5. Space Environment Monitor

The GOES-NOP space environment monitor (SEM) measures solar radiation in the X-ray and EUV region and the in-situ magnetic field and energetic particle environment at geosynchronous orbit, providing real-time data to the NOAA Space Weather Prediction Center (SWPC). The SWPC, the nation's "space weather" center, receives, monitors, and interprets a wide variety of solar terrestrial data, and issues reports, alerts, and forecasts for special events such as solar flares or geomagnetic storms. This information is important for military and civilian radio communication; satellite communication and navigation systems; electric power networks; geophysical exploration; shuttle and space station astronauts; high-altitude aviators; and scientific researchers. The GOES-NOP SEM suite maximizes data continuity with the present GOES SEM database and satisfies the new SEM measurement requirements for extreme ultraviolet and magnetospheric particles. Related to the SEM is the Solar X-ray Imager (SXI), which is described in Section 6.

The SEM subsystem consists of multiple instruments used to monitor the near-Earth (geostationary altitude) space environment and observe solar X-ray (XRS) and extreme ultraviolet (EUV) output. Figure 5-1 illustrates the SEM instrument suite. An XRS/EUV instrument mounted on a positioning platform, fixed on the solar array yoke, observes solar output. The energetic particle sensor (EPS)/high energy proton and alpha detector (HEPAD) instrument measures the flux of protons, alpha particles, and electrons over an extensive range of particle energies. Two redundant three-axis magnetometers, mounted on a deployed 8.5 meter boom, operate simultaneously to measure the Earth's geomagnetic field strength and variations in the vicinity of the spacecraft. The SEM instruments are capable of ground-command-selectable, in-flight calibration for monitoring on-orbit performance and ensuring proper operation.

XRS/EUV Instrument

The XRS/EUV sensor measures disk-integrated solar X-ray and EUV fluxes. The XRS/EUV consists of two channels in the X-ray sensor, five channels in the EUV sensor, and a Digital Processing Unit (DPU) that controls the instrument. The microprocessor based DPU supports both sensors, providing power, telemetry and command (T&C), and data processing. A schematic view of the XRS/EUV is shown in Figures 5-2 and 5-3. The spacecraft points the XRS/EUV sensor so that the field of view (FOV) is always pointed at the sun. The XRS/EUV sensor is mounted on a gimbaled X-ray positioner

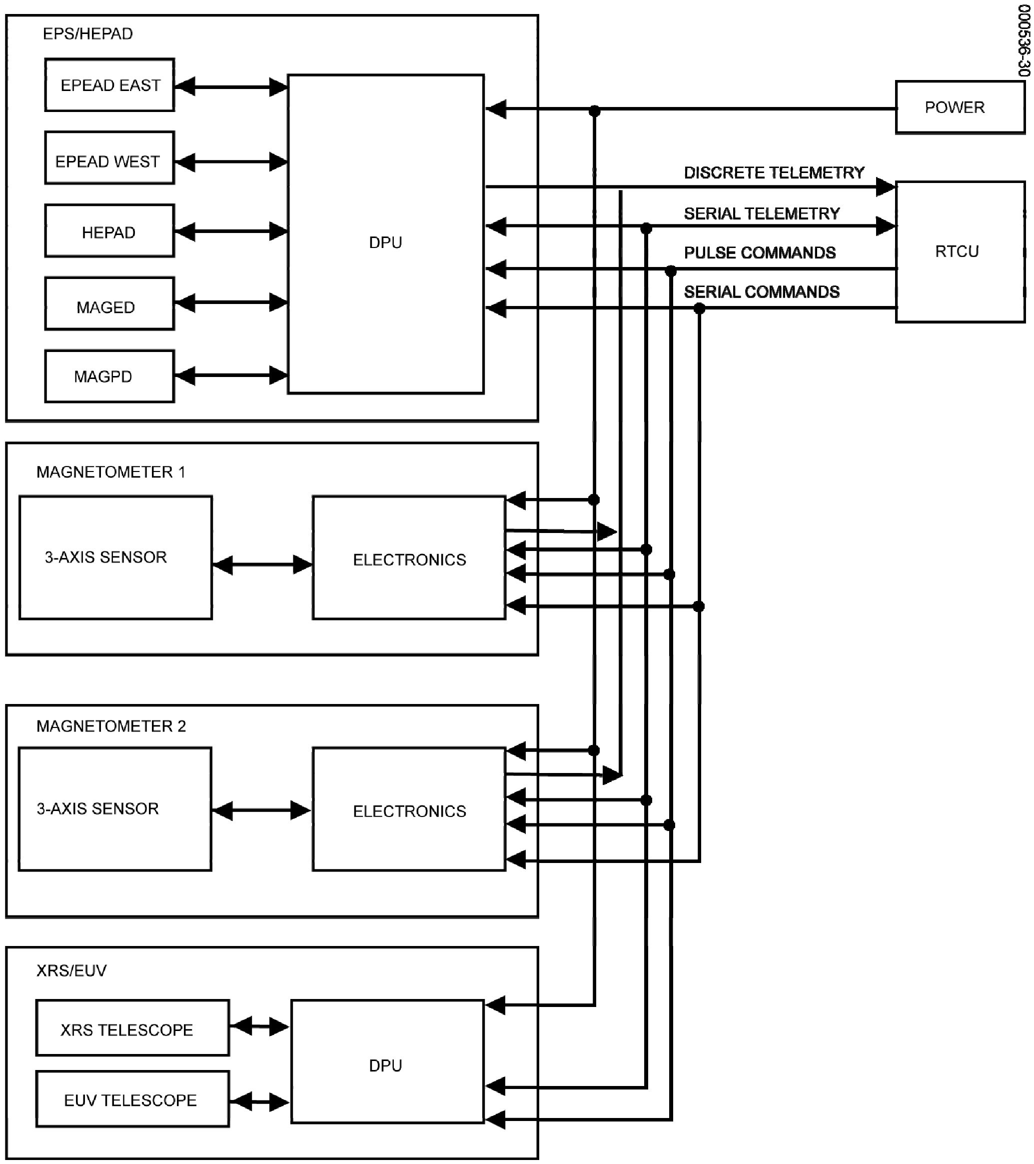

Figure 5-1. SEM Instrument Suite

(XRP) on the spacecraft solar array yoke, coaligned with the SXI. The XRP can track the sun along the elevation axis, while the yoke, along with the solar panel, is positioned by the spacecraft in the azimuth axis.

The XRS design is based on an ion chamber design from the GOES I-M spacecraft and the EUV sensor design is similar to one flown on the NASA SOHO spacecraft. The sensor telescopes use magnetic shielding to reduce the background from high energy electrons, and the detectors are all well shielded from ambient particles and bremsstrahlung effect.

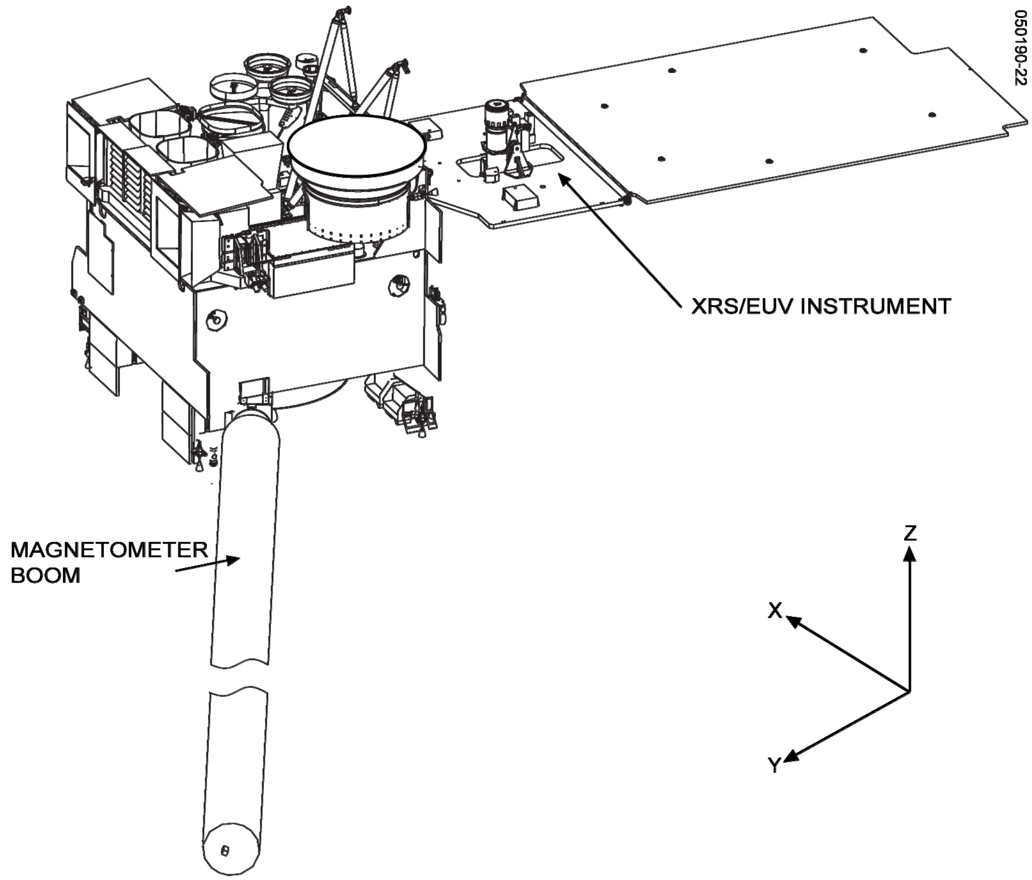

Figure 5-2. Deployed XRS/EUV Instrument – Schematic View

The XRS is an X-ray telescope that measures solar X-ray flux in two bands of 0.05–0.3 nm and 0.1–0.8 nm. The XRS assembly consists of a telescope collimator, sweeper magnet assembly, dual ion chamber and preamplifier subassemblies. Two ion chambers detect X-rays, one chamber for each spectral range. The detector output signals are processed by separate electronic channels that have a single range in each band, with the >5 decade dynamic range logarithmically compressed into a 15 bit data word. Data transmitted through the spacecraft telemetry permit real time ground determination of the solar X-ray emission in the two spectral bands.

The aperture of the XRS features a pair of sweeper magnets to deflect incoming electrons away from the ion chambers so that only X-rays are admitted. The XRS/EUV shielding magnet assembly is balanced to minimize the magnetic signature induced at the spacecraft magnetometers.

On GOES-N and GOES-P, the EUV telescope uses transmission gratings, filters, and solid state detectors to measure the extreme ultraviolet flux in five wavelength bands centered at 10 nm, 30 nm, 60 nm, 80 nm, and 126 nm respectively. The five EUV channels are mounted on three optical benches with channel pairs A-B and C-D sharing components such as gratings and front apertures. The A-B channel pair uses a 5000 line/mm transmission grating, and the C-D channel pair uses a 2500 line/mm transmission grating. The E channel uses a 1667 line/mm transmission grating and one Lyman Alpha Filter. A strong magnetic field sweeps out electrons below 4 MeV. Radiation shielding of detectors further reduces bremsstrahlung effects

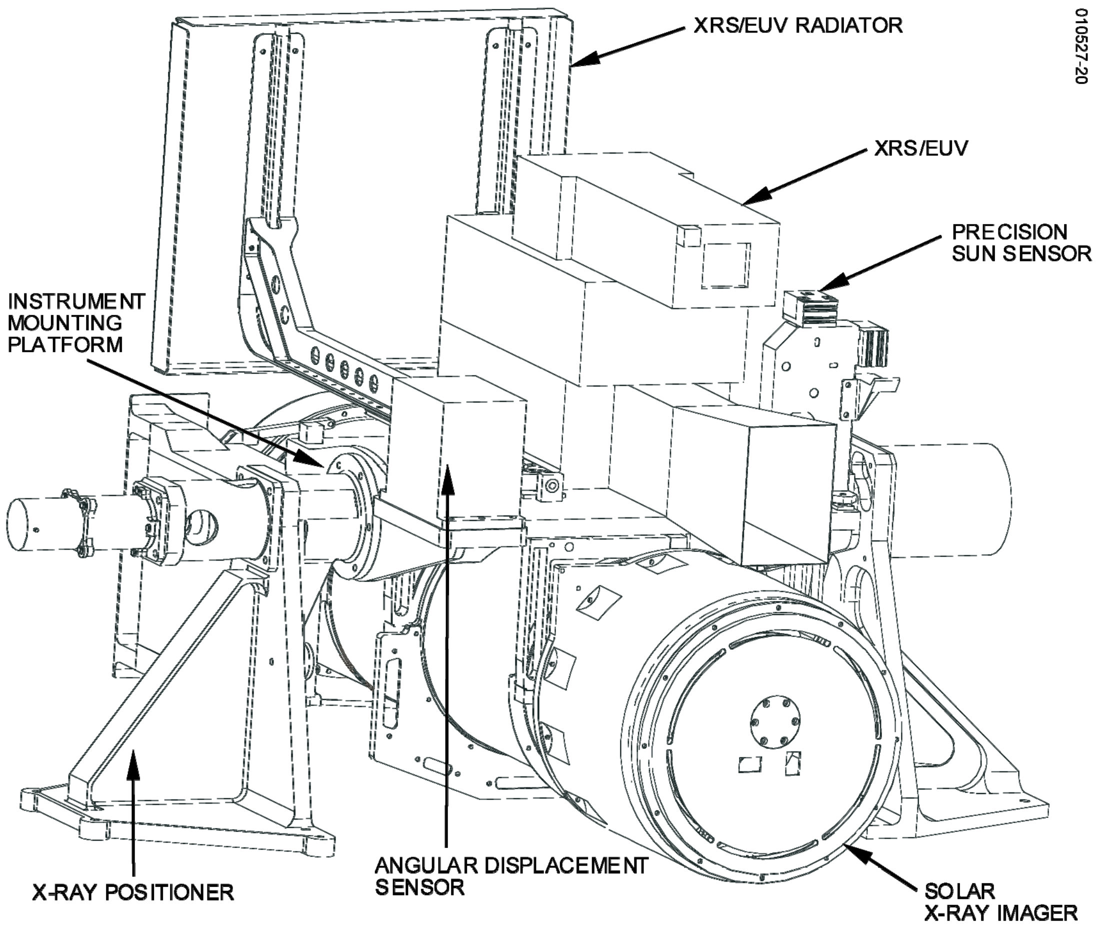

Figure 5-3. XRS/EUV/SXI Assembly

On GOES-O, the EUV telescope has been modified to measure the extreme ultraviolet flux in three wavelength bands centered at 10 nm, 30 nm and 126 nm respectively, and two redundant wavelength bands centered at 10 nm and 30 nm respectively. The five EUV channels are mounted on three optical benches with channel pairs A-B and B′-A′ sharing components such as gratings and front apertures. The A-B channel pair uses a 5000 line/mm transmission grating, and the B′-A′ channel pair uses a second 5000 line/mm transmission grating with the detectors arranged in the opposite order from the A-B detectors. The GOES-O EUV E channel, magnetic filed sweeping, and radiation shielding are identical to those in the GOES-N and GOES-P EUV sensors.

The DPU contains the dc/dc converter and all processing electronics. The X-ray and EUV flux outputs are all digitized in the DPU and delivered to the spacecraft. The pre-amplifiers are located in the telescopes, close to the detectors (ion chambers for the XRS and solid state detectors [SSD] for the EUV). The EUV SSD analog signal processors use the same data compression algorithm as the XRS even though the required dynamic ranges are only 10^3 and 10^2. The final signal digitization is done in the DPU, which provides the compressed data words to spacecraft telemetry. Each spacecraft minor frame contains four XRS/EUV 8-bit words.

Table 5-1. XRS/EUV Performance Summary for GOES-N and GOES-P

Parameter	Performance	
Spectral bands		
XRS-A	0.05–0.4 nm	
XRS-B	0.1–0.8 nm	
EUV-A	5–15 nm	
EUV-B	25–34 nm	
EUV-C	20–65 nm	
EUV-D	20–82 nm	
EUV-E	118–127 nm	
Threshold flux, dynamic range	Threshold Flux	Dynamic Range
XRS-A	5×10^{-9} W/m^2	100 000
XRS-B	2×10^{-8} W/m^2	100 000
EUV-A	1×10^{-6} W/m^{2}nm	1 000
EUV-B	2×10^{-6} W/m^{2}nm	1 000
EUV-C	1×10^{-6} W/m^{2}nm	100
EUV-D	2×10^{-6} W/m^{2}nm	100
EUV-E	1×10^{-4} W/m^{2}nm	100
Threshold Sensitivity		
Signal to noise ratio, 10 second interval	>1	
Resolution		
XRS, fluxes >20 times threshold	<2%	
EUV	0.25%, full scale	
Noise	Mean signal equal to the standard deviation of the data over a 10 second interval.	
Sampling rate		
XRS	Once every 2.048 sec	
EUV	Thrice every 32.768 sec	
Wavelength response	±5%	
Angular response		
Sensitivity varies less than 5%		
XRS	29.1 arc minutes	
EUV	30.1 arc minutes	
Pointing knowledge with respect to sun center	±2 arc minutes	

Table 5-1. XRS/EUV Performance Summary for GOES-O

Parameter	Performance	
Spectral bands		
XRS-A	0.05–0.4 nm	
XRS-B	0.1–0.8 nm	
EUV-A	5–15 nm	
EUV-A’	5–15 nm	
EUV-B	25-34 nm	
EUV-B’	25-34 nm	
EUV-E	118–127 nm	
Threshold flux, dynamic range	Threshold Flux	Dynamic Range
XRS-A	5×10^{-9} W/m^2	100 000
XRS-B	2×10^{-8} W/m^2	100 000
EUV-A	3.619×10^{-5} W/m^2	1 000
EUV-A’	3.619×10^{-5} W/m^2	1 000
EUV-B	8.082×10^{-5} W/m^2	1 000
EUV-B’	8.082×10^{-5} W/m^2	1 000
EUV-E	6.599×10^{-4} W/m^2	100
Threshold Sensitivity		
Signal to noise ratio, 10 second interval	>1	
Resolution		
XRS, fluxes >20 times threshold	<2%	
EUV	0.25%, full scale	
Noise	Mean signal equal to the standard deviation of the data over a 10 second interval.	
Sampling rate		
XRS	Once every 2.048 sec	
EUV	Thrice every 32.768 sec	
Wavelength response	±5%	
Angular response		
Sensitivity varies less than 15%		
XRS	29.1 arc minutes	
EUV	30.1 arc minutes	
Pointing knowledge with respect to sun center	±2 arc minutes	

The ACE samples XRS-B and EUV-A data, and then relays it to the SXI for use in the SXI’s flare detection function – which is described further in section 6.

EPS/HEPAD Instrument

The EPS/HEPAD instrument is partially based on the GOES I-M EPS/HEPAD design for the measurement of medium and high energy protons, electrons, and alpha particles, that originate from the sun, are trapped in the magnetosphere, or are generated by cosmic rays deep in space. The complete EPS/HEPAD instrument consists of two energetic proton, electron, and alpha detectors (EPEADs), a magnetospheric proton detector (MAGPD), a magnetospheric electron detector (MAGED), a high energy proton and alpha detector (HEPAD), and a DPU that controls the five sensors and interfaces with the spacecraft. EPS/HEPAD instrument locations on the GOES-NOP spacecraft are shown in Figure 5-4.

EPEAD

Protons in the energy range 0.74–900 MeV, alpha particles in the energy range 3.8–500 MeV, and high energy electrons in three energy ranges >0.6, >2, and >4 MeV are measured using two detector sets (EPEAD's) mounted on opposite sides of the spacecraft to provide the required equatorial angular coverage. The two EPEADs each contain a telescope assembly to measure the lower energy particles and a dome assembly to measure the higher energy particles. The dome detector also provides three integral electron flux measurements.

The telescope assembly uses two SSDs to measure the energy of protons and alpha particles in three bins each. These SSDs are shielded from electrons by a sweeper magnet and from light by a thin metal foil. Table 5-2 lists energy ranges for the telescope detectors.

The dome assembly contains three sets of two SSDs with differing shielding thicknesses to provide higher energy proton measurements in four bins, higher energy alpha particle measurements in three bins, and the three integral electron channels. Table 5-3 lists energy ranges for the dome detectors.

5. Space Environment Monitor

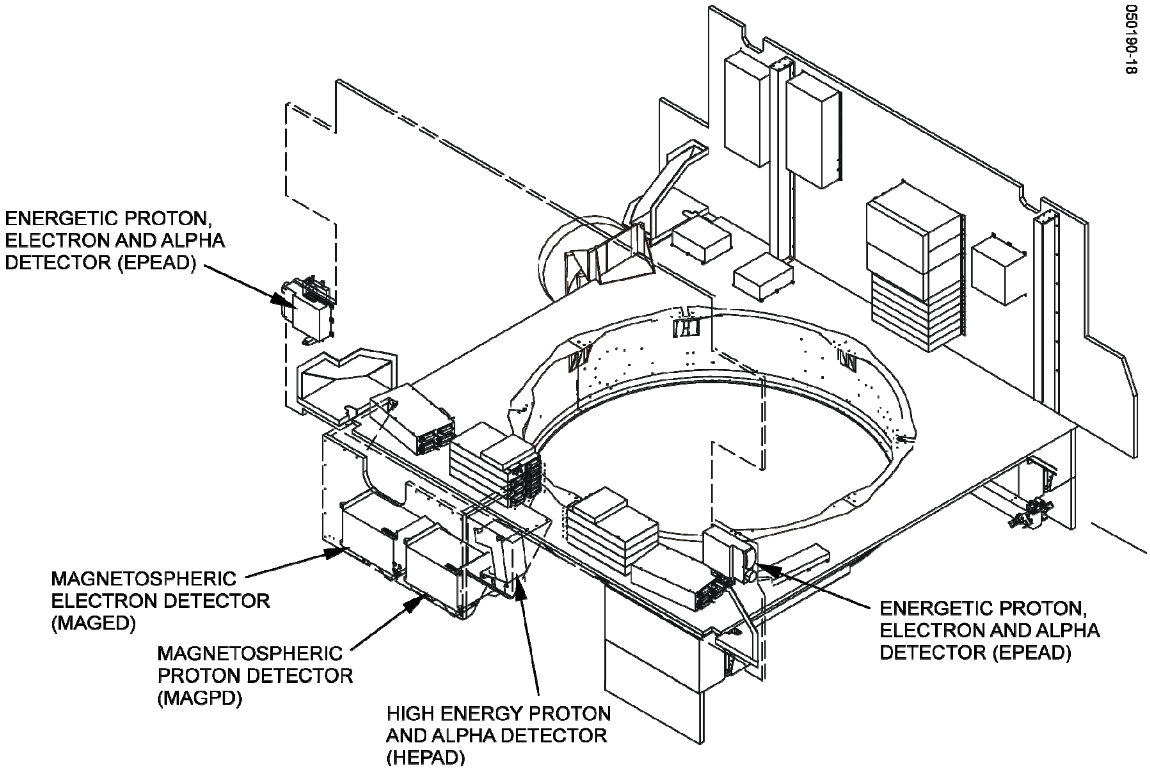

Figure 5-4. EPS/HEPAD Instrument Locations

Table 5-2. EPEAD Telescope Detector Energy Range

Particle	Channel	Range, MeV	Sample Time, sec
Proton	P1	0.74–4.2	8.2
Proton	P2	4.2–8.7	32.8
Proton	P3	8.7–14.5	32.8
Alpha	A1	3.8–9.9	32.8
Alpha	A2	9.9–20.5	32.8
Alpha	A3	20.5–61	32.8

Table 5-3. EPEAD Dome Detector Energy Range

Particle	Channel	Range, MeV	Sample Time, sec
Proton	P4	15–40	32.8
Proton	P5	38–82	32.8
Proton	P6	84–200	32.8
Proton	P7	110–900	32.8
Alpha	A4	60–160	32.8
Alpha	A5	160–260	32.8
Alpha	A6	330–500	32.8
Electron	E1	>0.6	4.1
Electron	E2	>2	16.4
Electron	E3	>4	16.4

MAGPD and MAGED

Magnetospheric protons and electrons are measured at nine pitch angle directions using two detector sets (MAGPD and MAGED). The detector sets are mounted on the anti-earth side of the spacecraft and measure protons or electrons at 0°, ±35°, and ±70° from the anti-earth direction in both the equatorial and the azimuthal plane. Each detector telescope has a full detection cone angle of 30°.

The MAGPD measures protons in five differential energy channels from 80–800 keV and is based on the SEM-2 MEPED instrument on the NOAA polar orbiting operational environmental spacecraft (POES). The MAGPD telescopes each have two SSDs that operate in an anticoincidence mode to provide the required proton channels. Sweeping magnets exclude electrons below several hundred keV. Table 5-4 lists the energy ranges for the MAGPD detectors.

The MAGED measures electrons in five differential energy channels from 30–600 keV and is also based on the SEM-2 MEPED instrument on the POES spacecraft. Physically, the MAGED is very similar to the MAGPD, the only difference being the detector assemblies. The MAGED telescopes each use a single SSD with a foil light shield and do not have sweeping magnets. Algorithms are provided to correct the electron channels for the proton contamination that is unavoidable with this detection system. Table 5-5 lists the energy ranges for the MAGED detectors. Table 5-6 summarizes the EPEAD, MAGPD, and MAGED performance.

Table 5-4. MAGPD Detector Energy Range

Channel	Range, keV	Sample Time, sec
MP1	80–110	16.4
MP2	110–170	16.4
MP3	170–250	16.4
MP4	250–350	32.8
MP5	350–800	32.8

Table 5-5. MAGED Detector Energy Range

Channel	Range, keV	Sample Time, sec
ME1	30–50	2.0
ME2	50–100	2.0
ME3	100–200	4.1
ME4	200–350	16.4
ME5	350–600	32.8

Table 5-6. EPEAD, MAGPD, and MAGED Performance Summary

Parameter	Performance
Dynamic range	From typical particle background levels to largest likely event levels
Stability	3%
Resolution	No worse than pseudolog compression of 19 to 8 bits, using 4 bits of mantissa and 4 bits of exponents
Noise	10 keV for electrons and protons at thresholds below 100 keV. 10% of threshold energies above 100 keV

HEPAD

The high energy proton and alpha detector (HEPAD) is based on the instrument on the GOES I-M spacecraft but modified to provide channel count accumulation within the HEPAD unit. The HEPAD interfaces with the DPU, which controls the HEPAD and formats the accumulated counts and housekeeping data for spacecraft telemetry. The instrument uses two SSDs in a telescope arrangement with a Cerenkov radiator/ photomultiplier tube (PMT) detector to measure relativistic protons and alpha particles. A triple coincidence among these three detectors sends a particle detection signal, and the PMT measures the energy. The HEPAD measures protons with energies above 330 MeV and alpha particles with energies above 2.56 GeV, as detailed in Table 5-7. The house keeping data for the HEPAD can be found in the T&C handbook. The last five rows of Table 5-7 are for diagnostic and calibration purposes. Table 5-8 summarizes the HEPAD performance.

Table 5-7. HEPAD Detector Energy Range

Particle	Channel	Range, MeV	Sample Time, sec
Proton	P8	330–420	32.8
Proton	P9	420–510	32.8
Proton	P10	510–700	32.8
Proton	P11	>700	32.8
Alpha	A7	2560–3400	32.8
Alpha	A8	>3400	32.8
Detector D1	S1	Diagnostic	4.1
Detector D2	S2	Diagnostic	4.1
PMT	S3	Alpha lamp low	4.1
PMT	S4	Alpha lamp mid	4.1
D1/D2 coincidence	S5	Fast coincidence	4.1

Table 5-8. HEPAD Performance Summary

Parameter	Performance
Field of view	Conical, ~34° half angle
Geometric factor	0.7-cm^2-sr
Dynamic range	From typical particle background levels to largest likely event levels
Accumulation efficiency	100%
Stability and accuracy	≤±15%
Count resolution	No worse than pseudolog compression of 19 to 8 bits, using 4 bits of mantissa and 4 bits of exponent
Contaminants	
Proton contamination in alpha channels	≤0.1%
Characterize response to penetrating electron in 2–13 MeV range	As specified
Lifetime	Ground commands to compensate for performance degradation during 5 year lifetime

Magnetometers

There are two magnetometers on the spacecraft. Each magnetometer consists of a triaxial fluxgate sensor and an electronics unit. Each magnetometer measures three orthogonal vector components of the magnetic field in the vicinity of the spacecraft. The three magnetometer axes are orthogonal to within ±0.5° and have a linear range of ±512 nanoTesla (nT). The determination of the ambient magnetic field in the vicinity of the spacecraft is continuous and simultaneous.

The excitation and feedback signals from the sensors are routed to magnetometer electronics units located within the spacecraft main body where the signals are processed and formatted for spacecraft telemetry. An analog signal processor demodulates the flux-gate signals to produce an analog voltage proportional to the field magnitude with a polarity related to the direction of the field vector component being measured. Three analog signals representing the X, Y, and Z components of the surrounding magnetic field are digitized by a 16-bit analog-to-digital converter, producing as output a serial bit stream in which three groups of 16 bits are allocated to the polarity and magnitude of each of the three axes (a total of 48 bits).

The two three-axis magnetometers provide redundancy for measuring the geomagnetic field. One magnetometer is mounted at the end of the boom 8.5 meters away (outboard) from the spacecraft, and the second, 0.8 meters inboard from the first on the same boom. These large distances from the spacecraft significantly reduce magnetic effects from the spacecraft body. The magnetometer boom is shown in Figure 5-2. Table 5-9 summarizes the magnetic field measurement performance.

The ACE monitors the magnetometer readings for indications of saturation, which may occur occasionally due to ESD. Should saturation occur, the ACE will autonomously cycle the affected magnetometer to restore nominal performance.

Table 5-9. Magnetic Field Measurement Performance Summary

Parameter	Performance
Dynamic range	±512 nT, ambient field in any orientation
Resolution	0.03 nT
Accuracy	<±4 nT without temperature correction
	<±1 nT with temperature correction
Noise	≤0.3 nT, 3 σ
Data rate	1.95 Hz
Bandwidth	0.5 Hz, 3 dB
Sensor axes orthogonality	Within ±0.5°
Sensor orientation	≤±1.0°, in spacecraft coordinates (accuracy knowledge)
Spacecraft field contamination	
Maximum permanent field per axis	±100 nT
Sensor stability	±0.25°