C.2.1 Magnetic Field Experiment (MAG)

C.2.1.1 System Description

Accurate measurements of the interplanetary magnetic field and its dynamics provide essential supporting data for the studies to be carried out by the IMPACT investigation. In addition, magnetic field measurements are essential is establishing the background geometrical framework in which the interplanetary plasma and energetic particle processes take place. The observations of time variations of the characteristics of the interplanetary medium require the correct identification of propagating interplanetary shock waves, interaction regions associated with different solar sources, the well known interplanetary sector structure and/or position relative to the heliospheric current sheet, and other structural features known as directional discontinuities. The investigation of the role of turbulence in a magnetized astrophysical plasma such as the solar wind is also a fundamental characteristic to be studied. The classification of time variations of the interplanetary magnetic field will depend upon simultaneous observations of the solar wind plasma with similar time resolution. Collective knowledge of these macro/micro/structural characteristics of the interplanetary medium will provide critically needed data for meaningful studies of three-dimensional transient event acceleration and propagation in the heliosphere to be carried out by STEREO.

The magnetometer system proposed for IMPACT is a simplified version of the highly successful magnetometers flown on Mars Global Surveyor and Lunar Prospector. These wide dynamic range instruments consists of one or more triaxial fluxgate magnetometers mounted on a boom or spacecraft appendage. The MGS magnetometer sensors are mounted at the edge of identical solar arrays diametrically opposite each other while the LP single sensor is mounted at the end of a rigid, deployable boom which is shared with the Electron Reflectometer instrument mounted at the base of the rigid portion of the boom. For IMPACT we propose to simply reverse the positions of the Electron Analyzer and MAG sensor; the Electron Analyzer will be placed at the end of the fixed boom and the MAG sensor at its base and this assembly in turn attached to a deployable astromast type boom.

The IMPACT triaxial fluxgate magnetometer measures the magnetic field intensity along three mutually orthogonal axes simultaneously. The choice of fluxgate magnetometers is based upon more than 25 years of highly successful and satisfactory experience with such detectors in space research. They provide accurate and direct vector measurements of magnetic fields while requiring a minimum of electronic circuitry, mass, and power. The fluxgate sensors utilize the ring core geometry, have a low drive power requirement, are smaller in size, and possess an improved zero level stability compared to other types of fluxgate sensor configurations. The magnetic cores consist of an advanced molybdenum alloy, developed over 20 years ago in cooperation with the U.S. Naval Surface Warfare Center in White Oak, Maryland and since then transferred to industry. This alloy exhibits extremely low noise and high stability characteristics and in the ring core sensor geometry allows the realization of compact, low power, and ultra-stable fluxgate performance.

A block diagram of the instrument and its interface to the IDPU is shown in Figure C.1-1. To optimize sensitivity at the low field values to be found in interplanetary space, the magnetometer dynamic range is divided into 8 separate ranges, shown in Table C.2.1-1, along with their 12-bit analog to digital quantization step sizes. This basic design will be optimized during the development phase to tradeoff analog-to-digital converter resolution versus the number of magnetometer dynamic ranges and the IDPU data compaction algorithms.

Table C.2.1-1

Range	**± Field (nT)**	**± Quantization Step Size (nT x 10-3)**
1	4	1
2	16	4
3	64	16
4	256	62.5
5	1024	250
6	4096	1000
7	16384	4000
8	65536	16000

These dynamic ranges are automatically switched whenever the field being measured exceeds a pre-determined level. Note that automatic range switching can be overridden by ground command. Note also that the maximum range is sufficiently large so that operation of the instrument as a magnetometer while within the Earth's magnetic field is possible without the need for any special field cancellation coil systems or magnetic field mu-metal shield canisters.

It is estimated conservatively that absolute accuracies of ±0.1 nT are achievable with this magnetometer system depending on the ultimate level of spacecraft magnetic cleanliness achieved. Since the smallest quantization step size is a small fraction of this level, substantially smaller fluctuations of the magnetic field can be studied reliably with this instrument.

C.2.1.2 Pointing Accuracy

The absolute orientation [with respect to inertial coordinates] of the magnetometers must be known to ±0.5º after the fact. The pointing stability must be ±0.25º. Both of these constraints can be easily accommodated by the proposed STEREO spacecraft anticipated performance (ref: Mission Requirements Document).

C.2.1.3 Power Requirements

In the normal operating mode the magnetometer will be powered continuously. The approximate power required is ~0.4 watts (regulated). The magnetometer incorporates an electrical reversing system to monitor electronic drifts caused by aging and radiation effects. This system will be activated 5 minutes every month to establish the electrical zero baseline. The additional power required during this procedure is negligible.

C.2.1.4 Data Rates and Format

Data handling is an important feature of this experiment due to the limited telemetry rate available. The basic internal sampling rate of the IMPACT magnetometer is 32 vector samples per second, which generates 1280 bits per second (bps) of raw data to be processed by the IDPU. Several data compaction algorithms to be executed in the IDPU are under consideration (differencing, averaging, decimation) which will reduce the output data rate to the allocated values for MAG within IMPACT. The baseline scheme is averaging the data to 8-Hz time resolution, followed by 6-bit differencing, with full samples sent every 4 seconds. This produces an output rate of 154 bps.

C.2.1.5 MAG Data Storage

No MAG data storage buffers beyond those already incorporated in the A-to-D converter are required. The IDPU can collect data from the MAG in real time at 1Mbps with no handshake required.

C.2.1.6 Experiment Processor Requirements and Software

All data collection and MAG control functions are executed from the central IDPU system. This system is identical to that already developed for the MGS and LP missions. Interrupt driven routines slaved to a master hardware clock provide an absolutely deterministic sampling system which acquires magnetic field data without clock jitter problems.

C.2.1.7 Ground Support Equipment

Specialized GSEs will be used at GSFC for testing and calibration of the magnetometer. We have developed and used similar GSEs in the past for many space instruments in the past. The UCB command and display GSE will be used at the system level.

Measurement equipment required for the Magnetic Cleanliness program at APL will be provided by GSFC.

C.2.1.8 Instrument/Spacecraft Interface

The mechanical, geometrical, thermal, and electrical interface requirements are summarized in Table C.2.1-2. Note that AC magnetic interference must be limited to less than 0.05 nT over the frequency range 0 to 10 Hz, as well as at the primary and first few harmonics of the sensor drive frequencies. Limited mapping of the spacecraft magnetic field will be conducted in order to verify the successful adherence to the magnetic field constraint discussed earlier, namely that the static spacecraft magnetic field at the sensor position be less than 0.5 nT and its variable component less than ±0.05 nT.

All electrical interfaces are handled by the IMPACT investigation with the exception of sensor heaters and/or temperature transducers.

Table C.2.1-2

Thermal Regimes	**Electronics (C)**	**Sensor (C)**
Operating	-20 to +60	-40 to +50
Non- operating	-50 to +75	-60 to +75
Power:	0.4 watt in all modes @ ±12.0 volts	
Magnetic Cleanliness:	Less than 0.5 nT @ the MAG sensor (static)	
EMC:	Less than 0.05 nT, 0-10 Hz at MAG sensor. EMC control plan to include MAG drive frequency and harmonics over a bandwidth of 100 Hz.	
Processing	Control and data by IDPU	
Commands	12-bit serial word from IDPU	

C.2.1.9 Calibration Plan

The IMPACT magnetometer will be calibrated pre-flight at the GSFC Magnetics Test Facility and post-flight at the Laboratory for Extraterrestrial Physics using highly successful methods and procedures developed over the last 30 years. Accurate and stable fields generated at the GSFC facility will be used to calibrate the magnetometer scale factors. Magnetic shields and mechanical reversals in a known low field will be used to establish the magnetometer zero levels. Dynamic performance such as frequency response and noise levels will be established in the LEP laboratories.

C.2.1.9.1 On-orbit Calibration. The MAG instrument should be active during the deployment of the IMACT boom. This will allow us to model the spacecraft residual magnetic field by measuring the field as a function of distance from the spacecraft. Periodic spacecraft rolls allow the measurement of two axes of the spacecraft residual field, plus any drift in the sensor effects. Any opportunity to collect data during yaw and pitch maneuvers would help calibrate the third axis. The electrical flipper, described in C.2.1.11, will aid in determining electronic offset variations.

C.2.1.10 MAG development

The MAG instrument and its analog processing electronics are systems that do not require further development. However, optimization trade studies will be conducted to optimize the scientific data return within the allocated telemetry and other spacecraft resources. These include the selection of an optimal A-to-D converter resolution and IDPU data compaction scheme, the number of dynamic ranges to be implemented in the MAG electronics, etc.

In addition to the above we plan to update the layout of the MAG electronics to take advantage of the latest packaging technologies such as surface mount and related techniques. This will require a detailed survey of available high reliability components in the selected packaging format including an assessment of the radiation tolerance of semiconductors and microcircuits. Long lead parts will be procured as soon as funding becomes available to minimize schedule impacts to the STEREO project. Finally, thermal control tradeoff studies will be conducted (passive versus active) to assure that the MAG sensors will be operated within their specified temperature range.

C.2.1.11 MAG Summary

The heritage and reliability of GSFC's magnetometers are well known through many successes such as those of Voyagers 1 and 2. Launched in 1977, the magnetometers have worked continuously without failures. IMPACT will benefit from the experience gained from these early instruments and that of the latest instruments developed for MGS, NEAR-Shoemaker, Lunar Prospector, Messenger and many other missions. Their performance and reliability are well established and the MAG development for IMPACT involves little technological or programmatic risk.

The accurate measurement of magnetic fields on a spacecraft is limited both by the zero level stability of the sensors themselves, as well as the magnitude of the spacecraft magnetic field. The IMPACT investigation includes a magnetometer boom sufficiently long and magnetic contamination specifications sufficiently stringent so that the spacecraft magnetic field will not exceed 0.5 nT at the MAG sensor. The sensor offset variations have been found to be less than ±0.2 nT/yr while operating over a wide temperature range. Passive thermal design and control of the magnetometer sensors can be achieved in principle but tradeoffs versus active control schemes will be pursued during the design phase.

Spacecraft roll maneuvers permit measurement of the spacecraft magnetic field zero level offsets perpendicular to the roll axis. Accurate measurements of the interplanetary field parallel to the roll axis depends upon both the pre-flight procedures and testing but also can be validated through in-flight analysis of interplanetary fluctuations with a number of well known and well tested algorithms. These are mathematical procedures which advantageously utilize the intrinsic property of minimum variance of the magnitude of the interplanetary field, when averaged over various intervals of time.

Additionally, the magnetometer system will be equipped with an electrical flipper which will reverse the sensor polarity for in flight electrical zero offset determination. These offsets may be due to radiation effects, component aging, and temperature and voltage variations. The typical sensor noise level is 0.006 nT rms over a bandwith of 0–8.3 Hz. This noise level has been verified in flight when the Voyager 1 and 2 spacecraft were located in the Jovian magnetic tail, an exceptionally quiet magnetic field regime within the heliosphere.