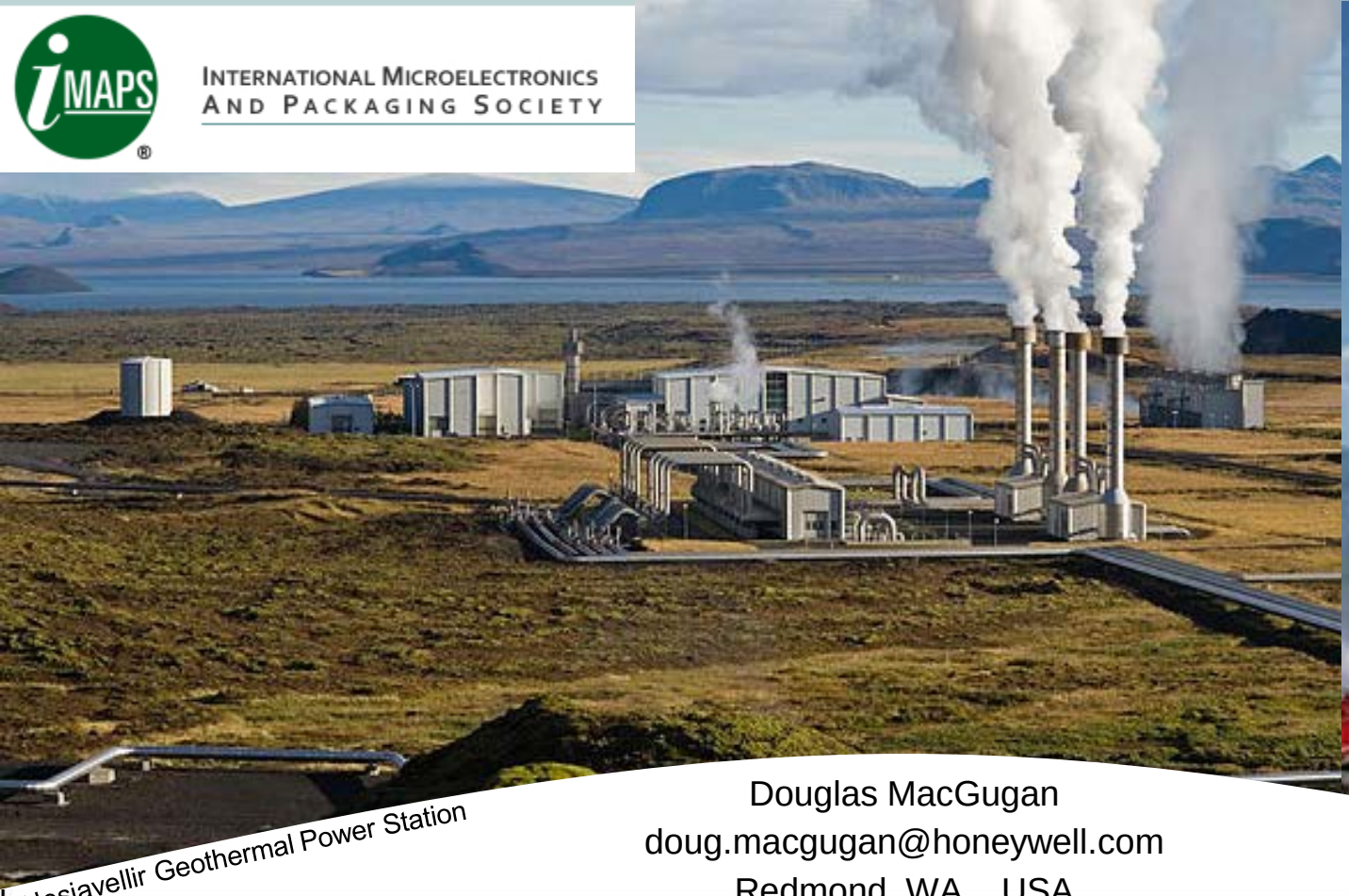

Nesjavellir Geothermal Power Station

Douglas MacGugan
doug.macgugan@honeywell.com
Redmond, WA USA

DM300 – A 300°C Geothermal Directional Module Development

Honeywell

Honeywell

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Development Partners:

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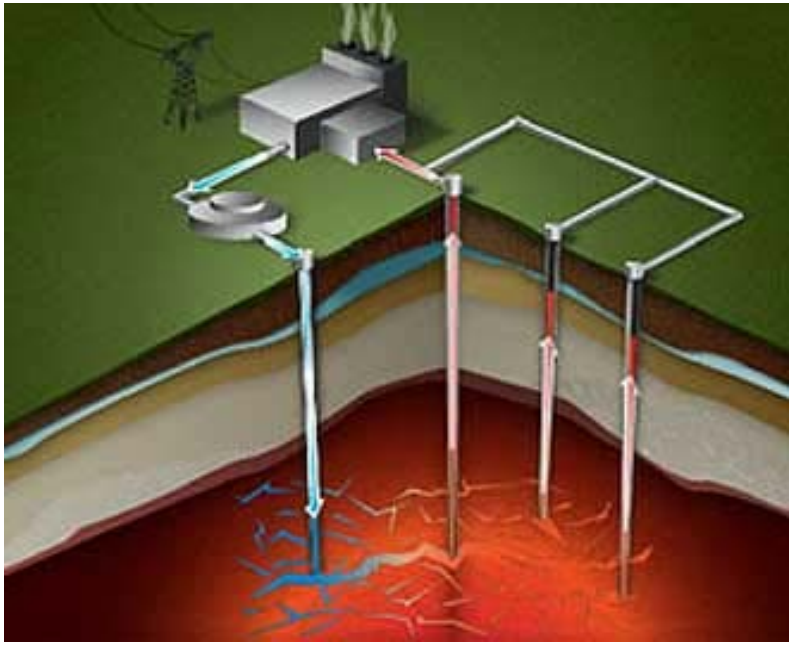
Honeywell - Microelectronics & Precision Sensors, Plymouth, MN
Applied Physics Systems, Mountain View, CA



DM300 – 300°C Directional Module Development

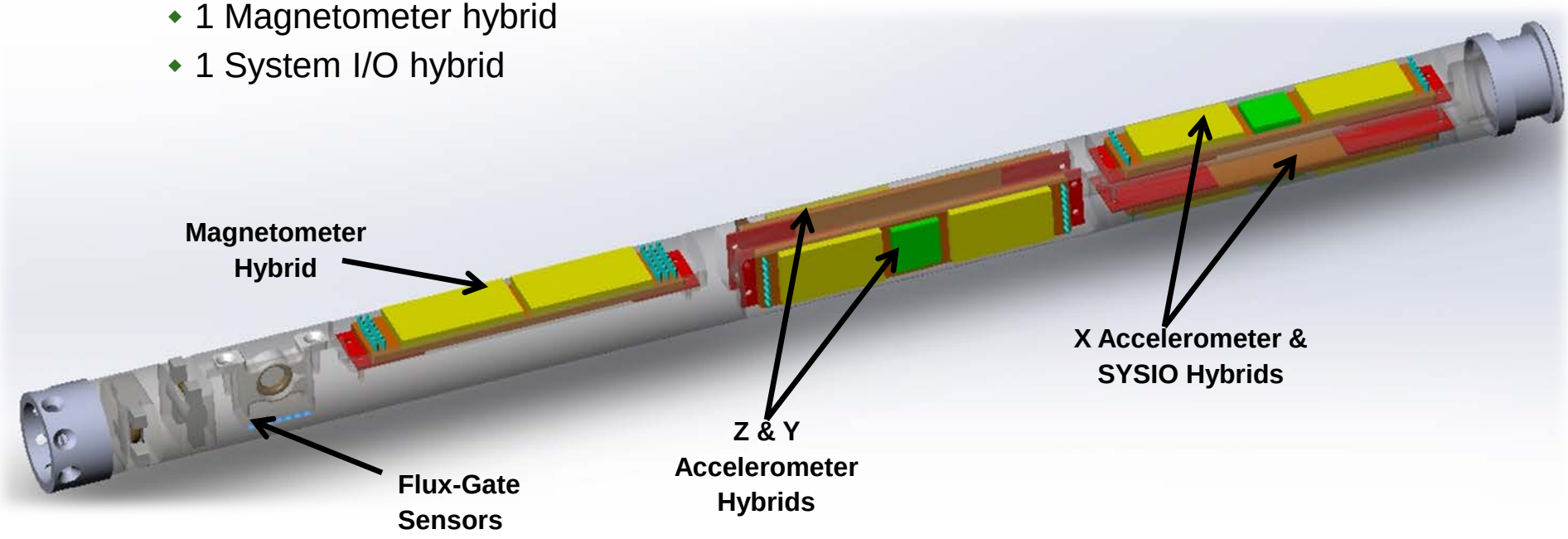
Honeywell

- **New paradigm for 300°C directional drilling orientation instrument**
  - **3 orthogonal sensors referencing gravity and magnetic vector**
    - Flux-gate magnetometers
    - Vibrating beam accelerometer (VBA)
  - **Minimize electronics complexity**
    - Utilize frequency based pseudo-digital sensors
    - Digital outputs from sampling frequency periods/phase over selected gate time
  - **Address materials issues and processes**
    - Titanium housing and mechanical interconnect
    - Flux-gate core, bobbin, and windings
    - Hermetically sealed silicon MEMS VBA
    - High-temperature Co-fired Ceramic (HTCC) hybrid electronics
    - Chip & wire circuit design
    - Circuit assembly using stepped-eutectic 80Au/20Sn brazing
    - CuNi Wire with specially developed >300°C polymer insulation
    - Interconnects with brazed pins on HTCC and ceramic SIP header
    - Connectors with non-polymer pin encapsulants

Directional Module Mechanical Design

Honeywell

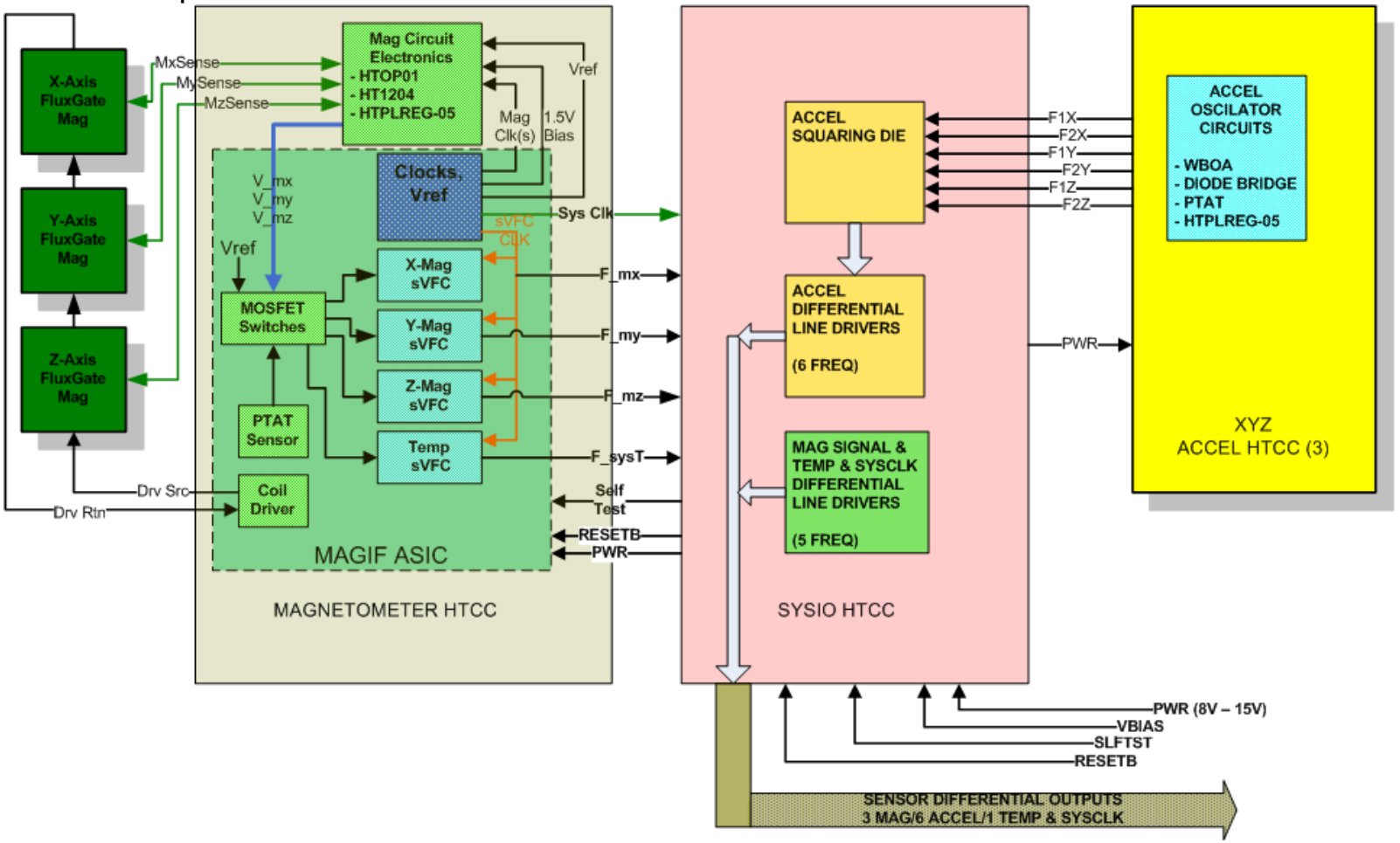
- **DM300 – Features**
  - **~1.2” dia titanium housing (1.25” dia with cover tube)**
  - **Titanium end fixtures – laser welded to housing**
    - High end – electrical connector
    - Lo end – mechanical interface
  - **5 HTCC hybrid electronic boards + 3 flux-gate magnetometers**
    - 3 VBA accelerometer hybrids
    - 1 Magnetometer hybrid
    - 1 System I/O hybrid



DM300 – Block Diagram

Honeywell

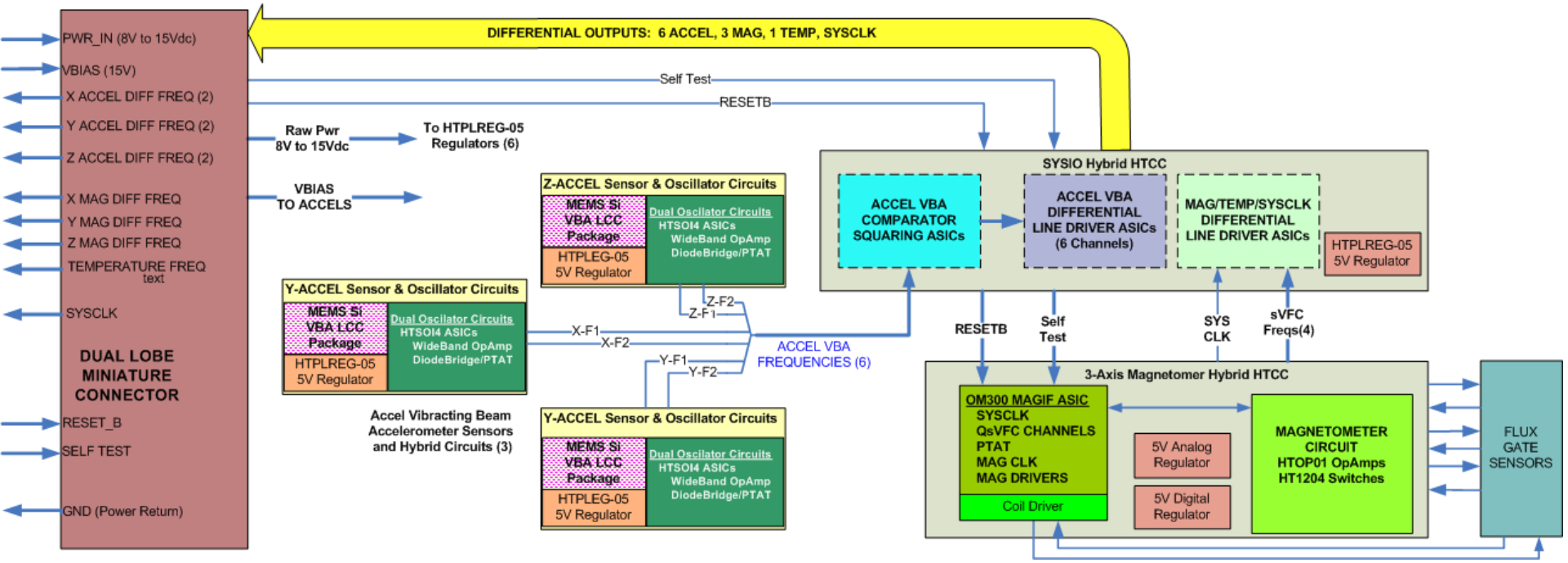
- **300°C Sensor demonstration**
  - **Frequency outputs with minor handshaking**
    - 3 Magnetometer frequencies
    - 6 Accelerometer frequencies (2 from each VBA)
    - Temperature and SYSCLK



DM300 – 300°C Interconnect Approach

Honeywell

- Hybrids mount directly onto Ti housing using heat-sink plates
- Hybrid-to-hybrid interconnect from brazed pins on hybrid
  - Wires routed in channels machined into housing
- Module connector
  - 15-pin dual lobe sub-miniature
  - Non-polymer pin encapsulant

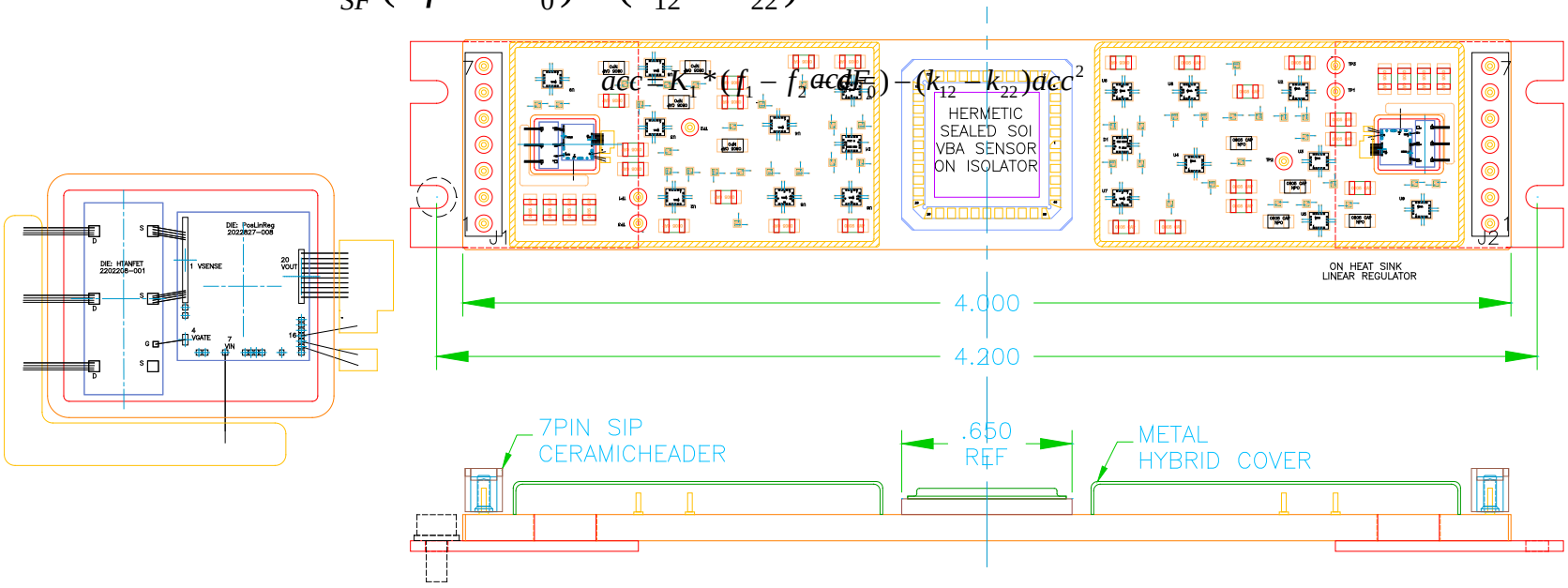


DM300 – Hybrid Circuits

Honeywell

- Common 4” x .8” size with CuW heat plate mounts
- Independent power-regulator die on heat sink
- Vibrating Beam Accelerometer (VBA)
  - Silicon MEMS Sensor in hermetic sealed LCC
  - Two oscillator circuits – Using HTSOI4 custom components
  - Frequency output proportional to sensed acceleration

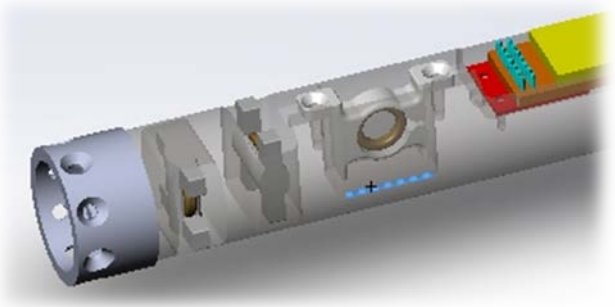
$$acc = K_{SF}(\Delta f - dF_0) - (k_{12} - k_{22})acc^2$$



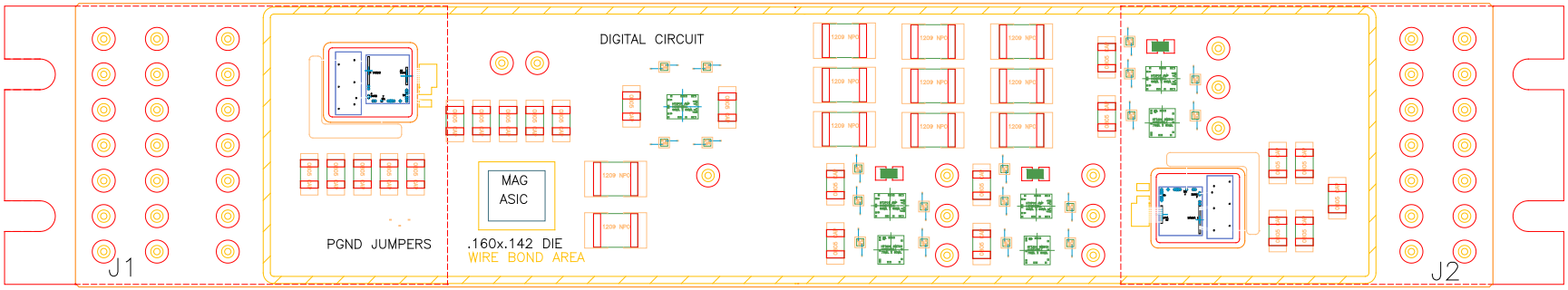
MEMS – Micro-machined Electro-Mechanical Systems

DM300 – Hybrid Circuits

Honeywell



- **Magnetometer**
  - **Three flux-gate sensors**
  - **2nd Harmonic drive & sense circuit**
  - **Honeywell 300°C HTSOI4 Components**
    - MAGIF ASIC with clocks, Quad-sVFC, and coil drive functions
    - Dual op-amp and quad switches

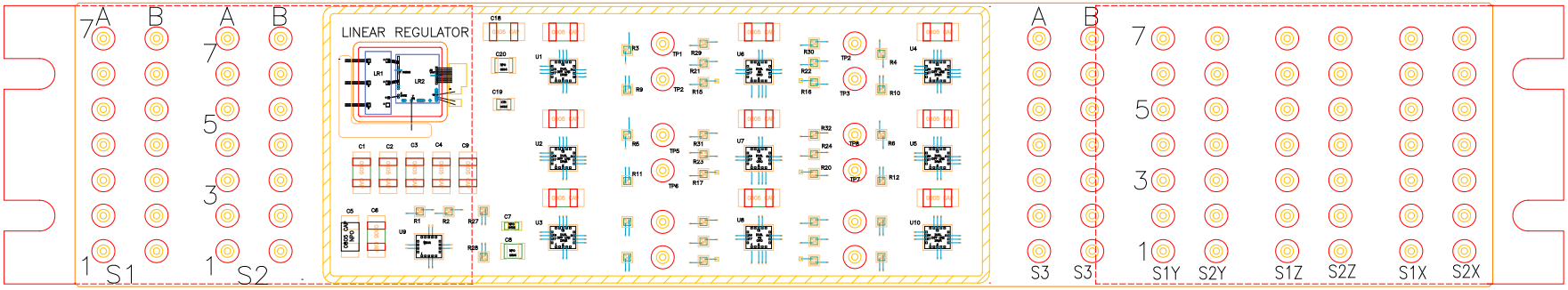


sVFC – Synchronous Voltage-to-Frequency Converter

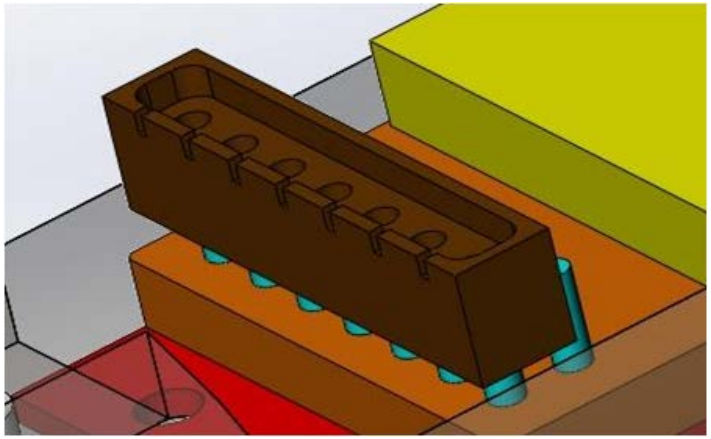
DM300 – Hybrid Circuits

Honeywell

- **SYSIO HTCC**
  - Gathers sensor signals and outputs via twisted pair to test system
  - Squares VBA frequency signals – 300°C HTSOI4 comparator
  - Outputs frequency signals to test system – HTSOI4 differential driver



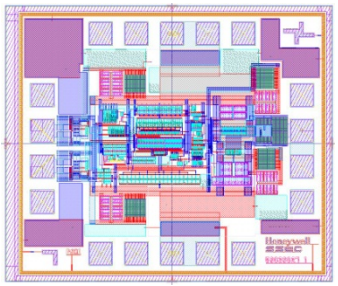
- **Interconnects using custom 7-pin SIP header on brazed HTCC pins**
  - Ceramic body
  - BeNi contact inserts
  - TIG welded 300°C CuNi wire



DM300 300°C SOI Electronics

Honeywell

- **Complete set of 300°C SOI chips designed and fabricated**
  - **All tested and validated at 300°C**
  - **Common footprint and pad arrangement**

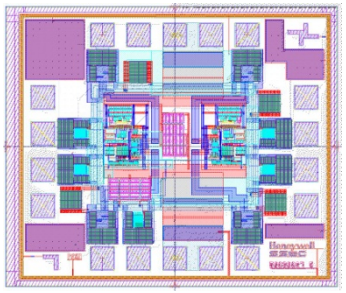


Wide-band Opamp

Multiple instances used on each for Accelerometer CCA for interface and signal conditioning

15.8MHz Unity gain bandwidth, 45° phase margin at 300C (15pF load)

3 Versions with varying levels of ESD protection



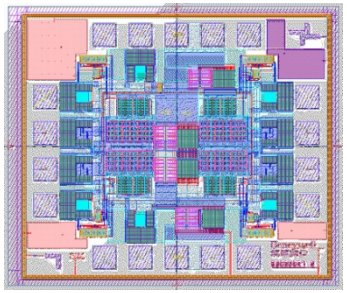
Dual Comparator

Squares VBA frequency outputs to full CMOS logic levels

Built in hysteresis (Enabled/Disable)

Fast response for minimal skew/jitter of freq outputs.

Propagation delay at 300C ≤40nsec 100mV pk-pk input (into 12pF load)

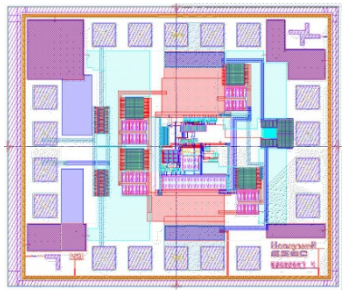


Quad Line Driver

Configurable as Quad single ended or Dual Differential output.

Differential-mode output is 3V (minimum) into 120 Ω termination

Outputs can be tri-stated by control input



Temperature Sensor & Small-signal diode bridge

(PTAT) current source : temperature sensor for system calibration.

Diode bridge VBA drive limiter

DM300 300°C SOI Electronics

Honeywell

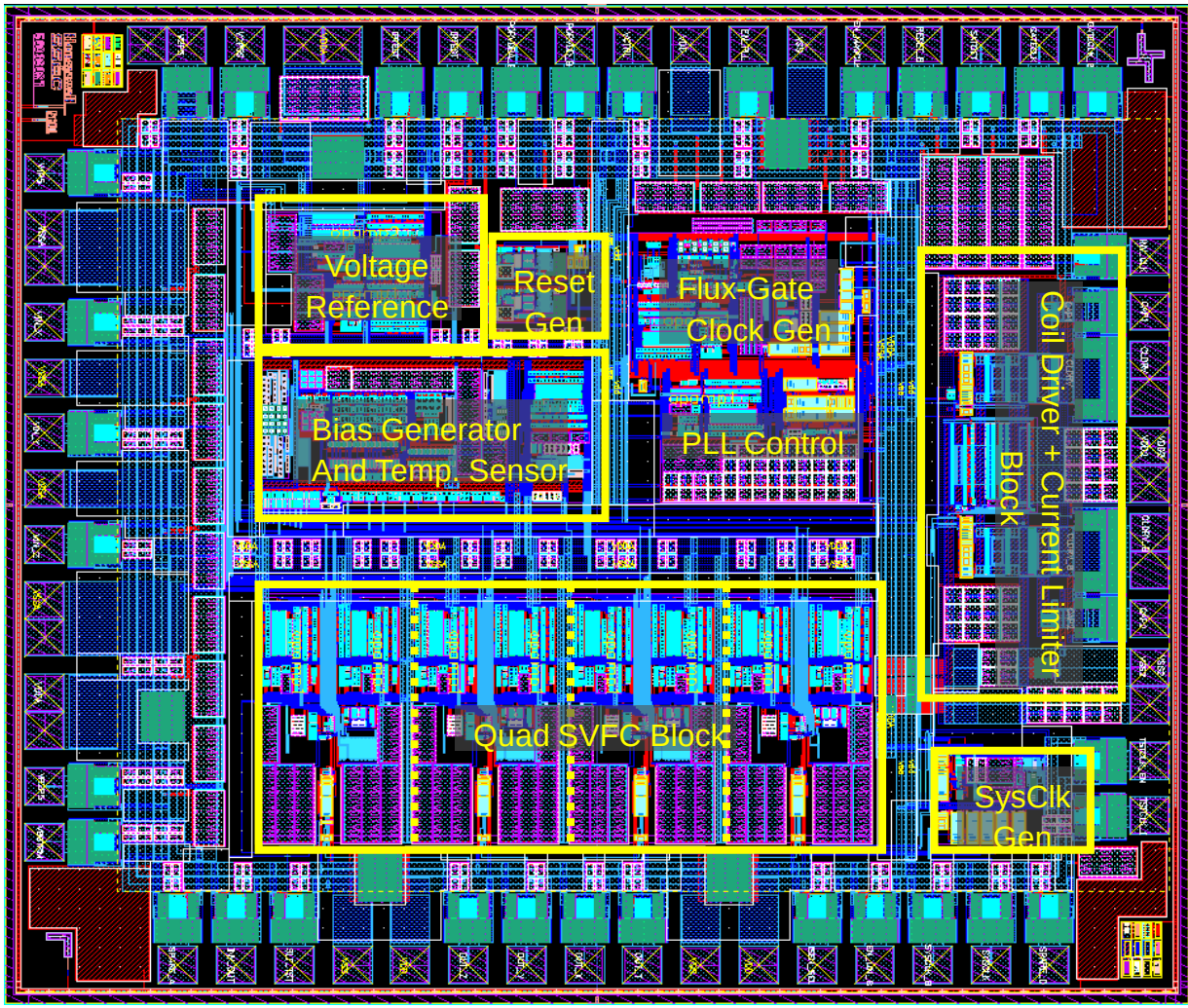
Magnetometer Interface ASIC

Die Size ~ 160 x 141 mils

61 Bond Pads Total

Major Function Blocks

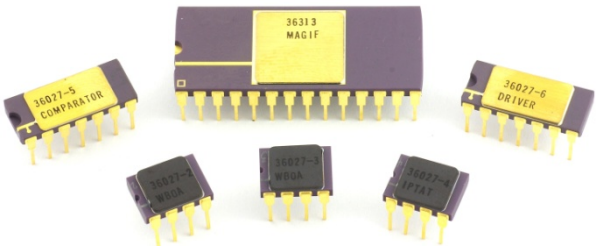
- Quad synchronous Voltage-to-Frequency Converter (sVFC)
- Bias Generator and Temp. Sensor
- Voltage Reference Block
- Flux-gate Clock Generator w/Phase-Locked Loop Control
- Coil Driver + Current Limiter Block
- System Clock Generator
- Reset Generator

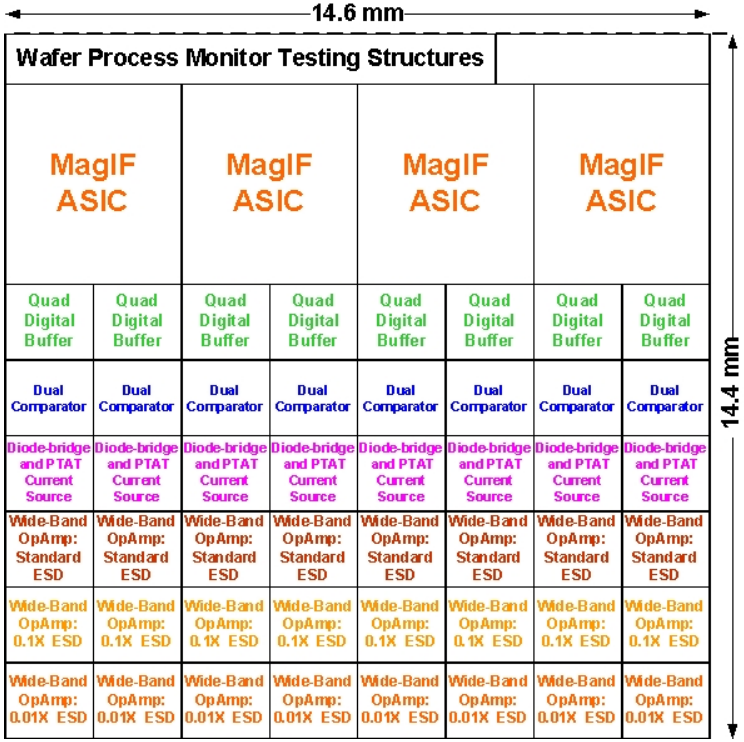


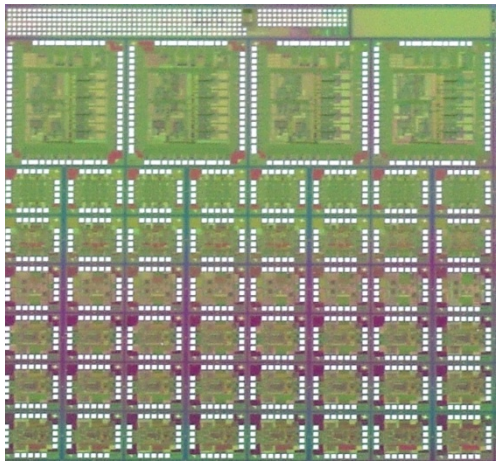
DM300 300°C SOI Fabrication & Usage

Honeywell

- **Custom DM300 Die on Single Reticle**
  - **Yield ≥ several hundred: 3-wafer lot**
  - **Common footprint + MagIF ASIC**
- **Catalog HTSOI4 components have been sample tested at 300°C**
  - **HTPLREG-05: 5V Linear Voltage Regulator**
  - **HT1204: Quad Analog Switch**
  - **HTOP01: Dual Precision Operational Amplifier**







DM300 – Full System Function (Future Development)

Honeywell

- **Replace SYSIO board with "SMART" system**
  - **Incorporate development from "Deep Trek" program**
    - Reconfigurable Programmable Data Acquisition (RPDA)
    - Replace FGPA from RPDA with Honeywell HT2300 Gate Array
    - Eliminate SRAM requirement
    - Utilize 32kbyte EEPROM
      - Has demonstrated >100,000 read-write cycles up to 300°C
      - Store system ID and sensor characterization data
  - **Utilize RPDA MCM ceramic HTCC**
    - Incorporate onto new DM300 system level HTCC (same 4" x .8" size)
- **Gate Array captures and formats data**
  - **Counters for frequency signals**
  - **EEPROM control**
  - **SPI Bus communications**
- **Possibility of including other down-hole functionality into gate array**

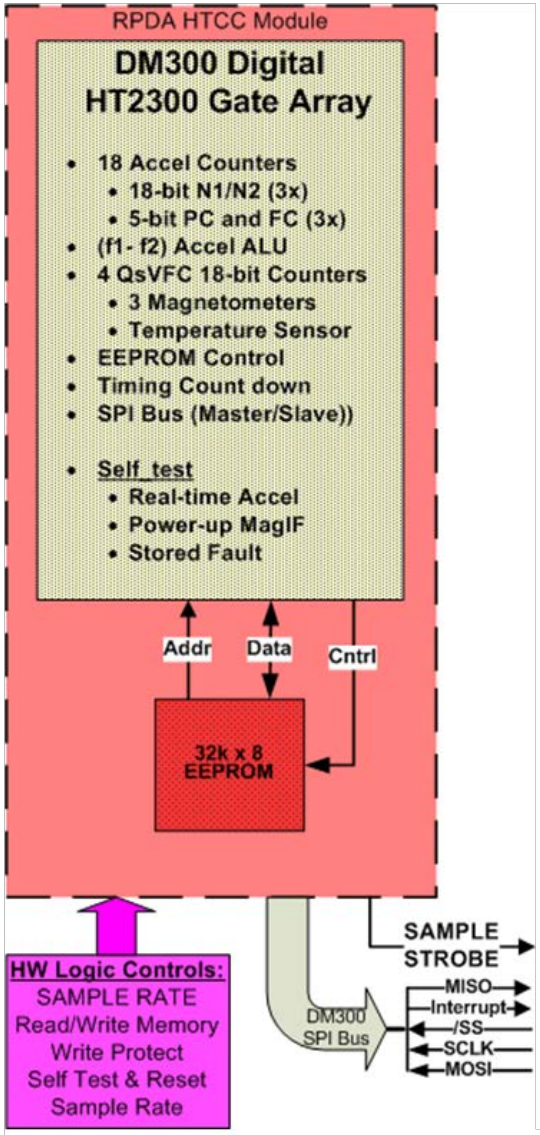


Figure 10: DM300 Gate Array & Memory

DM300 – 300°C Directional Module Summary

Honeywell

- **Demonstration of base module and sensor characterization**
  - **Frequency based sensor system – eliminates need for ADC**
  - **Electronic circuits developed and hybrids in fabrication**
    - Utilize step-AuSn braze for component mount
    - Independent power regulation on each hybrid
    - All chip & wire construction
  - **Active electronics fabricated and validate at 300°C**
- **Mechanical issues resolved**
  - **Titanium housing, connector, and mechanical interface**
  - **Ceramic hybrid mounting with heat sinking**
  - **300°C wiring and board-to-board interconnect routing**
- **Sensor development finalized**
  - **Silicon MEMS VBA**
  - **Flux-gate magnetometers with sVFC electronics**
- **Operational demonstration scheduled for October**

New paradigm for 300°C directional drilling module nearing completion