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System Architecture of the IPEI Payload on ROCSAT-1

Y.-S. Chang[1], W.-L. Chiang[1], S.-J. Ying[1],
B. J. Holt[2], C. R. Lippincott[2] and K.-C. Hsieh[3]

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ABSTRACT

The Ionospheric Plasma and Electrodynamics Instrument (IPEI) is one of the three payloads on the ROCSAT-1 satellite. The IPEI consists of two major packages: Sensor Electronics Package (SEP) and Main Electronics Package (MEP). The SEP carries four sensors: an Ion Trap (IT), Horizontal and Vertical Drift Meters (HDM and VDM), and a Retarding Potential Analyzer (RPA). These sensors measure ion concentration, ion temperature, cross-track ion velocity, and major ion composition at the satellite position along the ROCSAT-1 orbit. This will nominally yield coverage at 600km altitude within the latitude band of ±35°. The MEP contains four major parts: a digital processing unit (DPU), command interface, science data interface, and power supplies. The MEP provides the electrical interface between IPEI and the spacecraft. Also, the MEP implements the operational modes of IPEI: NORMAL, FAST, and AUTO. In the NORMAL mode the IT, HDM, and VDM provide measurements of the total ion concentration and the cross-track ion drift velocity at 32 Hz, while the RPA provides the in-track ion drift, the ion temperature and the major ion composition at a nominal 1/2 Hz rate. In the FAST mode these sample rates are 1024 Hz and 1/4 Hz respectively. The AUTO mode enables IPEI to switch from the default NORMAL mode to the FAST mode when sudden large changes in the ion concentration, commonly associated with plasma structures called bubbles, are detected. The unique feature of the AUTO mode allows the scientists to investigate spatial structures with scale sizes as small as 16 meters.

(Key Words: Ion temperature, Ion concentration, Ion velocity, Ion composition, Satellite)

[1]National Space Program Office, No. 9, 8th FL, Prosperity Rd. I, Science-Based Industrial Park, Hsin-Chu, Taiwan, ROC

[2]William B. Hanson Center for Space Sciences, The University of Texas at Dallas, Richardson, TX 75080, USA

[3]Department of Physics, University of Arizona, Tucson, AZ 85721, USA

1. INTRODUCTION

An overview of the scientific objectives of the IPEI onboard the ROCSAT-1 is given in the feasibility study report [1]. The ion concentration and velocity at equatorial latitudes may vary dramatically affecting large scale features such as the total electron content and the reflection of the radio waves and much smaller scale features like plasma irregularities affecting the propagation paths of navigation and communication signals. Thus a comprehensive observation of the plasma composition and velocity over a wide range of spatial scales in the equatorial region is necessary. Of particular interest to scientists are electric fields generated by the dynamo action of neutral winds, the fine structure of plasma irregularities called bubbles, spatially periodic plasma structures in the topside and bottomside of the equatorial ionosphere, and the phenomenon of interhemispheric plasma transport [2].

Many of these investigations require high spatial-resolution measurements of ion drift velocities and total ion concentration, and this capability is uniquely achieved on ROCSAT-1 by directly sampling the required IPEI outputs at 1024 Hz in the regions of interest. Since a Solid State Recorder(SSR) is used on ROCSAT-1 for science data storage, and the data can only be relayed to the ground stations in Taiwan during passes when the satellite comes into view, the time allocated to IPEI for this fast data sampling is limited by the SSR storage capacity and the other onboard data storage requirements. Some 16 minutes per orbit are allocated for the IPEI high rate sampling, and the mode can be initiated either directly by ground command or by an on-board algorithm designed to trigger high rate sampling when plasma structure is detected and the IPEI SSR allocation is not exceeded.

The ion concentration, composition, and temperature are strong functions of the plasma motions both perpendicular and parallel to the Earth's magnetic field. In order to successfully study these relationships an accurate measurement of the ion velocity vector is required. This measurement is obtained by combining the capabilities of the Retarding Potential Analyzer (RPA) and Ion Drift Meter (IDM) [3,4,5]. The RPA measures the ion velocity in the direction of the spacecraft motion, the ion concentration, and ion temperature. The Ion Drift Meter (IDM) measures two mutually perpendicular angles of arrival of ions with respect to the sensor's look direction from which the cross-track ion drift components are obtained. Thus, by combining the RPA and IDM measurements, the bulk ion velocity vector is determined.

The IPEI sensors have a strong heritage with similar designs previously flown on the Atmosphere Explorer (AE), Dynamics Explorer (DE), and DMSP programs spanning the period from 1970 to the present [3-8]. The IPEI design has been optimized to provide simultaneous cross-track ion drift measurements and to utilize the higher sampling rates available on ROCSAT-1 to achieve a higher spatial resolution than that obtained on earlier missions. On ROCSAT-1 the retarding potential can be stepped at a 64 Hz. rate, usually providing the measured RPA parameters 4 times each second, but with a capability of 10 times each second. The ROCSAT-1 IT, HDM, and VDM have the ability to provide both amplitude and phase measurements of ion density and drift variations up to 512 Hz by directly sampling at 1024 Hz. Finally, two drift meter sensors are included on ROCSAT-1 so that simultaneous vertical and horizontal measurements can be made. The inputs are switched each 32 seconds to measure the slowly varying electrometer imbalances and allow their subsequent removal in the data processing while accomodating the 1024 Hz sample rate.

2. GENERAL CONFIGURATION OF THE IPEI

The IPEI consists of two major packages; the Sensor Electronics Package (SEP) and the Main Electronics Package (MEP), along with an interconnecting cable. The envelope dimensions of SEP and MEP are 47 cm x 42 cm x 19 cm and 28 cm x 13 cm x 14 cm, respectively. The housings for both packages are mainly made from aluminum alloy. The total mass of the IPEI, including the cable, is 9.26 kg. The SEP is installed to have the aperture plane face in the velocity direction (ram direction or sensor look direction). Both the SEP and MEP are mounted on the payload adapter of ROCSAT-1 as sketched in Figure 1. The SEP has its aperture plane (sensor look direction) normal to the ram direction. The flight IPEI is shown in Figure 2. The large flat plate facing the viewer is the aperture plane. The four circular "Remove Before Flight" covers are used to protect the openings to the four sensors described in detail in the text. The IPEI is thermally protected by multi-layer insulation (MLI) and has heaters on the mounting adapter to control the operational thermal environment in orbit.

The SEP contains four ion sensors, two Drift Meters(DM), a Retarding Potential Analyzer (RPA) and an Ion Trap (IT), along with intimately associated electronics and power supplies. The Drift Meters are designated as +YDM and -YDM corresponding to their Y axis location in the aperture plane. The MEP contains the instrument microprocessor, power supplies for the digital circuitry, and ROCSAT-1 spacecraft interface circuits. It is crucial that the plasma entering the sensors are not perturbed by any electromagnetic field that may be generated by ROCSAT-1 in the vicinity (a few Debye lengths in the local plasma) of the sensor

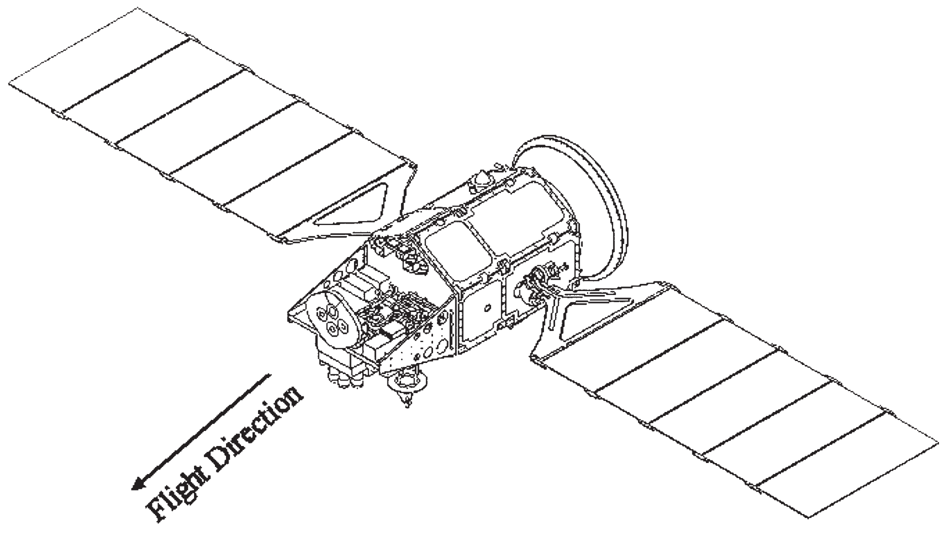

Fig. 1. A sketch of the IPEI on ROCSAT-1.

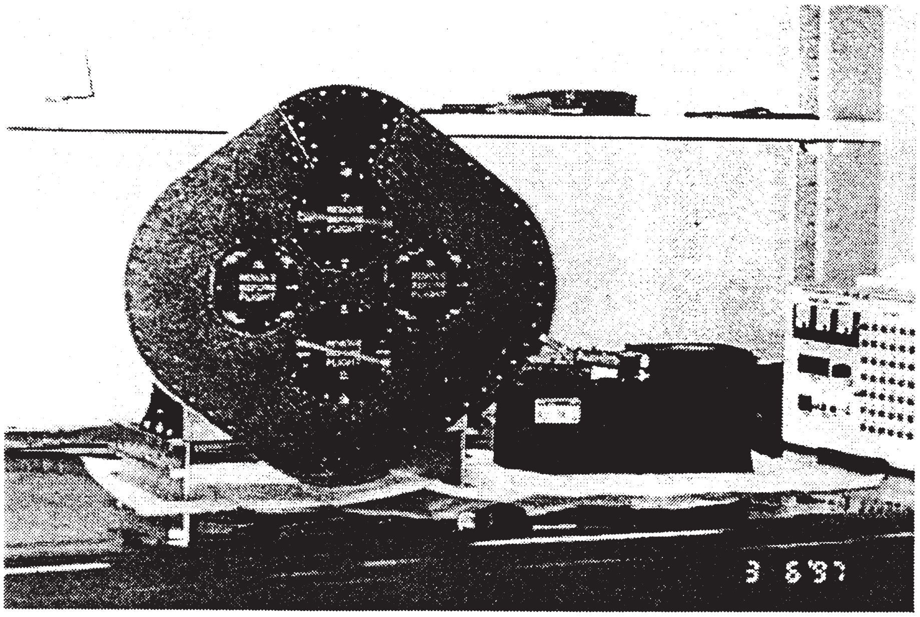

Fig. 2. A photo of the flight IPEI.

apertures. This critical requirement is met by having a conducting aperture plane of 42 cm x 47 cm (see Figure 1) that is electrically isolated from the rest of the spacecraft and whose potential (V_{AP}) is kept near the ambient plasma potential by the sensor potential circuit (SENPOT) [8]. The SENPOT circuit senses the potential on a reference surface (the sector at the top of the aperture plane shown in Figure 2) that is electrically isolated and allowed to float to the potential at which equal ion and electron currents are collected. The SENPOT circuit develops the V_{AP} potential that is equal to the potential on the reference surface but also is able to drive the required loads. The sensor housings and some internal sensor elements are also connected to V_{AP} and gold plated to reduce contact potentials. The electrometers and amplifiers, used to sense the small ion currents, are housed in the SEP with the individual sensors to allow for good electrostatic shielding. The analog to digital (A/D) converter, sweep generators, and other analog circuits are also housed in the SEP to preclude induced noise from the signals associated with the MEP power supplies and digital circuits, and to provide a simple digital interface between the MEP and SEP.

3. DESCRIPTION OF SENSORS

3.1 Ion Trap

The Ion Trap (IT) is a Faraday cup with a planar ion collector whose schematic cross-section is shown in Figure 3. The large circular aperture (6 cm dia.) views approximately

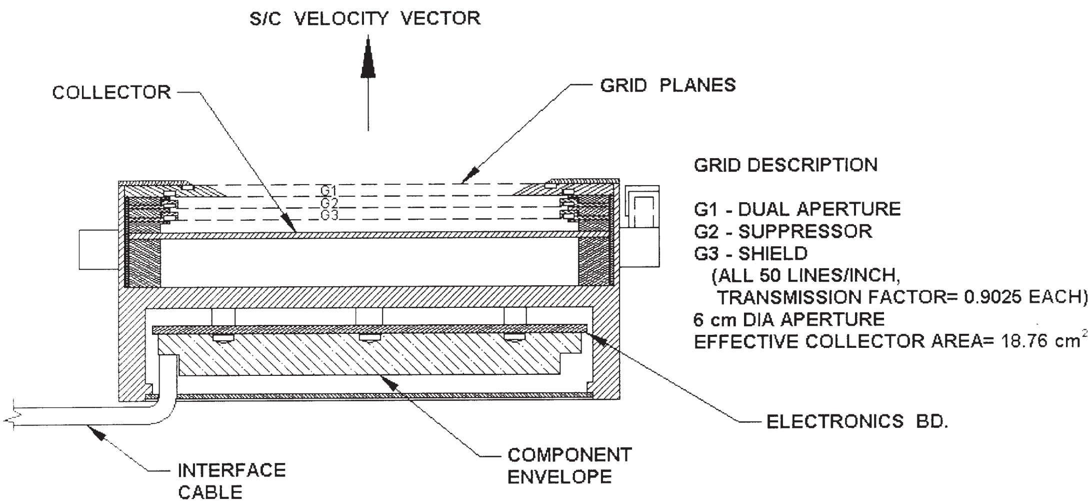

Fig. 3. A schematic diagram for the cross-section of the Ion Trap.

along the spacecraft velocity vector allowing a flux of ambient ions to enter. Inside the sensor, a suppressor grid (G2) is biased to -12 volts to exclude thermal electrons and to aid in suppressing photo emission from the collector. The aperture grid (G1) and the collector are all held at V_{AP}. The shield grid (G3) is biased to -1.5V to suppress photo emission from the collector and to reduce the microphonic noise that would result if G2 were allowed to be coupled capacitively to the collector. The ion current to the collector is measured using a logarithmic electrometer whose output is digitized with 12 bit resolution. The electrometer output is directly proportional to the logarithm of the incoming ion flux. This ion flux is in turn linearly proportional to the ion concentration, N_i, to the effective ion collecting area of the sensor, which is known, and to the ion incident velocity relative to the spacecraft. This velocity is measured by the RPA, but can be approximated by the spacecraft velocity in this direction. At ROCSAT-1 latitudes this approximation will produce less than a 5% error in the derivation of the total ion concentration. Thus, simple sampling of the electrometer provides the required geophysical parameter (N_i). The electrometer output is sampled at 32 Hz in the NORMAL mode and at 1024 Hz in the FAST mode.

3.2 Ion Drift Meters

The +Y Drift Meter (+YDM) and -Y Drift Meter (-YDM) are physically identical and either one can be configured, in-flight, to measure either horizontal (H) or vertical (V) arrival angles or to alternate between the two. Two sensors are utilized to provide the required temporal resolution with one normally configured for vertical and one for horizontal velocity measurements. The sensor cross section is shown schematically in Figure 4. The sensor presents a planar 2.8 cm square entrance aperture that views approximately along the spacecraft velocity vector. A suppressor grid (G6, like G2 in IT) is biased at -12V and utilized to

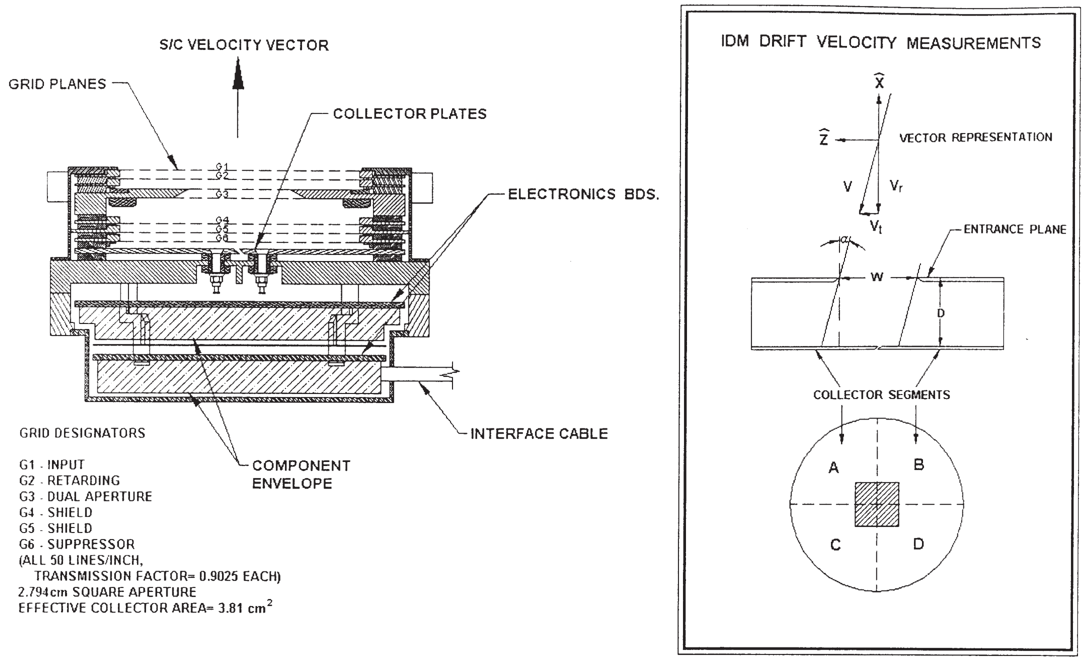

Fig. 4. A schematic diagram for the cross-section of the Ion Drift Meter.

prevent access to the collector by the ambient thermal electrons. The input grid (G1), aperture grids (G3), shield grids (G4/G5), and collector are held at V_{AP} providing a field free region immediately inside the sensor. The incoming ion beam is incident on a quadrant collector arranged so that the current to the two horizontal halves (if configured for H) or the two vertical halves (if configured for V) can be separately measured. The current to each collector half is measured with a logarithmic electrometer. With simple algebra and geometric considerations (Figure 4) it can be shown that

$$\log I_{AB} - \log I_{CD} \approx 2K\frac{\Delta I}{I} = \frac{4KD}{W}\tan\alpha \tag{1}$$

where,

$$I = I_{AB} + I_{CD}$$

$$\Delta I = I_{AB} - I_{CD}$$

$$K = \frac{1}{\ln(10)}$$

W is the dimension of the aperture, D is the effective distance from the aperture to the collector, and α is the projection of the ion arrival angle in the plane that bisects the collectors into (A+B) and (C+D) halves. There is a similar set of equations for the angle β in the plane that bisects the collectors into (A+C) and (B+D) halves. In each sensor, the outputs of the logarithmic electrometers provide the inputs to a linear difference amplifier with two ranges differing in sensitivity by a factor of 4. Automatic ranging circuits are used to select range 1 (x4 gain) for ion arrival angles less than about 7° and range 2 (x1 gain) for angles above about 7°. The horizontal and vertical components of the transverse drift velocities are expressed by the expressions

$$V_{tH} = V_r \tan\alpha \qquad \text{and} \qquad V_{tV} = V_r \tan\beta \tag{2}$$

where, V_r is the ram velocity measured by the RPA, which is dominated by the spacecraft velocity. Thus the transverse horizontal and vertical ion drift components can be directly obtained from the difference amplifier outputs. On range 1 the 1 bit sensitivity corresponds to about 0.50 meters per second.

Each pair of logarithmic electrometers is carefully matched and temperature compensated. Any imbalances that occur with time in the electrometers, however, appear as an apparent arrival angle offset at the difference amplifier output. To determine the presence and magnitude of any offset so that it can be subsequently removed from the measurement, the inputs to the two logarithmic electrometers are inverted once every 8 seconds in the NORMAL mode and once every 32 seconds in the FAST mode. Comparison of the samples before and after the inversion allows any offset to be determined,since in its absence the signals are equal and opposite. Each of the +YDM and -YDM difference amplifiers is digitized with 12-bit resolution and these data together with one bit designating the amplifier sensitivity level and two bits designating axis and polarity constitute a drift meter sample. In the NORMAL mode both +YDM and -YDM are sampled at 32 Hz and in the FAST mode each is sampled at 1024 Hz.

3.3 Retarding Potential Analyzer

The RPA provides a measure of the ram energy of the incoming ions with respect to the spacecraft and it is shown schematically in Figure 5. The planar sensor views approximately along the satellite velocity vector and presents a circular gridded 4-cm diameter entrance aperture (G1) to the incoming ions. The internal retarding grid (G2) presents a potential that controls the minimum energy required by ions to have access to the ion collector. The -12V suppressor grid (G3) prevents ambient thermal electrons from reaching the collector. The shield grid (G4) prevents potential variations applied to the previous retarding grids from coupling to the collector and reduces microphonics to the collector caused by the suppressor grid. It is biased to -1.5V to suppress secondary emission from the collector. Each ion entering the RPA has an energy of about 0.3 eV per amu by virtue of the spacecraft motion. Thus, when the retarding potential is stepped through a series of discrete potentials in the range 0 to +25.5 volts, it allows access to all ion species at 0 volts and denies access to all species with mass less than 85 amu at +25.5 volts. The electrometer output is proportional to the incident ion flux at the collector. For a planar retarding potential analyzer, the flux of ions ϕ(P) of mass m and temperature T with energy greater than P that are allowed access to the collector is given by

$$\Phi(P)=C\frac{N_i}{2}V_r\left[1+erf\left(\beta f\right)+\frac{1}{\sqrt{\pi}\beta V_r}\exp\left(-\beta^2 f^2\right)\right] \qquad (3)$$

where f = V_r-(2P/m)$^{1/2}$; β = (m/2kT)$^{1/2}$ and C is the effective area of the detector.

The ion current impinging on the collector is measured by a linear ranging electrometer with 8 ranges, each differing in sensitivity by (10)$^{1/2}$. The electrometer is free to range at any time and three bits are used to designate the range. A retarding potential versus ion current characteristic curve is obtained by stepping the RV through a series of discrete steps. At each RV step the ion current to the collector is measured by the RPA electrometer. A 12-bit conversion of the electrometer output voltage together with the three range bits comprise an RPA sample. The RV steps are pre-determined from sequences stored in a selected 32 address by 8 bits wide block of memory. The 8 bits at each address define one of 256 discrete RV potentials in the range 0 to +25.5 volts with 0.1 volts per count. Any one of 8 blocks of RV memory can be selected for use by ground command. Default sequences are stored on board in ROM and transferred to RAM at power on. The RV values stored in RAM can be altered by ground command.

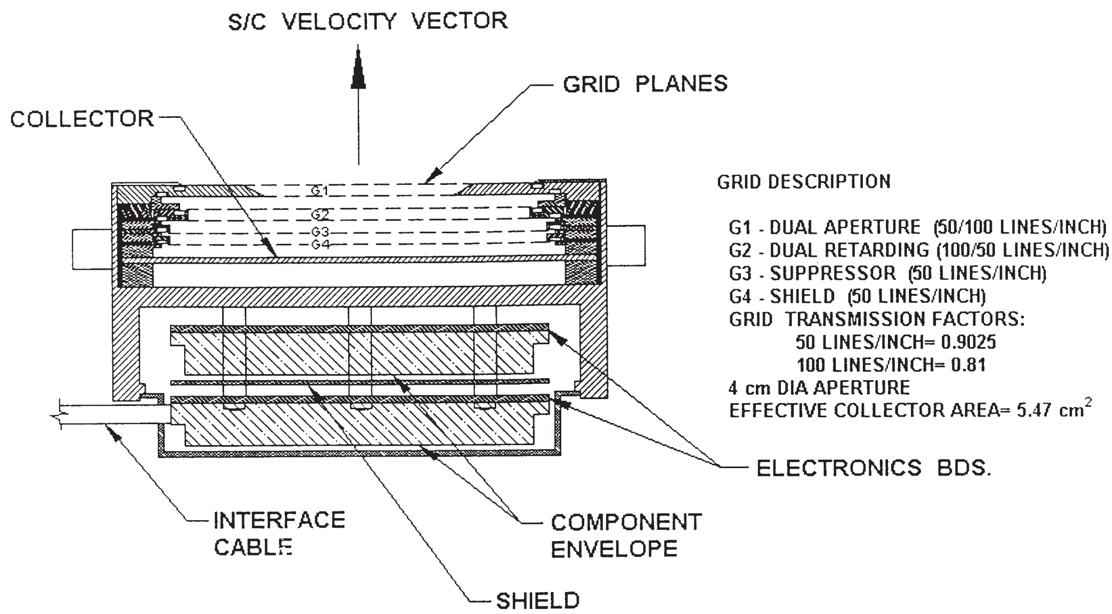

Fig. 5. A schematic diagram for the cross-section of the Retarding Potential Analyzer.

In the NORMAL mode the RPA output is sampled and the RV stepped at a 32 Hz rate. The RV memory block address is sequentially incremented after each sample such that all addresses in the selected block are cycled through each second. In the FAST mode the RPA is sampled at a 64 Hz rate such that the selected memory block is cycled through twice each second. In the NORMAL mode the ion temperature, ram velocity and limited ion composition information will thus be available at 1 Hz rate if a 32-point RV sequence is used and at a 2 Hz rate with a 16-point sequence. In FAST mode the geophysical parameters will be available at 2 Hz and 4 Hz for the 32 points and 16 points sequence, respectively.

4. FUNCTIONAL DESCRIPTION

The MEP contains four major parts: Digital Processing Unit (DPU), command interface, science data interface, and power supplies. The MEP provides the electrical interface between IPEI and the spacecraft. The maximum power consumption for the MEP and SEP are 6W and 4W, respectively. The MEP power supply provides a regulated +15V output to the SEP for use as the SENPOT pedestal voltage. The circuitry of the MEP power supply contains a continuously powered input filter to prevent excessive turn-on surge current. The RS-422 interface port of the MEP is used to transmit science data serially to the spacecraft. The science data are packetized using the Consultative Committee for Space Data Systems (CCSDS) source packet standard format. Each science data packet is 278 bytes. The science data transmission rates are 2.224 Kbps and 53.376 Kbps for NORMAL and FAST mode, respectively. The 1553B bus of the MEP is used to receive serial commands and time code from the spacecraft and to output the state of health data that is downlinked seperately from the science data.

A functional diagram of the MEP Digital Processing Unit (DPU) is shown in Figure 6. The DPU contains an output port to provide parallel commands to the SEP and an input port to accept parallel input data from the SEP. To synchronize the input data with the control data for each sensor of the SEP, it is essential to allow adequate settling time before the next sample is taken. This synchronization is accomplished by using a time base called Start To Convert (STC) generated by the MEP. The STC is a continuous pulse stream of 128 pulse per second (PPS) in the NORMAL mode and 4096 PPS in the FAST mode. The major operating modes of the IPEI are NORMAL, FAST, and AUTO. In the NORMAL mode, each of the four sensors is sampled at 32 samples/sec. In the FAST mode, +YDM, -YDM and IT are sampled at 1024 samples/sec each, and RPA is sampled at 64 samples/sec.

In the AUTO mode, the IPEI operates in the NORMAL mode until the FAST mode is initiated by an algorithm in the DPU. This algorithm is described as follows and is shown in the Figure 7:

1. Store the first IT sample after execution of AUTO mode command and set Counter = 0.
2. Compare the stored sample to the next sample taken (current sample). If the current sample is below the stored sample by an amount DIFF1, then increment Counter.
3. If the current sample is not below the stored sample by the pre-determined value DIFF1, then replace the stored sample with the current sample and set Counter = 0.

4. If there are NUM consecutive samples that are below the stored sample by DIFF1 (Counter = NUM) and the next sample is below the stored sample by an amount DIFF2, then trigger the FAST mode. If not, replace the stored sample with the current sample, set Counter = 0, and repeat the above.

The following parameters used in the AUTO mode trigger algorithm can be modified by ground command. The default values are indicated in the flow chart of Figure 7.

NUM= Sample separation for which depletion shoulder will be recognized.

NSEC= Duration of each FAST mode sequence after initiated.

NREP= Number of times the FAST mode sequence can be initiated.

DIFF1= Minimum difference between electrometer outputs to qualify as a decreasing slope.

DIFF2= Magnitude of difference between initial and final samples that define a depletion shoulder.

5. SUMMARY

The IPEI described above has its roots in the earlier versions of ionospheric instruments flown on AE, DE, and DMSP [3-8], but differs qualitatively from the earlier versions in having the following features.

1. The simultaneous measurement of the vertical and horizontal components of the transverse ion drift velocity.
2. The high time-resolution sampling by the FAST mode that can be triggered automatically or commanded from the ground.

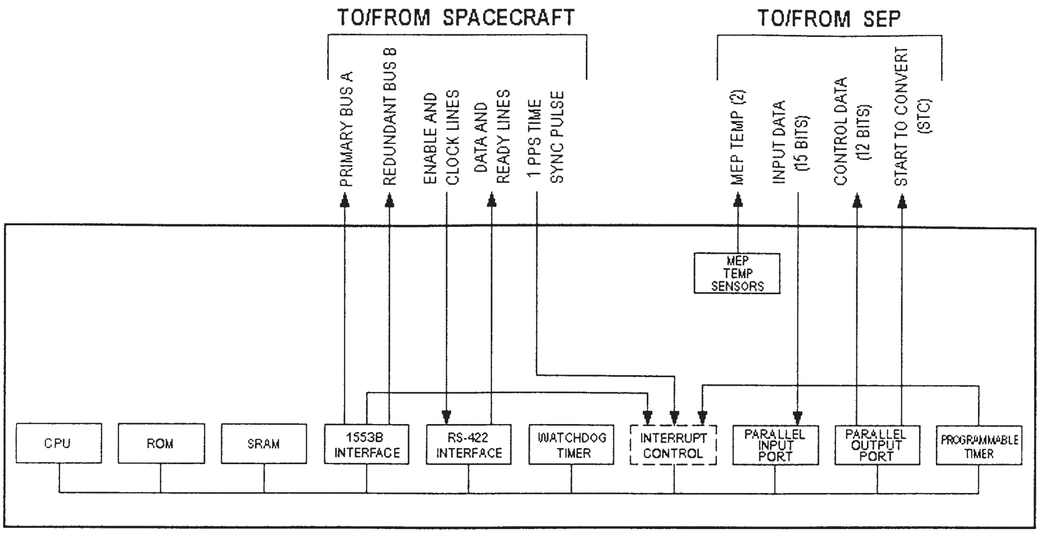

Fig. 6. Functional block diagram of the MEP.

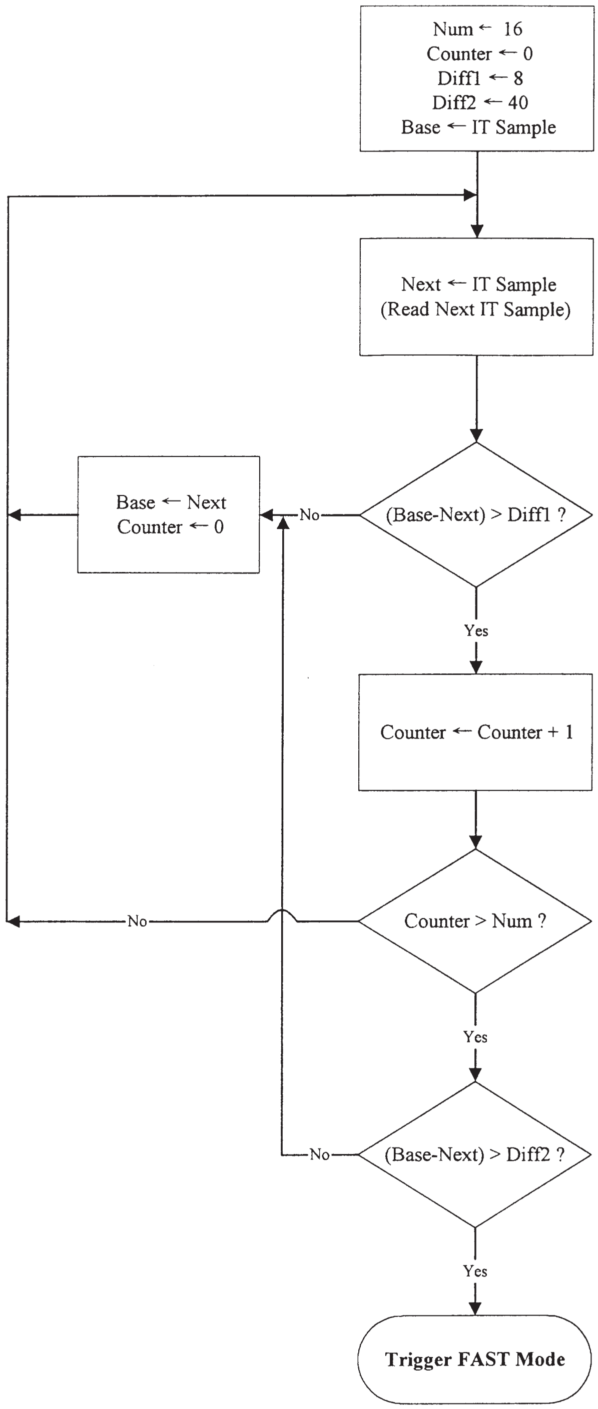

Fig. 7. Flow chart for the algorithm of triggering FAST Mode.

The IPEI on ROCSAT-1 is a versatile instrument that promises to provide critical data that will advance our understanding of small and large scale structures in the plasma and its dynamics in the low and middle latitude ionosphere. With an anticipated 100% duty cycle and the capability to resolve features with spatial scale sizes of 16 meters, the ROCSAT-1 mission will provide a new data set with unprecedented global coverage. The conduct of the mission during the forthcoming solar maximum period will also provide opportunities to examine space weather phenomena when they are most prevalent.

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