ADAPTIVE AEROMAGNETIC REAL-TIME COMPENSATION FOR UAVs

Magnetometer interface counter
(1 or 2 sensors)

Real-time compensation: up to 2 TFs and true-gradient

Magnetics & general-purpose data acquisition & recording

Embedded GPS receiver (AARC52)

Compact, light, low power –
133 x 133 x 216 mm
+28 VDC (19–36 VDC)
AARC51: < 1.8 Kg, 3.0 A
AARC52: < 2.0 Kg, 3.5 A

- Front-end sampling rates up to 1280 Hz
- Magnetometer processor: 0.32 pT resolution, < 0.1 pT system noise, ±10 ppb temp. stability
- Proven, highly-robust compensation algorithms (AADCII legacy)
- Adaptive signal processing techniques
- User may customize Front End processing to specific installation requirements
- Interface for external GPS receiver
  AARC52: embedded GPS receiver option (single-, dual- or triple-frequency)
- Data recording & output, up to 80 Hz: complete raw, pre-processed and compensated data sets
- Post-flight compensation & analysis functions
- Dynamic compensation of on-board electronics
- Gating of magnetometer readings for concurrent use with EM systems – AARC52 only
- Real-time graphical output and user interface on any external display
- Two general-purpose analog inputs (e.g., radar altimeter), two assigned to embedded barometric-pressure & temperature sensors
- Data acquisition via Ethernet
- Full monitoring/control from any Windows device (via Ethernet, or remotely via internet)
- Features targeted to UAV applications
- State-of-the-art HW & FW architecture based on advanced 64/32-bit processors
- Real-time operating system (RTOS): QNX 6.5
**Aeromagnetic Compensation**

The quality of the data collected in aeromagnetic surveys is largely dependent on the quality of compensation. Despite the outstanding sensitivity of modern magnetometers, in the absence of good compensation anomaly signals can be completely masked out by the interference of the nearby magnetics of the aircraft.

The aircraft’s magnetic interference is related to its motions about its principal axes. A mathematical model may be built to accurately represent the aircraft’s magnetic signature. Careful optimization and implementation of this model, within the framework of sophisticated hardware and firmware technologies, can lead to real-time compensation that effectively eliminates the aircraft’s magnetic interference.

The RMS Instruments’ AARC51/52 Adaptive Aeromagnetic Real-Time Compensator provides real-time compensation of local magnetic interference for inboard magnetometer systems in fixed-wing aircraft, helicopters, or UAVs to the point where the full resolution of modern high sensitivity magnetometers can be utilized. The compensation accounts for the effects of permanent and induced magnetism, eddy currents, and heading errors from the sensors.

**The importance of real-time compensation**

State-of-the-art aeromagnetic surveying requires real-time monitoring of compensated data, so that problems are identified immediately and are promptly corrected. The magnetic signature of typical survey aircraft can be rather unstable and change in-flight; detecting these changes while monitoring uncompensated data is practically impossible. By eliminating costly and error-prone post-flight processing, real-time compensation further contributes to increased productivity, efficiency and cost-effectiveness.

**Calibration mode, model and solution**

The AARC51/52 uses a 3-axis fluxgate magnetometer to monitor the aircraft's position and motion with respect to the ambient magnetic field while flying a set of standard maneuvers of rolls, pitches and yaws in orthogonal headings. This calibration process, which typically takes 6-8 minutes, yields a (mathematical) solution that models the aircraft's magnetic signature. The solution is calculated instantly, upon termination of the calibration maneuvers. It is immediately available for use in compensated (i.e., survey) mode, or for further analysis and comparison with other solutions.

With the AARC51/52 there is no need for any post-flight software. The calibration is effective for the full 360° range of headings. At very low dip angles, partial calibrations for each active zone can be readily combined to produce a single robust solution for the full 360° range.

**Compensation – total fields & gradients**

In compensation mode the total-field (TF) high-sensitivity magnetometers, as well as the associated gradient (AARC52), are compensated in real-time using the last solution obtained (or any other solution previously archived). Compensated and uncompensated data, along with the 3-axis vector magnetometer and other ancillary data, are monitored and recorded in real-time.

Importantly, the system provides true gradient compensation: an independent calibration solution is calculated for the gradient.

**Adaptive compensation**

The AARC51/52 incorporates adaptive signal processing techniques that allow the system to continuously "learn" from input signals, and adapt the solution coefficients for optimum compensation. The underlying recursive algorithm has significant computational advantages over the "conventional" alternative, and leads to improved band-passted and gradient compensation. Adaptive compensation substantially eases calibration procedures, and yields solutions that remain close to optimum as the aircraft’s magnetic signature changes with time.

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Left – Bandpassed uncompensated and compensated data for a full calibration flight (8 minutes). The uncompensated waveform clearly shows the aircraft interference on the four headings.

Performance indicators: $\sigma_{\text{uncomp}} = 0.5502$ nT, $\sigma_{\text{comp}} = 0.0282$ nT, $IR = 19.5$. (Waveforms are offset for clarity.)

Right – Wideband uncompensated and compensated waveforms. (Mean value subtracted for clarity.)
**Dynamic compensation of OBE systems**

The AARC51/52 incorporates new technology that allows real-time dynamic compensation of the effects of DC currents from on-board electronic (OBE) systems, such as avionics, hydraulics, control systems and other instrumentation. OBE compensation simplifies operational requirements, increases robustness and tolerance to electrical sources, and improves overall compensation performance. The technology works with fixed- and variable-current devices, for up to two independent OBE systems.

**System Architecture**

RMS Instruments’ compensation technology is based on a flexible architecture with dual 64/32-bit processors. It includes state-of-the-art COTS (industrial-grade) electronics, and a proprietary magnetometer interface with excellent accuracy. Front-End sampling rates up to 1280 Hz and finely-tuned transfer functions deliver outstanding anti-aliasing characteristics, and may be customized by the user to the specific requirements of an installation.

The main program and real-time operating system (RTOS) reside in (solid-state) Flash memory. The RTOS is QNX 6.5 (or later). This is a deterministic and extremely reliable operating system tailored to mission-critical applications.

A three-axis fluxgate (vector) magnetometer is included with the system. Signals are processed using a high-resolution (16-bit) A/D converter.

The software includes an easy-to-use graphical user interface, and a rich set of utilities to analyze data and help troubleshoot aeromagnetic installations.

**Remote control from Windows**

A remote connectivity tool for the AARC51/52 allows users full control and operation of the unit from a remote Windows-based system, across an IP network.

The user interface of the AARC51/52 is seamlessly replicated in the Windows-based computer. The mouse and keyboard attached to the computer have the same effect as if they were directly connected to the AARC51/52.

This technology facilitates flexible architectures for complex systems that incorporate the AARC51/52. A single computer/laptop can be used to control and operate the AARC51/52 and other instruments (e.g., gamma-ray spectrometer, gravity system, etc.). Any other Windows applications can also be running simultaneously (e.g., navigation software). This remote connectivity is also very useful for training and remote support (from any location, via Internet).

**GPS receiver**

An interface for an external GPS receiver is standard. The AARC52 supports also an embedded GPS receiver (optional). A variety of receivers are available to satisfy different requirements in accuracy. One port on the receiver is used internally; an additional two ports are accessible by the user (for example, to interface to a navigation system). GPS data are appended to recorded and transmitted magnetics data packets. Timing throughout the system is tied to the PPS trigger from the GPS receiver.

**Post-flight compensation & analysis**

Advanced embedded functions allow post-flight survey compensation, in the event a suitable calibration was not available at time of flight. This complements the fundamental real-time compensation function, key for productive and efficient airborne magnetometry. Also included are functions for in-depth analysis of calibration data, and frequency-domain analysis.

**General-purpose data acquisition**

The AARC51/52 supports data acquisition via 1-Gbps Ethernet (TCP/IP packets), and includes two differential, high-resolution analog inputs to complement magnetics data – e.g., radar/laser altimeter, etc.

**UAV Applications**

The AARC51/52 is ideally suited to Unmanned Aerial Vehicle (UAV) applications because of its light weight, compact package, and low power consumption.

In typical UAV use the unit would be pre-configured on the ground at the start of a project, set up to automatically start data acquisition, compensation and recording on power up. The configuration is easily carried out using a laptop/computer via Ethernet, or by attaching a display and mouse/keyboard. During surveys the AARC51/52 is essentially a “black box” continuously recording in an embedded solid-state drive (Flash) magnetics data (raw and compensated), GPS and other ancillary data. Upon landing, the data are extracted from the system through a USB memory stick or via Ethernet.

For optimum performance a suitable calibration flight must be carried out as far as possible from any geological and/or cultural interference. Without an operator on-board this presents unique challenges in UAV systems. The AARC51/52 allows real-time command and control from the ground with a long-range wireless Ethernet link onboard the UAV. Alternatively, it provides two comprehensive approaches to automate the calibration process: time-framed calibrations (TFC), and altitude-controlled calibrations (ACC). With TFCs the operator pre-defines a specific time window after power up, during which calibration maneuvers must be flown. With ACCs the start/end of calibrations may be controlled through the embedded barometric pressure sensor (or an external sensor/altimeter), or GPS altitude.
**AARC51/52 SPECIFICATIONS**

**Magnetometer Inputs:**
One (AARC51) or two (AARC52) high-sensitivity magnetometers:
- Cs: Typ. 70 kHz – 350 kHz

**Magnetic Field Range:**
Per the magnetometer’s range; e.g.: [1]
- G-822A, G-823A: 20,000–100,000 nT
- CS-3, CS-L, CS-VL: 15,000–105,000 nT

**Transfer Function (bandwidth):** 1.6 Hz,

**Accuracy:** per Front End sampling rate

**Event tags included with output data**

**Oversampling, 16-bit, self-calibrating ADC**

**Co-pilot:**
- Sampling rate: 160, 640, 800 or 1280 Hz

**CS-3, CS-L, CS-VL:** 15,000–105,000 nT

**G-822A, G-823A:** 20,000–100,000 nT

**System Components:**
- LS-TTL levels, edge-sensitive
- Two general-purpose latched event inputs

**3-axis fluxgate sensitivity magnetometers:**
- Cs: Typ. 70 kHz – 350 kHz

**PPS trigger signal from external GPS**
- Event Inputs:
  - PPS trigger signal from external GPS
  - Two general-purpose latched event inputs
  - LS-TTL levels, edge-sensitive
  - Event tags included with output data

**Accuracy:** per Front End sampling rate

**Embedded Barometric Pressure & Temperature Sensors:** [6]
- Differential inputs, 16-bit ADC
- 600 to 1100-mbar range; ±5 mbar total accuracy
- –50 to +100°C range; ±1°C abs. error

**EM Gating (AARC52 only):**
- For concurrent use with EM systems
- LS-TTL input with pull-up

**Raw Data Logging:**
- At Front End sampling rate
- 1-MB buffer

**FE-Sampled Analog:**
- Two differential inputs
- 16-bit resolution, self-calibrating ADC
- Input range: ±5 Volts
- Input resistance: 1 MΩ, typical

**Data Acquisition via Ethernet:**
- 10/100/1000Base-TX Ethernet (RJ45)
- TCP/IP packets, ASCII/Binary
- Sampling & recording: FE-sampled analog
- 1-MB buffer

**Remote Control:**
- Via serial (RS232) port – ASCII cmdns.; AARC52 only
- Via IP ntwk. over Ethernet – replica of AARC51/52’s user I/F on computer

**Indicators, General-Purpose I/O:**
- 1 LEDs for mag. input status
- 2 LEDs for Front End status
- Three USB 2.0
- 10/100/1000Base-TX Ethernet (RJ45)
- Analog RGB (15-pin D-sub)

**GPS Receiver:**
- Standard: Interface to any GPS receiver that outputs NMEA GGA packets via serial (RS232) port (up to 10 Hz), and PPS trigger (LS-TTL or LV-TTL)
- Optional (AARC52): Internal (embedded) GPS receiver; single-, dual- or triple-frequency, Novatel’s OEMV-1, OEMV-2, OEM6 or OEM7 series
- Magnetics data tagged with GPS time, lat., long., altitude, and auxiliary data
- Up to 10 Hz

**Post-Flight Compensation:**
- Advanced analysis functions on standard system-recorded d-files:
- Post-flight compensation
- Calibration/solution robustness analysis
- Frequency-domain analysis

**Power:**
- Nominal: +28 VDC, 3.0 A (AARC51) or 3.5 A (AARC52)
- (Total power requirement, including magnetometer sensor(s) [7])
- Range: +19 to +36 VDC
- Absolute maximum: +50VDC, < 100 msec

**Environmental:**
- Operating Temperature: –10 to +50°C (0 to +50°C with HW Rev. < 3.00)
- Storage Temperature: –20 to +55°C
- Relative Humidity: 0 to 99%, non-condensing
- Altitude: 0–6,000 m (0–20,000 ft)

**Size (W x H x D):**
- 133 x 133 x 216 mm, (5¼ x 5¼ x 8½ in)

**Weight:**
- AARC51: < 1.8 Kg (4.0 lb)
- AARC52: < 2.0 Kg (4.4 lb)
- (Excluding external cables, mounting hardware & sensors)

**Notes:**
[1] Per manufacturer’s specs. at print time: G-822A, G-823A (Geometrics), CS-3, CS-L, CS-VL (Scintrex).
[5] With HW Rev. ≥ 2.10; otherwise, up to 40 Hz, 3/4 GB.

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Specifications subject to change without notice

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