DEVELOPMENT OF A NEW OPTICALLY PUMPED POTASSIUM MAGNETOMETER

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SAGEEP 2003
INTRODUCTION

- Near Surface Requirements
- Recent Developments
- Optically Pumped Potassium Theory
- GSMP-40 Potassium Design Considerations
- Short Case History with Target Comparisons
NEAR SURFACE REQUIREMENTS

- Migrating from “bump” location
  - Fast, “highly detailed” mapping and characterization

- Parallel requirement for manufacturers to develop instrumentation to meet needs:
  - More detail for analysis & modeling
  - Higher productivity
RECENT DEVELOPMENTS

- **Overhauser** for walking surveys (v6.0 2000):
  
  - High sensitivity, low weight, minimal power, high absolute accuracy & minimal orientation error

- Ongoing R&D led to **Optically Pumped Potassium** for walking & vehicular surveys (2001 & 2002):
  
  - Very high sensitivity, high absolute accuracy, minimal orientation error and 20x sampling

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OVERHAUSER MAGNETOMETER
POTASSIUM MAGNETOMETER

- Multi-sensor, "Sweep Initiated" system that locks on to the first peak in Potassium spectrum
POTASSIUM SPECTRAL LINES

6 Narrow Spectral Lines approximately 100 nT apart

Narrow, symmetrical lines a key enabler of the technology

Affect sensitivity and gradient tolerance ... GEM developed gradient optimization procedures (2002)

Sweep and “lock” on to first line for measurement

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POTASSIUM - PRINCIPLES

1. Light Polarization:
   - Illuminate K sensor bulb with light of a specific wavelength and drive high energy valence electrons (L2) to metastable state.
   - Electrons decay back to L1 & L2 levels. Eventually, L2 level is depleted and potassium vapour is fully polarized. K bulb is transparent.

2. Depolarize using RF:
   - Restore populations of nuclei to initial states. K bulb is opaque.
POTASSIUM - PRINCIPLES

Light Polarization

Absorption

Spontaneous decay

RF Depolarization

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POTASSIUM - PRINCIPLES

3. Detect light modulation and “lock”:
   - Chamber oscillates from transparent to opaque. Use this light modulation to detect a potassium resonance signal.
   - “Lock” to this frequency using a designated “VCO” circuit.

4. Measure the frequency of light modulation:
   - Convert to magnetic units.
POTASSIUM - MEASUREMENT

- K-lamp
- Circular Polarizer
- Filter
- Potassium bulb
- Photo measurement
- Depolarization Coils

GEM SYSTEMS
POTASSIUM - SENSOR
WHY DESIGN POTASSIUM?

• Very high sensitivity per sensor (0.009 nT / √Hz @ 10 samples per second)

• Gradient tolerance (13,500 nT / m @ 40 mm)

• High sampling rate (20 x per second +) for speed of operation and bandwidth

• “Clean” signal (“heading” errors @ +/-0.025 nT) due to narrow spectral lines

• High absolute accuracy (+ / - 0.1 nT)
SENSITIVITY - COMPARISON

Single Sensor Values (nT)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>3s</th>
<th>1s</th>
<th>0.5s</th>
<th>0.2s</th>
<th>0.1s</th>
<th>0.05s</th>
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<td>GSM-19T</td>
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<td>0.1</td>
<td>0.5</td>
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<td>GSM-19</td>
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<td>0.014</td>
<td>0.035</td>
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<tr>
<td>GSMP-40</td>
<td>0.002</td>
<td>0.003</td>
<td>0.005</td>
<td>0.009</td>
<td>0.014</td>
<td></td>
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</table>

Graph shows sensitivity comparison with sampling intervals of 3s, 1s, 0.5s, 0.2s, 0.1s, and 0.05s.
SENSITIVITY = \( k \frac{\Gamma}{\gamma_n S_n} \)

- \( k = \) Constant
- \( \Gamma = \) Spectral Line Width
- \( \gamma_n = \) Gyroscopic Constant
- \( S_n = \) Signal / Noise Ratio

<table>
<thead>
<tr>
<th>Width (nT)</th>
<th>Method</th>
<th>( \gamma_n (\text{MHz/T}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 to 1.0</td>
<td>Potassium</td>
<td>7000</td>
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<tr>
<td>4</td>
<td>Overhauser</td>
<td>42.58</td>
</tr>
<tr>
<td>15</td>
<td>Proton</td>
<td>42.58</td>
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<tr>
<td>20</td>
<td>Cesium</td>
<td>3500</td>
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GRADIENT TOLERANCE - 2002

• “Extra” sensitivity that can be “traded off”

• Previous sensor tolerance = 2,500 nT / m
  with 0.001 nT single sensor noise (unfiltered at 1 Hz)

• New 40mm sensor tolerance = 13,500 nT / m
  with 0.002 nT single sensor noise (unfiltered at 1 Hz)

• Tolerance for “noisy” settings plus very very high sensitivity work (archaeology)

• Look at the settings in which systems to be used
“CLEAN” SIGNAL

- Isolate geophysical sources from “heading errors”
  - Spectral shifts due to sensor geometry
- Potassium’s 6 spectral lines at well-defined locations 100 nT apart
- Through careful sensor design, each line can be made very narrow (i.e. between 0.15 - 1.0 nT).
- Locate and lock very precisely on a designated line
- Minimal heading errors (+/- 0.025 nT)
SPEED OF OPERATION

- Speed is key as industry moves to vehicular surveys
- Reflects Nyquist bandwidth (fastest detectable signal)

<table>
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<tr>
<th>Nyquist</th>
<th>0.5</th>
<th>1 Hz</th>
<th>2.5</th>
<th>5 Hz</th>
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<tr>
<td>GSMP-40</td>
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<td>0.003</td>
<td>0.005</td>
<td>0.009</td>
<td>0.014</td>
</tr>
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</table>
ABSOLUTE ACCURACY

Key for consistent surveys and for multiple sensor arrays

- All components operating within the same tolerances
- Consider factors that affect field values and accuracy
  - Gyromagnetic constant uncertainties
  - Zero crossing algorithms and heading errors
- +/- 0.1 nT. Field results show that GSMP-40 does not introduce substantial biases related to time, sensor orientation or sensor changes.

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CASE HISTORY

- York Environmental Site (YES), York University
- Opened in Fall, 1985 - 110m x 95m
- 42 - 15m x 15m cells containing “targets”
- First complete survey by a magnetic instrument manufacturer in December 2002
- Vertical gradiometer survey over parts of 2 days (no base station)

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### YES CELL CONFIGURATION

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<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>A</td>
<td>Chalcopyrite Ore EMPTY</td>
<td>Oil EMPTY</td>
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<td>Plastic Mines</td>
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<td>Al</td>
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<tr>
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<tr>
<td>D</td>
<td>Al Paint Cans</td>
<td>Steel Plastic</td>
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<tr>
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<td>Plastic Al Fe</td>
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<td>Plastic Al Fe</td>
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<td></td>
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</tr>
</tbody>
</table>
TOTAL FIELD, GRAD & ASIG GRAD

“Target-rich” with many Dipolar & Monopolar Signatures

Simplification through Analytic Signal

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TOTAL FIELD ASIG & GRADIENT

- ASIG shows region to left acquired on day 2 (no base station)
- Gradient removes diurnal

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• ASIG simplifies characterization & targeting of anomalies / background

• Prepares the way for analysis

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ARTILLERY SHELL - 0.5m
IRON PIPE (N/S) - 0.5m
CLAY POTS - 1.0m

Fig 34: E2, south-western sub-cell.
STEEL DRUM LIDS - 1.0m
STEEL DRUM - 0.6m

Fig 50: D3. Vertically placed
STEEL PLATES - 2.0m
CONCRETE BUNKER - 1.0m
CONCRETE BUNKER - 1.0m

Model depth = 0.9m, infinite depth
SUMMARY

+ R&D ongoing in magnetometer / gradiometer systems

+ Potassium instrumentation takes advantage of narrow line, “Sweep Initiated” sensor physics and electronics

+ Design considerations reflect needs for “high detail” mapping and rapid sampling

+ Potassium, Overhauser and Proton technologies offer a range of sensitivities, gradient tolerances, etc. that should be understood in selecting appropriate tool for problem

+ Potassium test results demonstrate effectiveness of tool for detailing and characterization

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Thank you for your attention ...