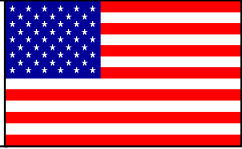




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# Communications: Status

## *Reduce Footprint*



### Replace This Aperture

- 4.52 m<sup>2</sup>
- 37 dB Gain
- 2.2 deg. beamwidth

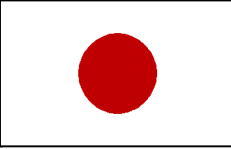


### With This Aperture

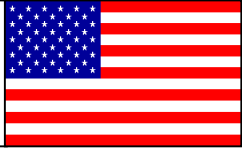
- 1.57 m<sup>2</sup> (35%)
- 32.5 dB Gain
- 1.8 deg. beamwidth



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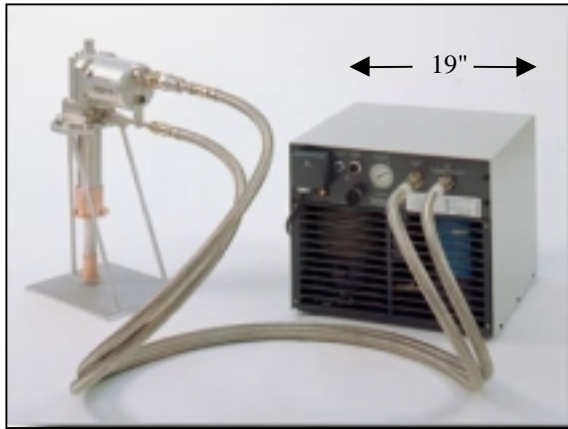
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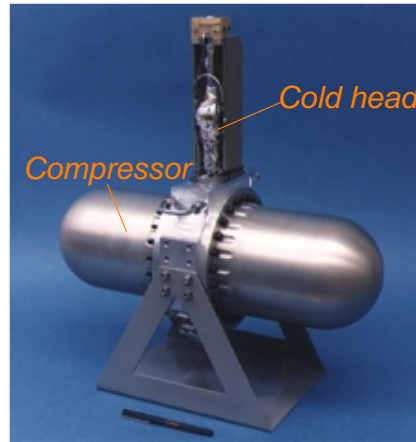
# Communications:

---

# Status

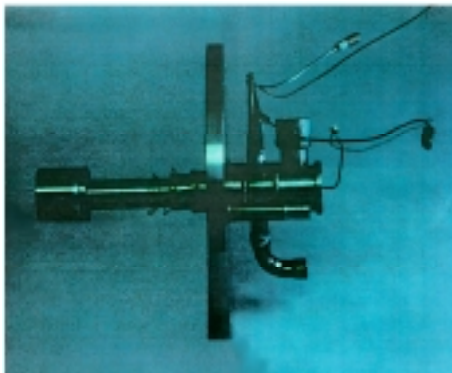


**Leybold 2-stage**

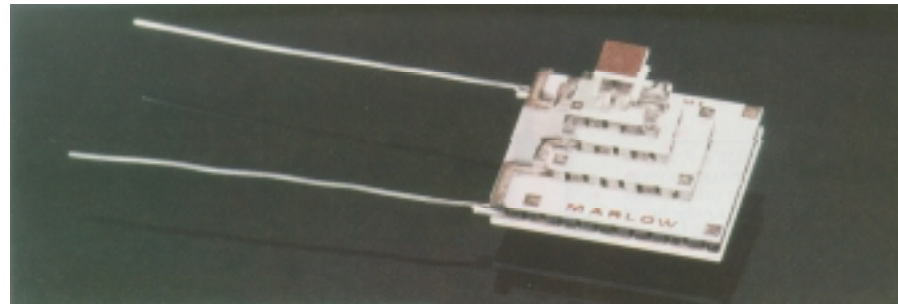


**TRW Pulse Tube**

## *Cryo-Packages*



**Custom - APD compressed gas**

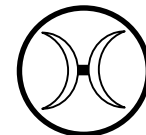


**Marlow Thermoelectric**



P. M. Grant

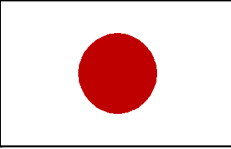
*Small-Scale SC Applications - The American Perspective*



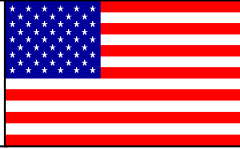
**HYPRES**



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# Communications: Status

*June, 1999*

- ~300 Systems Installed by 3 Companies
- Trials at All of the Top-10 Cellular Carriers in the US
- Trial Results Announced Include:
  - 30-100% Increases in Minutes of Use in Coverage-Limited Sites
  - 70% Increase in CDMA Capacity
  - 10-35% Reduction in Dropped Call Rates
  - Enhanced Voice Quality (5 dB SINAD Improvement)
- Deployments at Top-10 Carriers Include:
 

- ALLTEL	70 cell sites
- US Cellular	35+ cell sites
- Southwestern Bell	25 cell sites



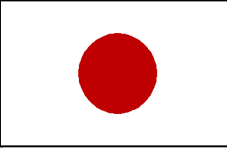
P. M. Grant

*Small-Scale SC Applications - The American Perspective*

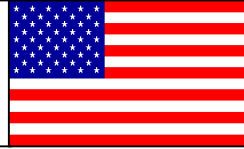




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# Communications: Outlook

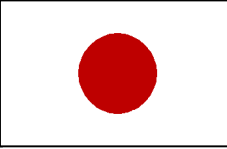
## *Government (Military)*

- Performance Driven
- Prime Requirements:
  - Ultra-Sensitivity
  - Interference Rejection
  - Large Dynamic Range
- Leads Development:
  - Smaller Systems
  - Narrow-Bandwidth Filters
  - Tunable Filters

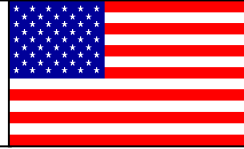
**Precursors to  
Private Sector**



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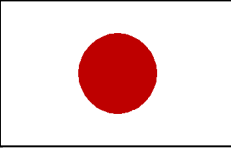
# Communications: Outlook

## *Private Sector*

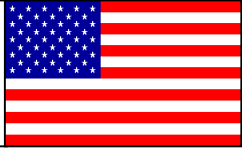
- Technology Does Work Very Well
- Reliability & Cryophobia Being Overcome
- Payback Analysis Gaining Acceptance
- When interference and coverage issues converge with greater user density, HTS will be the only solution.



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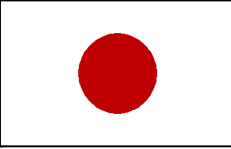
# Communications: Outlook

## *Issues*

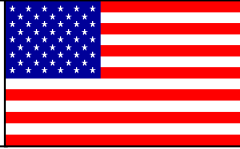
- Cost
  - Military \$60K, Commercial \$20K
  - Current BMC \$50K ???
- Market Share
  - 700,000 base stations worldwide by 2003...How many will be HTS?
  - Current Order Rate: 1000/yr ??
- Can 3 Companies Survive?



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# Sensors: Players

## Institutions

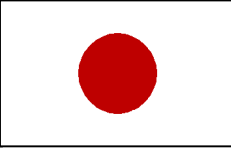
- Nyocera
- Cryogenic Electronic Systems
- AFOSR
- Hypres
- Vanderbilt University
- TCSUH
- CSR - UMD

## People

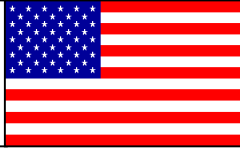
- Harold Weinstock\*
- Carl Rosner\*
- Paul Chu
- John Wikswo\*
- Fred Wellstood
- Venky Venkatesen



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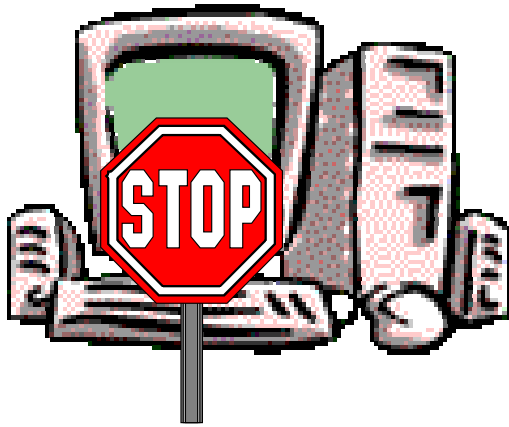
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# Sensors: Status

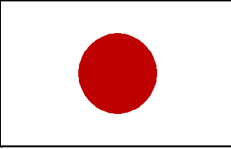
- High Speed
- Low Power
- Low Noise
- Quantum Accuracy
- Simple Fabrication

# "Y4K?"

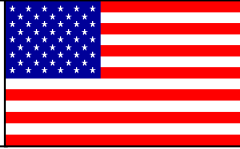




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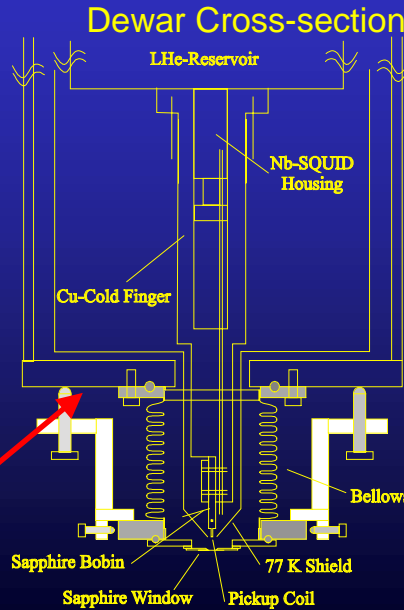
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# Sensors: Status

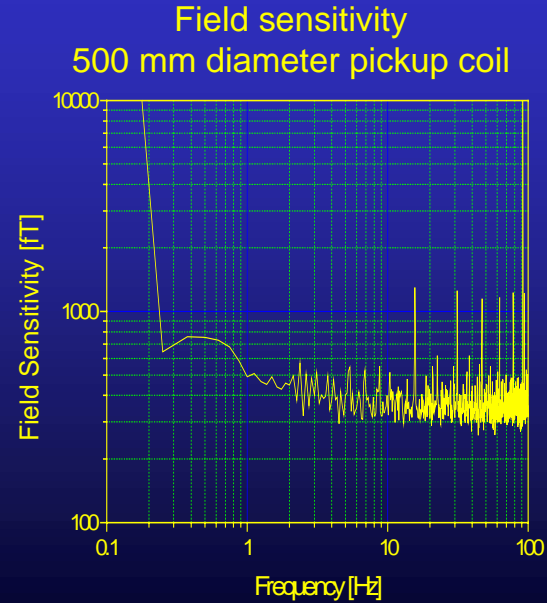


**LIVING STATE PHYSICS GROUP**  
DEPARTMENT OF PHYSICS AND ASTRONOMY, VANDERBILT UNIVERSITY

## High Resolution LTS-SQUID Microscope for Room-Temperature Samples



**4K-300K Sensor-Sample  
Spacing < 100 μm**



**Field sensitivity  
350 fT/Hz<sup>-1/2</sup> @ f>1Hz**

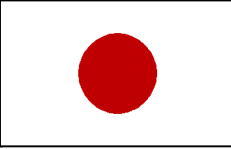


P. M. Grant

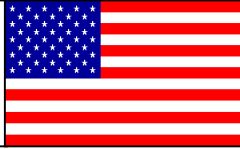
*Small-Scale SC Applications - The American Perspective*



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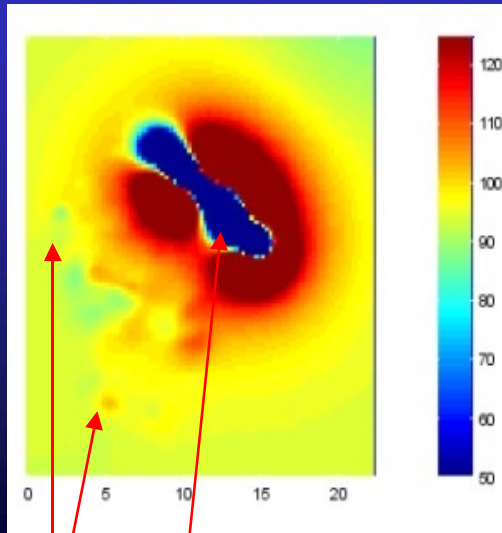
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# Sensors: Status



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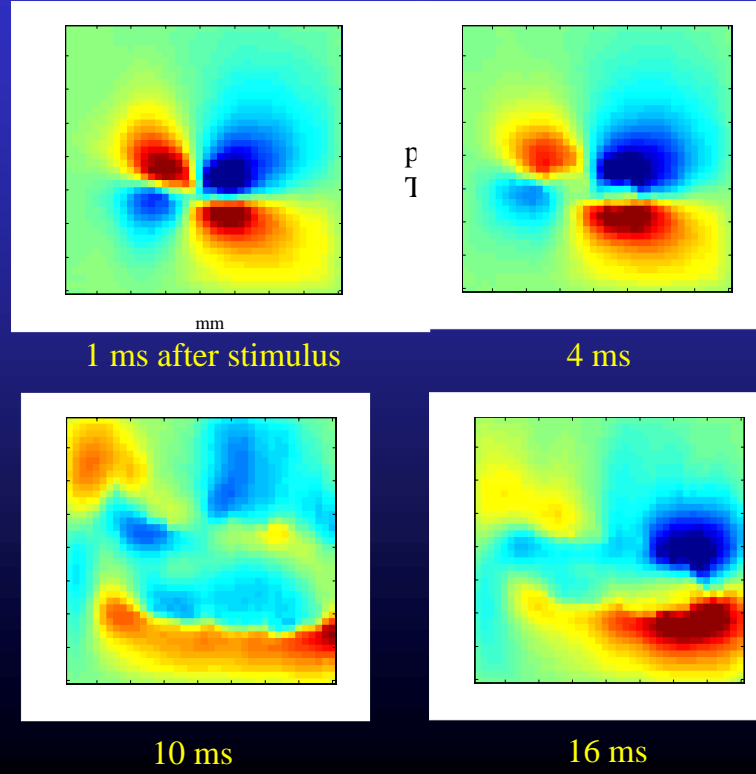
## Remanent Magnetization of Martian Meteorite ALH 84001



Crust from reentry

Fine structure that was not annealed upon reentry

## Propagation of Action Currents in Cardiac Tissue

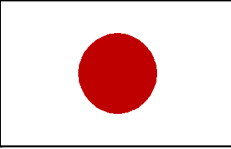


P. M. Grant

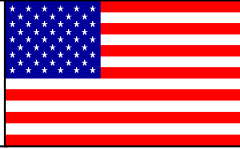
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# Sensors: Status

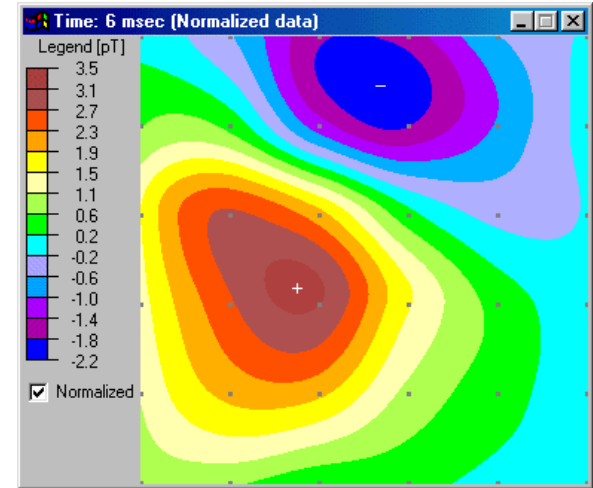


## Cryogenic Electronic Systems MagnetoCardioGraphy

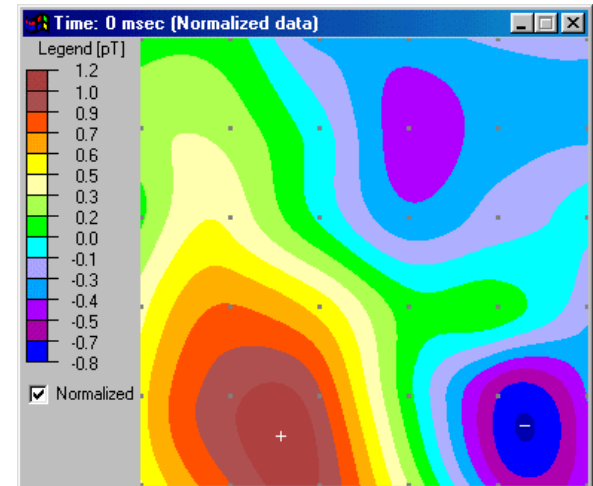


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Healthy Heart

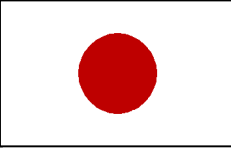


Ischemic Heart - Early Stages

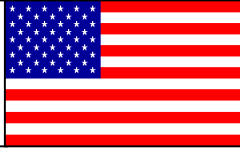




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# Sensors: Status

**Nyocera  
MAGMA-C1**

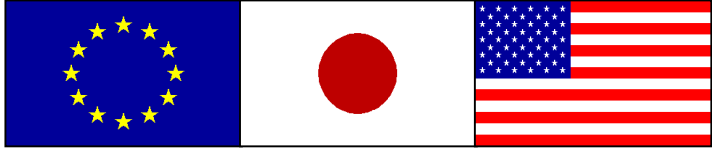
**HTS  
Scanning  
SQUID  
Microscope  
\$380K**



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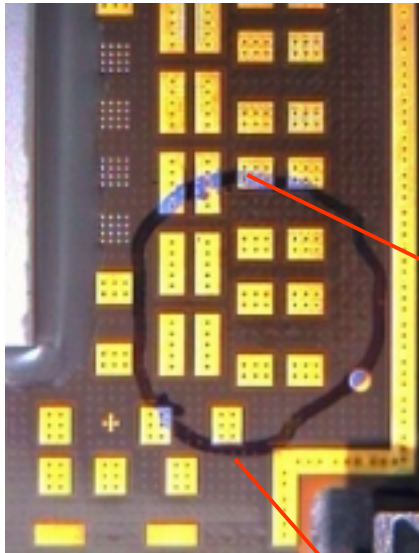
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# Sensors: Status

## Short Circuit Detection

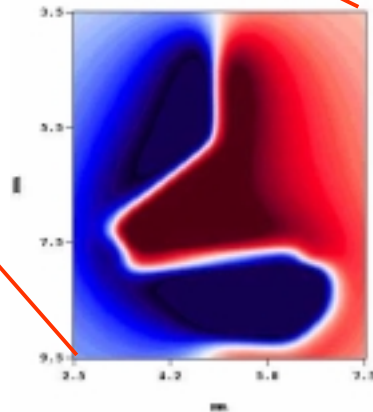
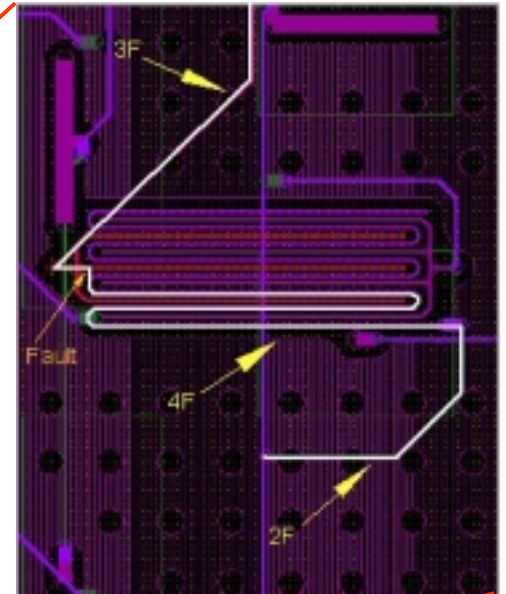
Intel, Sematech

Photograph of MCM



1 cm

CAD Layout of MCM  
with current path overlaid



Magnetic Image



Current Image

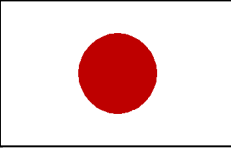
EPRI

P. M. Grant

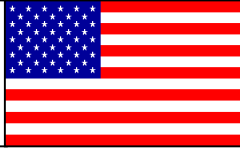
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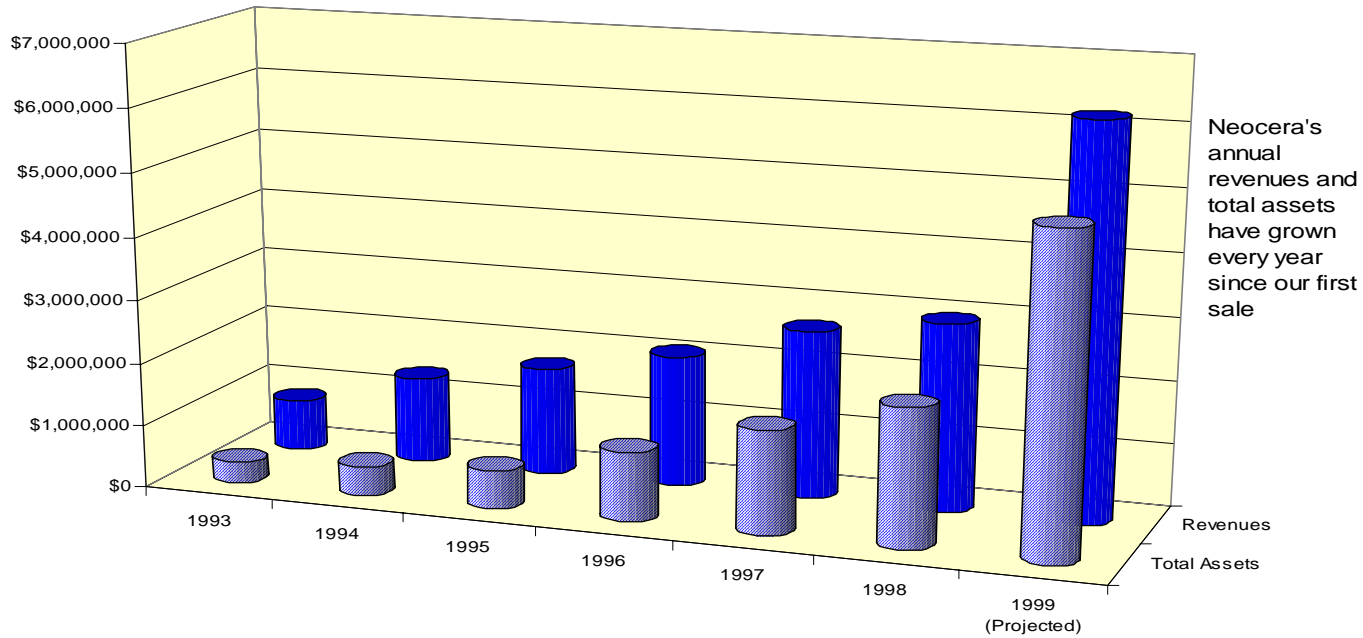
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# Sensors: Outlook



	<u>1997</u>	<u>1998(E)</u>	<u>1999(E)*</u>	<u>2000(E)</u>	<u>2001(E)</u>
Revenue:	2,669	3,010	10,171	15,665	21,870
Employees:	15	18	43	66	94

Revenue in \$1000



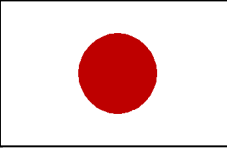
P. M. Grant

Small-Scale SC Applications - The American Perspective

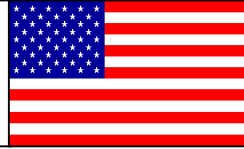




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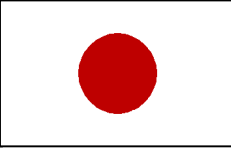
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# Sensors: Outlook

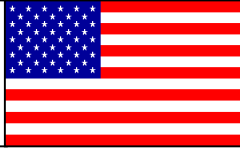
- Use of Scanning Squid Microscopy on Increase
  - NDA, QA, Biology/Physics Basic Research
- Potentially Huge Medical Applications
  - Combined MRI and SQUID MEG
  - Early detection of cardiac ischemia via MCG



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# Digital: Players

## Institutions

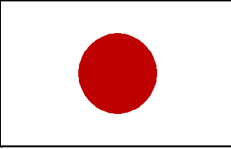
- SUNY-Stony Brook
- Hypres

## People

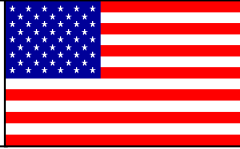
- Kostya Likharev\*
- Elie Track\*



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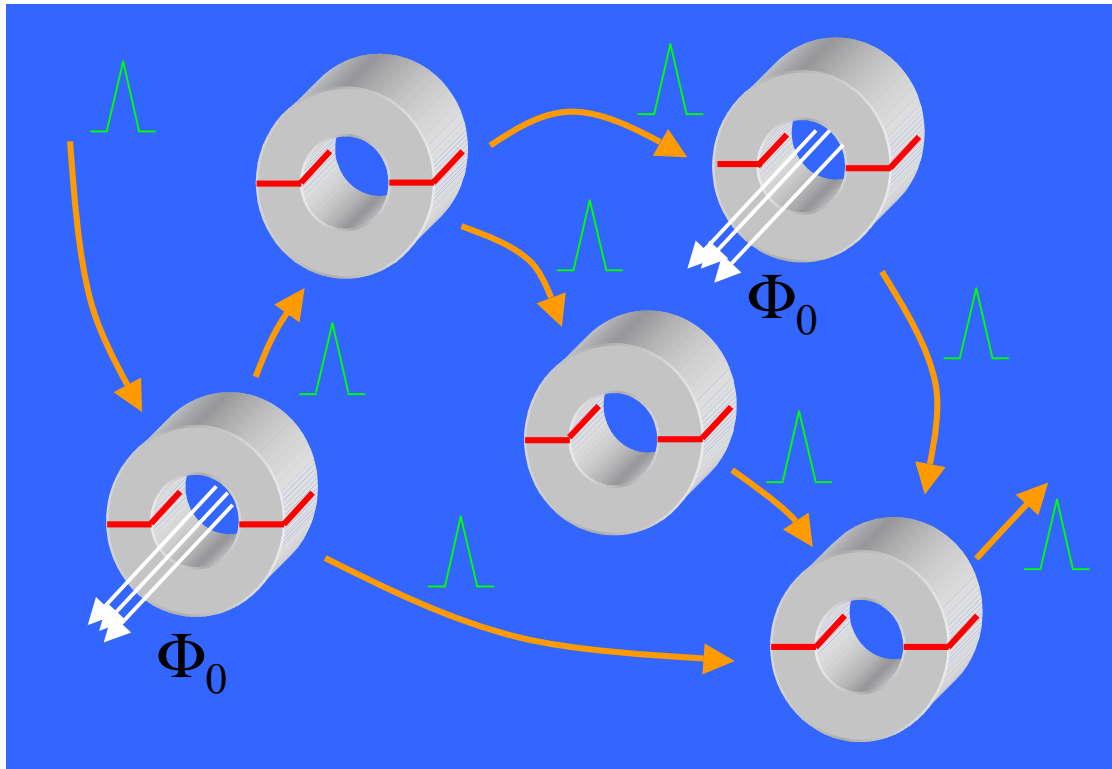


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# Digital: Status

## Rapid Single-Flux Quanta

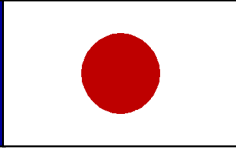


### Advantages over Semiconductors

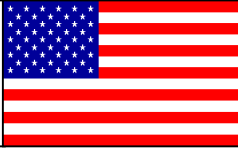
- Ballistic Transport
- j-j Speed, Density, Power
- Nb Trilayer (simpler than Si, III-V)



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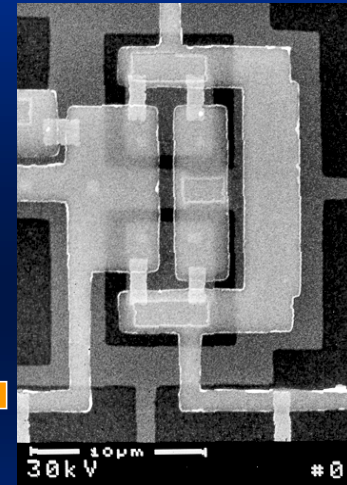
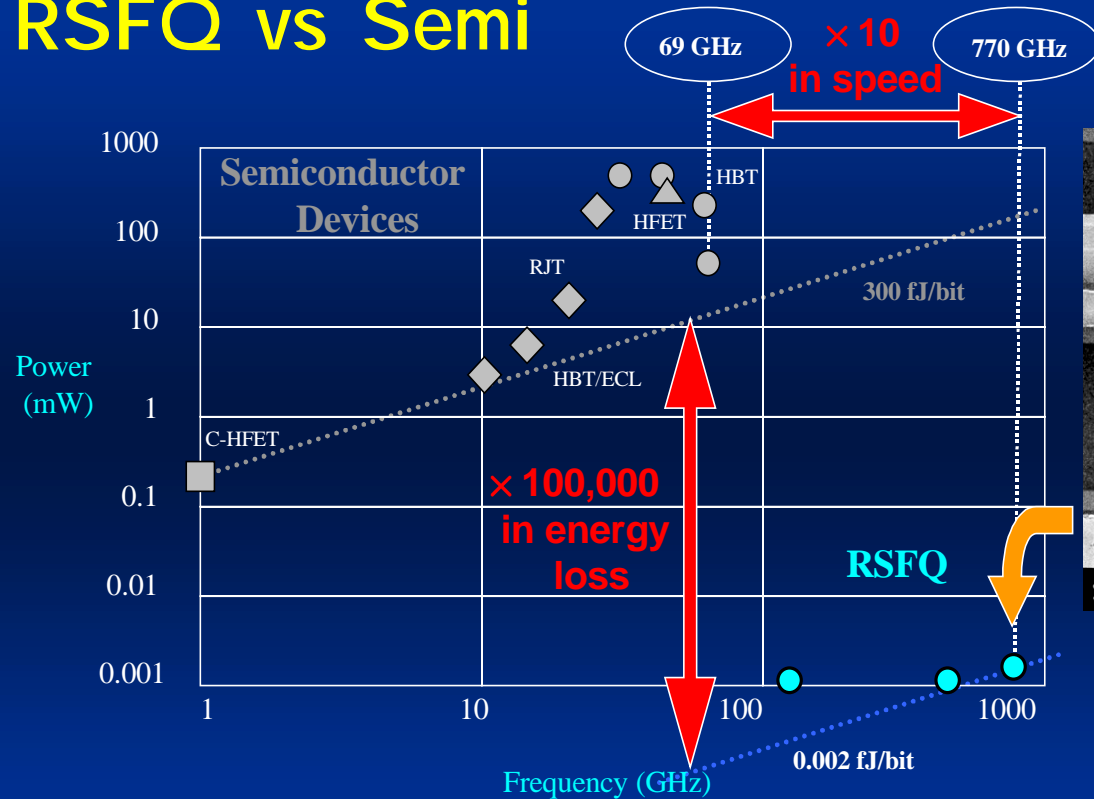


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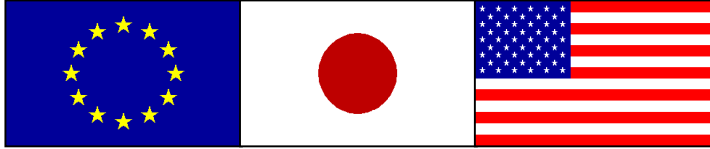
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# Digital: Status

## RSFQ vs Semi



$\times 10$  in fab costs  
(3 metallic layers & 0.5  $\mu\text{m}$  lithography give a 750 GHz, 1.5  $\mu\text{W}$  RSFQ device)



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# Digital: Status

## RSFQ Roadmap

RSFQ (Stony Brook Forecast)

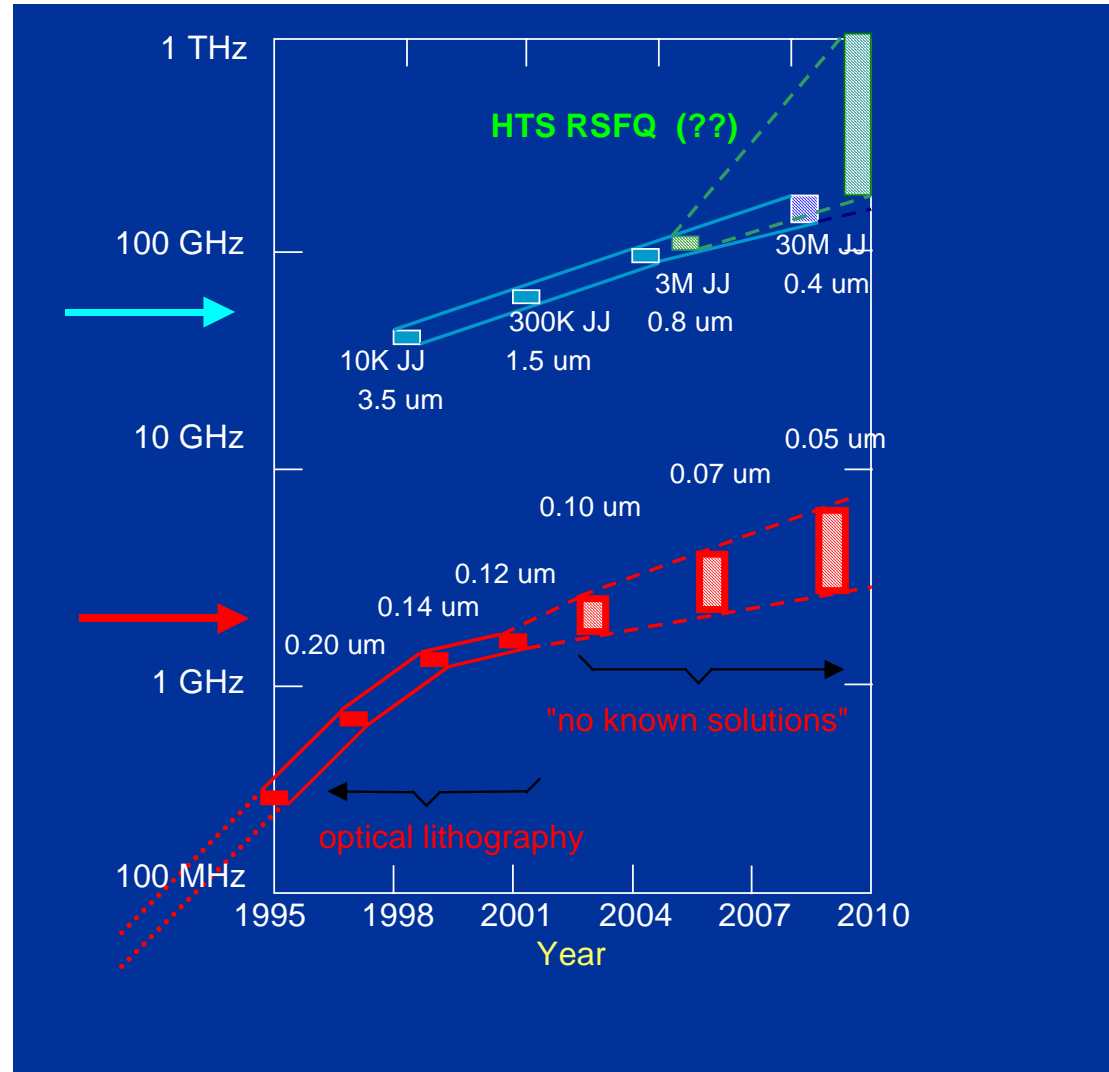
CMOS (SIA Forecast 1997)

Stony Brook



P. M. Grant

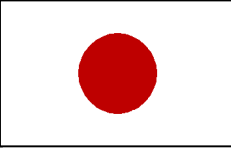
Small-Scale SC Applications - The American Perspective



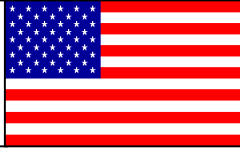




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# Digital: Status

## Year 2006 PetaFLOPS Hardware Projection

### Semiconductors (CMOS)

Performance:    > **100K** chips @  
                         <10 Gflops each

Power:            >150 W per chip  
                         total > **15 MW**

Footprint:        >30x30 m<sup>2</sup>  
                         Latency > **1 μs**

### COOL-0 (RSFQ)

Performance:    **4K** processors @  
                         256 Gflops each

Power:            0.05 W per SPELL  
                         total **250 W** @ 4.2 K  
                         (**100 kW** @ 300 K)

Footprint:        1x1 m<sup>2</sup>  
                         Latency **20 ns**



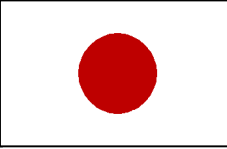
P. M. Grant

*Small-Scale SC Applications - The American Perspective*

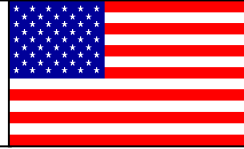
Stony Brook



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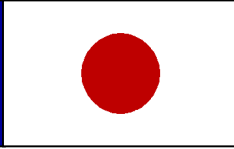
# Digital: Status

## RSFQ Scale-Up: Major Challenges

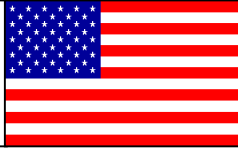
- networks: fine for CNET, too slow for PNET, MSU
- 3 chips per SPELL may not be enough
- contact pin count too large (up to 9,500 per chip)
- 4.2/300 K interface: too many wires (8M @ 8 Gbps)
- power supply current too large (in kA per chip)



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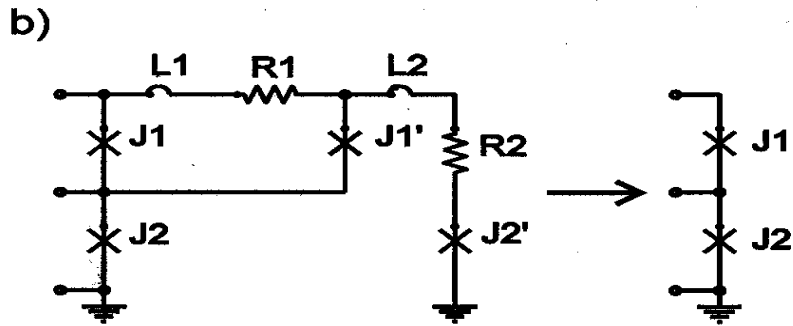
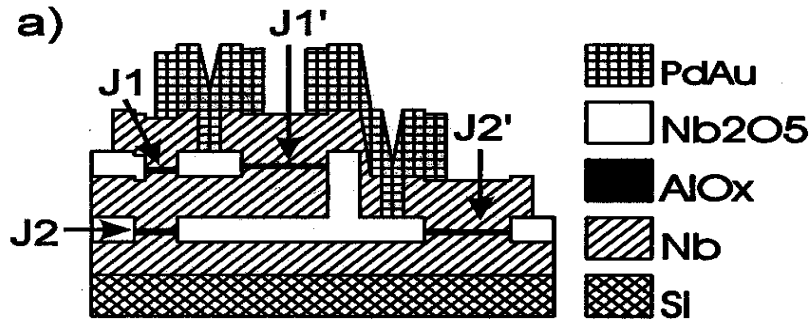


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# Digital: Status

## Breakthrough...Unfortunately not in the US!

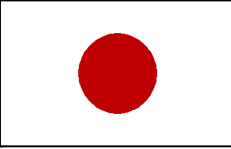


“Experimental Realization  
of a 3D Integrated RSFQ T-  
Flip-Flop Using Stacktrons”

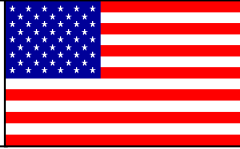
B. Ruck, R. Schmitz, N. Thyssen,  
B. Hermanns and H. Kohlstedt,  
ISI-Juelich, Germany, and S. Lomatch,  
Northwestern U., USA, In: *Proc. ASC'98*



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# Digital: Status

## From Japan: Interchip SFQ Pulse Transfer!

### ETL's SYSTEM

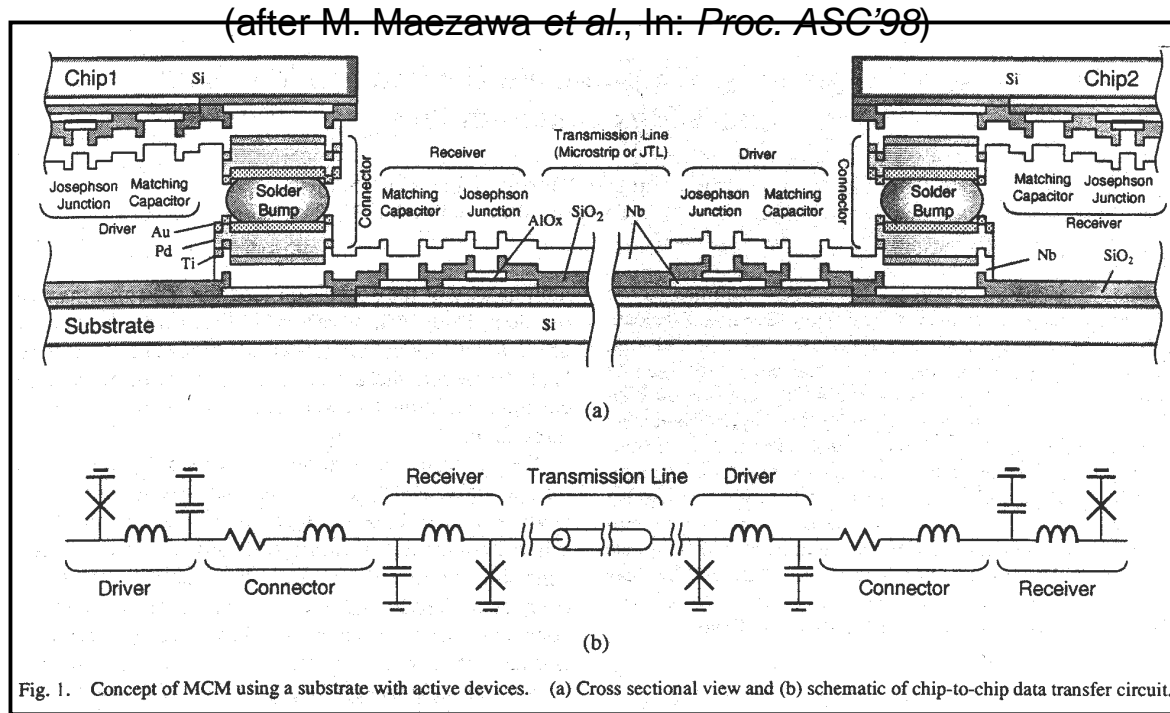


Fig. 1. Concept of MCM using a substrate with active devices. (a) Cross sectional view and (b) schematic of chip-to-chip data transfer circuit.



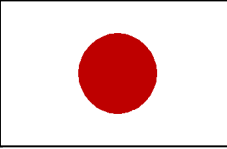
P. M. Grant

Small-Scale SC Applications - The American Perspective

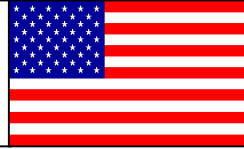
**Stony Brook**



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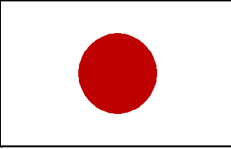
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# Digital: Outlook

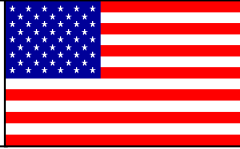
- Progress in RSFQ continues, but much of it outside US.
- PetaFLOPS computing capability considered essential to future US military/security supremacy. Is RSFQ the only practical approach?
- If yes, major US government initiative required...now!



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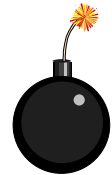
# Summary:

## UpSide



- Communications
  - Many more new installations in 1998-99
- Sensors
  - Potential major impact on high-tech quality control and medicine
- Digital
  - Progress continues in RSFQ performance and integration

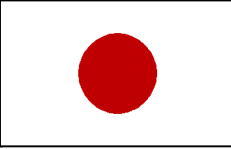
## DownSide



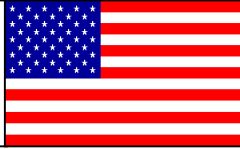
- Communications
  - \$50K vs \$20K...will TC industry buy into higher performance?
- Sensors
  - Capitalization & Cost
- Digital
  - US RSFQ program sub-critical...needs major government funding



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# Late Breaking News!

*From John Rowell at SCE Workshop*

“ Best work shop ever...everyone enthused over RSFQ-HTMT potential. Likely NSA will proceed with teraFLOPS development looking forward to petaFLOPS program by 2008. Major companies/institutions as players, TRW, Hypres, NG, nat labs, UCB”