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AEROSPACE & DEFENSE

ATTITUDE CONTROL MAGNETOMETER

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A three axis, fluxgate to be used to obtain measurements of the Earth's magnetic field vector to determine the attitude of a spacecraft.

The advent of large LEO (low Earth orbiting) satellite networks, has significantly increased the need for high reliability, radiation hardened, attitude control s. Existing instruments suffer from shortcomings in the areas of radiation hardness, power consumption/isolation and (economical) manufacturability in large quantities. The TFM100S described was designed to address these issues and provides significant improvement over our earlier design, which is used on IRIDIUM™ and other programs.

RADIATION HARDNESS

The TFM100S was designed for LEO spacecraft to meet the radiation hardness requirements necessitated by operation within the inner Van Allen Belt. This radiation environment can cause performance degradation by producing ionized particles in the silicon (Si) and silicon dioxide (SiO_2) layers of semiconductors, increasing leakage currents [1] [2]. The required on-orbit lifetimes of >12 years for future satellite networks, such as TELEDESIC™, make long term ionizing radiation effects the most likely constraint of useful instrument life. The new instrument design was implemented using inherently radiation tolerant analog and digital integrated circuits. This is an improvement over the earlier design which used older (30 years) radiation-hardened 4000 series CMOS logic chips. This logic family is at or near obsolescence, relatively expensive, and can require procurement times of >10 months. Total ionizing dose (**TID**) testing was performed on an unshielded instrument at NASA Goddard Space Flight Center's Cobalt 60 Radiation Test Facility in Greenbelt, Maryland. Testing was performed for 14 days at a dose rate of 16 RADs per minute or 23 kRADs per day for a TID of >300 kRADS. The test was concluded after 14 days as allocated facility time had expired. The instrument was re-tested after radiation exposure. Parametric shifts were minimal (zero offset change <7 nanoTesla) and the easily met all specifications. The actual flight s will be shielded by aluminum instrument housings having a wall thickness of >25 mm. The housing and incidental spacecraft structure shielding will greatly increase the ionizing radiation tolerance of the instrument beyond the 300 kRAD test level. The reduces the probability of damage by SEE , SEU, SEL and SEGR (Single Event Effects, Upset, Latchup and Gate Rupture) by a fail-safe current limiting power supply and the exclusion of power MOSFETS in the instrument design.

POWER CONVERTER

The power convertor is a very simple design using the "isolated flyback" [3] topology and is implemented using an intrinsically radiation tolerant, bipolar integrated circuit. The convertor transformer is driven by a single bipolar switching transistor having a breakdown voltage >200 VDC. This configuration gives reliable operation over an input voltage range between 10 and 120 VDC at a nearly constant conversion efficiency. This wide range of operation was necessary because many of the upcoming LEO satellite designs have not yet defined their power busses. At least one program is considering an unregulated buss of about 100 VDC. The power convertor provides total isolation (to >500 VDC breakdown) between power and signal grounds. This allows the spacecraft designers to select the optimum grounding configuration, between telemetry and the power buss, for best system noise rejection. The convertor design has been radiation tested to >300 kRADs and power on-off cycled to >325,000 times without "hang-up" or failure.

SENSOR CORE TYPE

Billingsley Magnetics manufactures Ring Core, Racetrack [4] [5],and Vacquier [6] sensors. The three different types of fluxgate sensor elements were evaluated to select the one most suitable for this new design. The evaluation testing of all three types was done with the sensors configured for the (low noise) voltage mode [7] of operation. The Ring core sensors were fabricated, using a proprietary technique, to eliminate "crossfield effects". The "Crossfield Effect" is an apparent shift in sensor axial alignment when different perpendicular fields are applied. The effect is usually negligible with perpendicular fields of >20 mTesla but can cause apparent alignment shifts of 0.5-1 degree or even greater in fields of 60 mTesla (earth's field). A rotating spacecraft, in low earth orbit, could have an incremental uncertainty in its attitude determination by this amount. Toroidal geometry sensors can be especially susceptible to this error source. Ring core sensors were ultimately selected as we have corrected the crossfield effect, and consequently they represent the best overall tradeoff of performance relative to the needs of an attitude control. Table 1 describes the considerations which resulted in this selection. Figure 1 depicts a Vacquier probe and a ring core sensor.

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TABLE 1: DESIGN TRADEOFFS FOR SPACECRAFT ATTITUDE CONTROL SENSORS

CHARACTERISTIC EVALUATED	FLUXGATE SENSOR TYPE		
	RING CORE	RACE TRACK CORE	VACQUIER (TWO ELEMENT) PROBE
Noise (RMS/ROOT/Hz @ 1Hz)	12 pT typical to 4 pT (vs. IRIDIUM >75 pT)	6pT typical to 3pT	25 pT
Drive Power	Lowest - 2 cores	Moderate - 3 cores	Higher -3 cores (open magnetic path, requires more drive power)
Manufacturability	Best	Most Difficult	More difficult than ring cores
Zero stability vs. Temperature	Good	Very good	Excellent
Ruggedness / Resistance to Shock	Excellent	Good	Excellent
Temperature coefficient of scale factor	Good	Excellent	Excellent
Full scale linearity (fields up to 1 Gauss)	<0.005%	0.0018 %	0.0018%
Cost	Lowest	Highest	Intermediate
"Crossfield effect" (errors due to large perpendicular fields)	(TFM100S design corrects to near zero)(non-linear above 20 μT on older IRIDIUM type ring cores)	Excellent (low and high fields)	Very good (linear, appears as a small misalignment of sensors)

TESTING

In the past, high performance s were flown (and tested) at a rate of a few per year. In contrast, today's large constellations of spacecraft requires production of a several per day on average. Data acquisition and analysis software was developed to achieve the levels of automation required to produce the instrument in large quantities within a limited time schedule. The tests which have historically been most time consuming, cost drivers, are described below.

NOISE / FREQUENCY RESPONSE

The is placed in a "six level" magnetic shield (fluxtank) and connected to the noise test setup. This setup consists of a 40 dB low noise amplifier, a 0.005 Hz Krohn-Hite high-pass filter, a Stanford Research SR770 FFT spectrum analyzer, and a PC running BMATS DAQ (Billingsley Magnetics Automatic Test System) software. This test is performed automatically and repeated for the instrument's other two axes. The spectrum analyzer accumulates at least 1024 data samples and then averages the RMS noise at 1 Hz. Frequency response is measured using the SR770's internal frequency source to stimulate the sensor under test.

LINEARITY / ORTHOGONALITY

The instrument is placed in a closed loop Helmholtz coil system. A minimum of ten field values, per axis, between ± full scale are applied and the resultant data are fitted to a straight line using a "least squares fit" algorithm. A report is generated which graphically and numerically represents the results. The sensor's orthogonality is calculated using the dot products of the generated field values.

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TFM100S SPECIFICATIONS

SPECIFICATIONS	
Radiation Tolerance	>306kRADs
Axial Alignment (Orthogonality)	better than ± 1° ; ± 0.5° special; calibration data provided to ± 0.1°
Input Voltage	+ 14 to + 45 VDC (or) +45 to +125 VDC
Input Current	20 mA @ 28 Volts
Field Measurement Range	± 100 μTesla
Accuracy	± 0.5% of full scale
Linearity	0.015% of full scale
Sensitivity	100 μV per nanoTesla
Scale Factor Temperature Shift	0.0075% full scale per °C
Output Ripple	3 mV peak to peak @ 2nd harmonic
Analog Output @ Zero Field	± 0.025 volt (to .002 with optional trim)
Zero Shift with Temperature	± 0.6 nanoTesla per °C
Susceptibility to Perming	± 25 nanoTesla shift with ± 5 Gauss applied
Output Impedance	332 Ohms ± 5%
Frequency Response	- 3 dB @ > 150 Hz
EMI	CEO1, CEO3, REO2, CS01, CSO2, CSO6, RSO1, RSO2, RS03
Random Vibration	20G RMS (20 Hz to 2 KHz)
Shock	>230G
Temperature Range	- 40° to + 85°C operating
Weight	200 grams (shielded to 306 kRADs)
Size	3.66 cm x 3.58 cm x 15.44 cm
Connector	(chassis mounted) 9 pin male "D" type gold-plated, mil-spec, non-magnetic (mating connector supplied)

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