Preliminary Design Considerations for the Suprathermal-Ion-Telescope (SIT)

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1. Introduction

The Suprathermal-Ion-Telescope (SIT) is part of the In-Situ-Measurements-of-Particles-and-CME-Transients (IMPACT) investigation on board the STEREO spacecraft. Each SIT sensor is a time-of-flight (TOF) mass spectrometer, designed to measure the ions, protons though iron, from ~20 keV/nucleon up to several MeV/nucleon in energy.

In-situ observations of solar and interplanetary energetic particles help us understand the important processes involved in the acceleration and transport of energetic particles. Since energetic particles are produced throughout the universe, these processes are relevant not only in the heliosphere but also in more exotic, astrophysical sites, where in-situ measurements are not possible.

SIT is designed to measure energetic particles produced by a wide variety of phenomena, including particles accelerated by CME driven shocks in the solar corona and in interplanetary space, solar flares, and corotating interaction regions (CIRS). Because the shocks associated with CMEs are often quite weak at 1 AU, the energy spectra produced by these shocks are usually soft and do not extend into the MeV energy range. The large geometry factor (0.3 cm^2 sr) and low energy response of SIT, therefore, makes it well suited for observing energetic particles produced locally by these events.

Another advantage of SIT is that good mass resolution allows the composition of the particles to be measured, thus helping to determine the source population of the particles. Composition measurements, for instance, are useful in distinguishing particles that are accelerated in the corona, in interplanetary space, or at the site of solar flares.

In this document, we shall give an instrument overview and discuss preliminary design considerations for the Suprathermal-Ion-Telescope. Because the SIT sensor is nearly identical to the Supra-Thermal-through-Energetic-Particle (STEP) sensors, on board the WIND spacecraft, much of the information given below was determined using the five years of data acquired by STEP (von Rosenvinge *et al*. 1995).

2. The SIT sensor

2.1. Instrument overview

Figure 1 shows a schematic diagram of a SIT sensor. There will be one SIT sensor on board each of the two STEREO spacecraft. A valid event is produced when an energetic ion passes through the front foil of the telescope. Secondary electrons, produced by the foil, are electrostatically directed into the "start" multi-channel plate (MCP). The signal from the start MCP provides the trigger for the time-to-amplitude-converter (TAC) electronics. Meanwhile, the energetic ion traverses the telescope and hits the solid-state-detector (SSD) at the back. In the energy range measured by SIT, the ions are stopped by the SSD, and, consequently, the kinetic energy is completely absorbed in the detector. In addition, when the incident ion strikes the SSD, it liberates more secondary electrons, which are then electrostatically directed into the "stop" MCP. The signal from the stop MCP provides the necessary coincidence for the TAC to measure the time-of-flight (TOF) of the ion.

By measuring the TOF from the TAC and the total kinetic energy from the SSD, the atomic mass and kinetic energy per nucleon of the incident ion is then determined (after energy loss corrections in the front foil and the SSD detector window) using the familiar equation for the kinetic energy

$$E = \tfrac{1}{2} \cdot (931.5 MeV / c^2) \cdot A \cdot \left(\tfrac{L}{T}\right)^2 \tag{1}$$

Here *E* is the total kinetic energy from the SSD. *A* is the atomic mass of the ion. *L* is the length of the telescope (10 cm), and *T* is the TOF.

2.2 Instrument Performance

As can be seen in equation (1), when *E* is plotted versus *T* on a log-log scale, the various atomic species organize themselves along straight tracks with slopes of -2 and offsets given by the atomic masses. This can be seen in figure 2, which slows pulse height analysis (PHA) data from the WIND/STEP sensors. The figure shows the TOF, measured in nsec, versus the total kinetic energy, measured in MeV. Each point represents the measurement of one solar energetic particle during the November 1997 event. As can be seen in the figure, the major species, p, He, C, O and Fe form distinct and well resolved tracks. The species Ne is partially resolved, and Mg, Si and S cannot be completely resolved by the instrument and are measured together as a group.

2.3 Count Rates

Based upon over five years of interplanetary data from WIND/STEP, we have found that the valid event rate almost never rises above 1000 counts/second. Even large SEP events such as the November 1997 event only produce valid event rates of a few hundred per second. Furthermore, because of the geometry factor of the front foil and the low efficiency for measuring protons and helium, the start MCP singles rate is typically about 300 times higher than valid event rate. We have found that with STEP, for start rates higher than about 100,000 counts/second the gain on the start MCP drops, thus reducing the efficiency for measuring the low Z species. We, therefore, consider 1000 counts/second to be an upper limit on the valid event rate for SIT. Correspondingly, the start MCP singles rate will be less than about 300,000 Hz. The other singles rates, e.g. the stop MCP and SSD rates, will be less than the start rate.

3. Time-of-flight Electronics

For each valid stop event, the time-of-flight electronics provides a 10 bit TOF for that event. The TOF for SIT ranges from 5 to 60 nsec. The TOF electronics also produces the start, stop and valid stop discriminator rates.

4. Solid-State-Detector Electronics

The solid state detector must measure particle energies from 0.08 MeV up to approximately 120 MeV. Since the SSD resolution is 12 bits, in order to reduce the dynamic range and improve the resolution at low channel numbers, the energy electronics, after the charge sensitive amplifier, has both a low gain (ramp = 1) and a high gain channel (ramp = 0). In addition, each gain channel has its own discriminator rate included in the science data record.

Table 1. SSD amplifier gains

Gain	Ramp bit	MeV/channel	Threshold energy (MeV)	Maximum energy (MeV)
high	0	0.0024	0.08	10
low	1	0.029	8.0	60

5. TOF and SSD Coincidence

The valid stop events from the TOF electronics and the events from the SSD electronics are checked for coincidences. These coincidences, called VSE, are the valid events for SIT.

6. Discriminator Rates

SIT has 6 discriminator rates, listed in Table 2. The discriminator rate data shall be accumulated over 32 second time intervals. The rates data are then compressed to 12 bits, and the 16 time intervals are included in each (512 second) science data record. This results in $16 \times 6 \times 12$ bits = 144 bytes of discriminator rate data in each science data record, which corresponds to a bit rate of 2.25 bits/sec. The total memory required to accumulate the discriminator rate data is 272 bytes.

Table 2. SIT Discriminator Rates

Discriminator rate	Counter resolution (bits)	Resolution in telemetry (bits)	Accumulation interval (sec)	Maximum rate (Hz)
Start TOF	24	12	32	300,000
Stop TOF	24	12	32	300,000
E (ramp = 0)	24	12	32	300,000
E (ramp = 1)	24	12	32	300,000
VS (valid stop)	24	12	32	100,000
VSE (valid event)	16	12	32	1,000

7. Data Processing

7.1 ROM Rates

Figure 3 is a block diagram of how each valid event from SIT is to be processed. The scheme uses several lookup tables (see Table 3) to convert the SSD channel number, the SSD ramp bit, and the TOF channel number into a 7 bit ROM box number and a priority bit. The total amount of memory needed for the SIT lookup tables is 27.65 kbytes. Furthermore, it is likely that new lookup tables will have to be uploaded at least once during the mission. Figure 4 shows how the valid event data appear after being processed. For comparison, a grid showing the resolution of the 128×32 ROM box lookup table (lookup table 6) is also plotted in the figure.

Once the ROM box number is calculated, the corresponding ROM box counter is incremented. Note that the priority bit, which is used in the PHA event selection, is not used for the ROM boxes.

There are two types of ROM boxes, high-time-resolution (HTR) and low-time-resolution (LTR) ROM boxes (see Table 4).

The 9 HTR ROM boxes are accumulated every 32 seconds with 16 bit resolution. These counts are then compressed to 12 bits, and all 16 time intervals, containing 9 HTR ROM boxes each, are included in each (512 second) science data record. This results in $16 \times 9 \times 12$ bits = 216 bytes of HTR ROM box data in each science data record, which corresponds to a bit rate of 3.375 bits/sec.

The 128 LTR ROM boxes are accumulated every 512 seconds (the length of one science data record) with 24 bit resolution. These counts are then compressed to 12 bits, and all 128 LTR ROM boxes are included in each (512 second) science data record. This results in 128×12 bits = 192 bytes of HTR ROM box data in each science data record, which corresponds to a bit rate of 3.0 bits/sec.

The total memory required to accumulate both the LTR and HTR ROM box data is 544 bytes.

Table 3. SIT lookup tables for event processing.

Lookup table	Number of elements	Resolution (bytes)	Purpose
1	4096	2	SSD Channel and ramp 0 → log(E)
2	4096	2	SSD Channel and ramp 1 → log(E)
3	1024	2	TOF Channel → log(M/E)+constant
4	1024	1	TOF Channel → f(log(E))
5	2048	1	log(M) → f(log(M))
6	128 × 32	1	f(log(E)) and f(log(M)) → LTR ROM box # and priority bit
7	128× 16	1	LTR ROM box # and clock → HTR ROM box #

Table 4. Types of ROM boxes.

ROM box type	Counter resolution (bits)	Number of bits in telemetry	Number of boxes	Accumulation interval (sec)	bytes per science data record
HTR ROM boxes	16	12	9	32	216
LTR ROM boxes	24	12	128	512	192

7.2 PHA events

Each valid event measured by SIT is made into a PHA event record. Table 5 lists the contents of one such record. The event record, stored as 5 bytes, is 36 bits long in the science data record. The valid event rate (same as the VSE rate) can be up to 1000 events/sec, and so, for a 512 second science data record, up to 512,000 events can be measured. This number is much larger than the 728 PHA events which can be included in a science data record. Therefore, an event selection must be made.

The selection of PHA event records will be based upon the priority bit from the LTR ROM box lookup table (lookup table 6). The priority bit for each event is found by the algorithm described in figure 3. There are two states used to select the PHA events, state A and state B. State A is made of one (364 × 5 byte) array, and state B is made of two (364 × 5 byte) arrays. As event records arrive, they are placed in the State A array first, with no selections made on the data. Once the state A array is full, state B is then filled. With state B, however, preference is given to events with the priority bit equal to 1. In state B, the records are placed in the first array if the priority bit is 1, and the records are placed in the second array, if the priority bit is 0. If a record belongs in an array that is already full, that event record is discarded. At the end of the 512 second accumulation interval, the following PHA event records are included in the science data record: all of the event records in the state A array; all the event records in the state B, priority 1 array; the number of event records from the state B, priority 0 array needed to make a total of 728 PHA event records (see figure 5).

Table 5. PHA event record

Data type	Size (bits)
SSD channel	12
TOF channel	10
Ramp	1
LTR ROM box #	7
priority	1
time within science data record	4
State A or B	1
Total	**36**

8. Housekeeping

Table 6. Housekeeping data

Data type	Size (bytes)
Temperature 1	1
Temperature 2	1
HV 1	1
HV 2	1
Total	**4**

9. Science date record

The SIT science data record contains PHA, ROM box and discriminator rate data as well as housekeeping for a 512 second time interval. The memory required to accumulate the data for 512 seconds is listed in table 7. The total memory requirement for the data is 6,410 bytes.

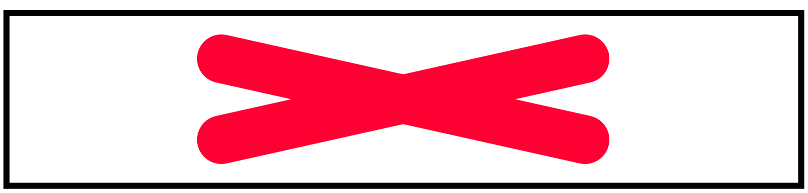
At the end of the 512 second interval, the data is compressed and formed into a science data record (Table 6). The entire SIT science data record is then transmitted. The entire record is 3,840 bytes long. Transmitting one record every 512 seconds results in a 60 bits/sec telemetry rate for SIT.

Table 7. Science data record

Data type	**Memory required (bytes)**	**Size (bytes)**
header	--	2
S/C time	--	4
HTR ROM boxes	288	216
LTR ROM boxes	384	192
Discriminator rates	272	144
PHA data	5,460 (728 events)	3,276 (728 events)
Housekeeping and data quality	6	6
Total	**6,410**	**3,840**

10. PHA Intensities

In addition to the ROM boxes, particle intensities can be constructed using the PHA event data. To do this, the ROM boxes are used as an overall normalization to take into account the effects of sampling. Equation 2 gives the formula for calculating the *jth* particle intensity, I_j.



(2)

N_{ij} is the number of PHA events with priority *i*, in the *jth* mass and energy range. ROM_{ik} is the number of counts in the *kth* ROM box with priority *i*. The remaining factors are the instrument efficiency for measuring the *jth* intensity, the geometry factor and the accumulation time.

Reference

von Rosenvinge, T. T., *et al.*, The energetic particles: acceleration, composition, and transport (EPACT) investigation on the Wind spacecraft, *Space. Sci. Rev.*, 71, 155, 1995.

Figure Captions

Figure 1. Schematic diagram of the sensor for the Suprathermal-Ion-Telescope (SIT).

Figure 2. TOF versus the total kinetic energy for solar energetic particles, measured during the November 1997 event. The pulse height analysis (PHA) data are from the WIND/STEP sensors.

Figure 3. Block diagram of the SIT event processing.

Figure 4. Valid events when processed as in figure 3. The grid shows the resolution of the 128×32 ROM box lookup table (lookup table 6).

Figure 5. Block diagram of the PHA event record acquisition.

Figure 1.

Suprathermal Ion Telescope (SIT)

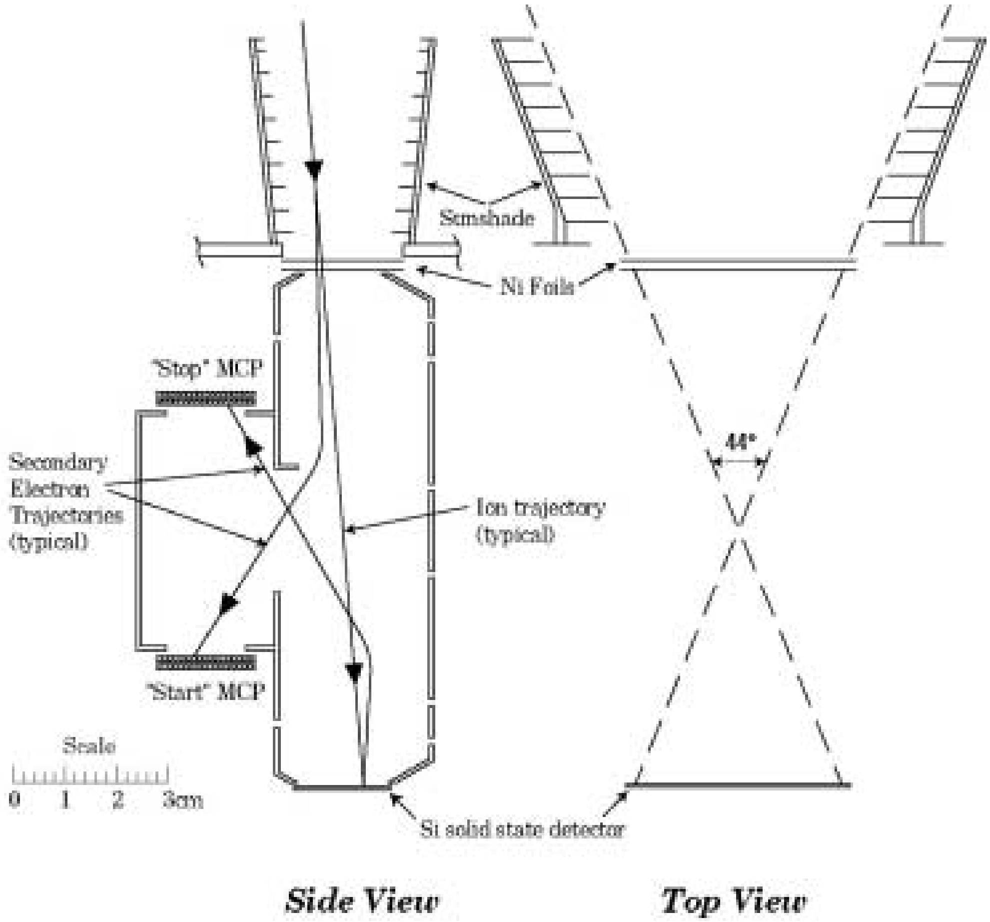


Figure 2.

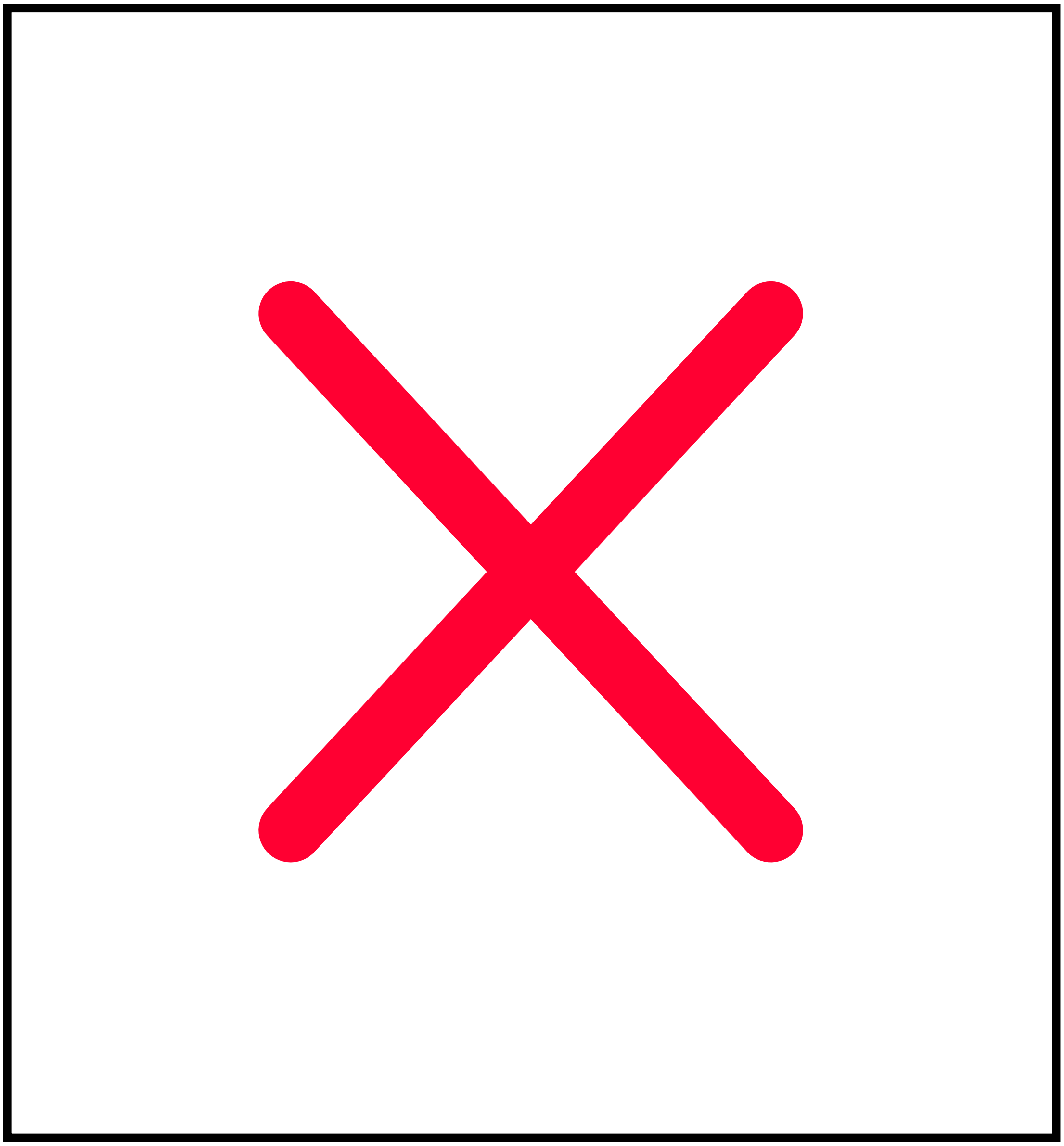
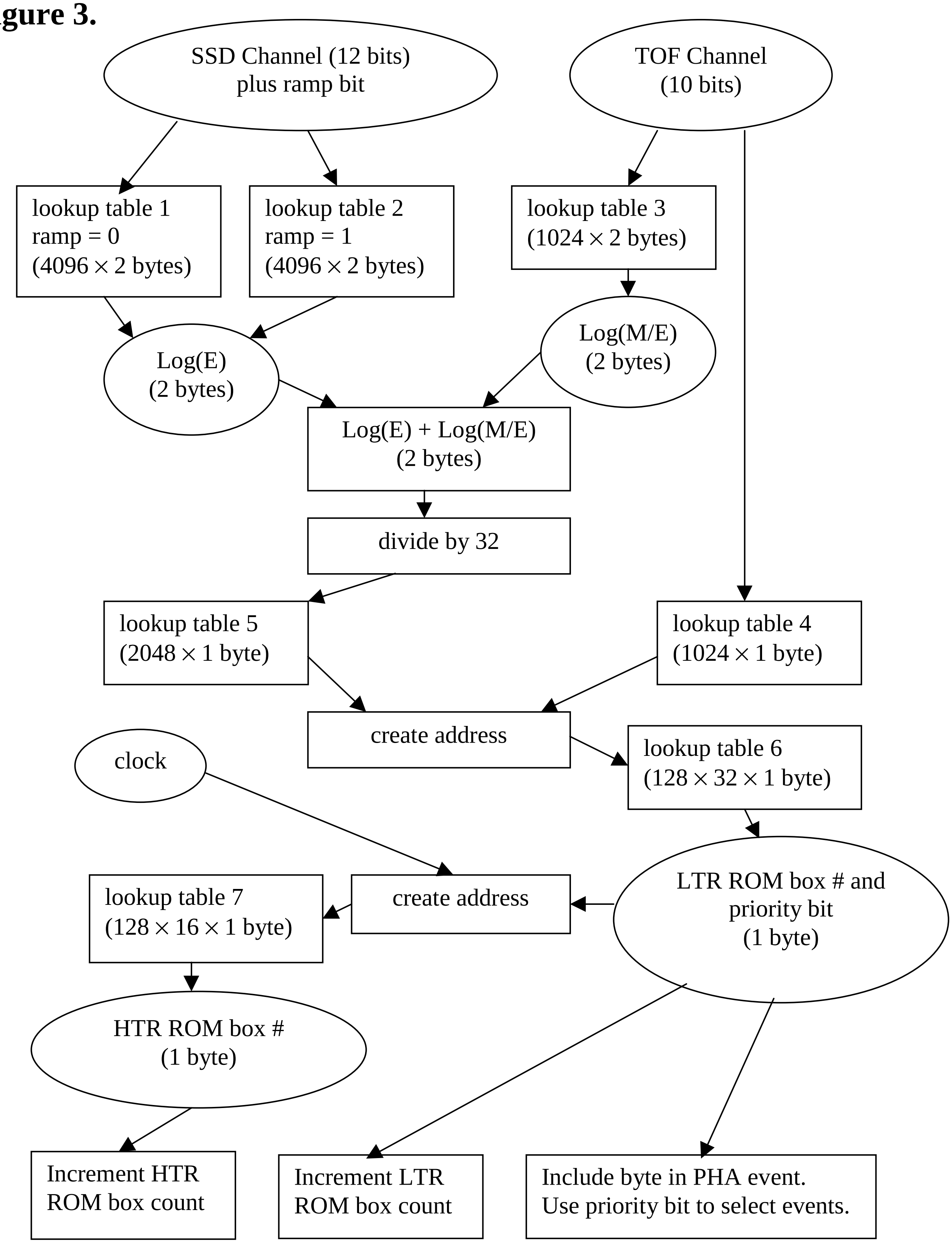


Figure 3.



SSD Channel (12 bits) plus ramp bit
TOF Channel (10 bits)
lookup table 1 ramp = 0 (4096 × 2 bytes)
lookup table 2 ramp = 1 (4096 × 2 bytes)
lookup table 3 (1024 × 2 bytes)
Log(M/E) (2 bytes)
Log(E) (2 bytes)
Log(E) + Log(M/E) (2 bytes)
divide by 32
lookup table 5 (2048 × 1 byte)
lookup table 4 (1024 × 1 byte)
create address
lookup table 6 (128 × 32 × 1 byte)
clock
lookup table 7 (128 × 16 × 1 byte)
create address
LTR ROM box # and priority bit (1 byte)
HTR ROM box # (1 byte)
Increment HTR ROM box count
Increment LTR ROM box count
Include byte in PHA event. Use priority bit to select events.

Figure 4.

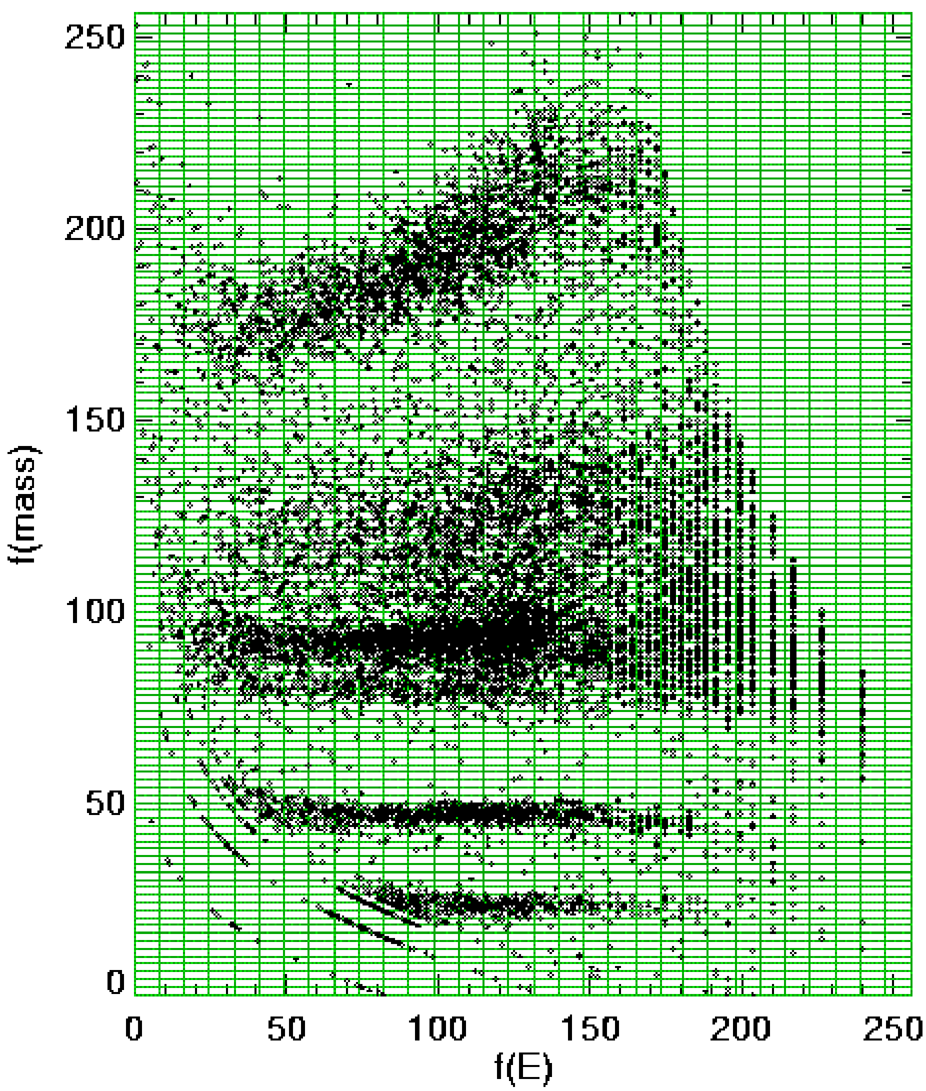


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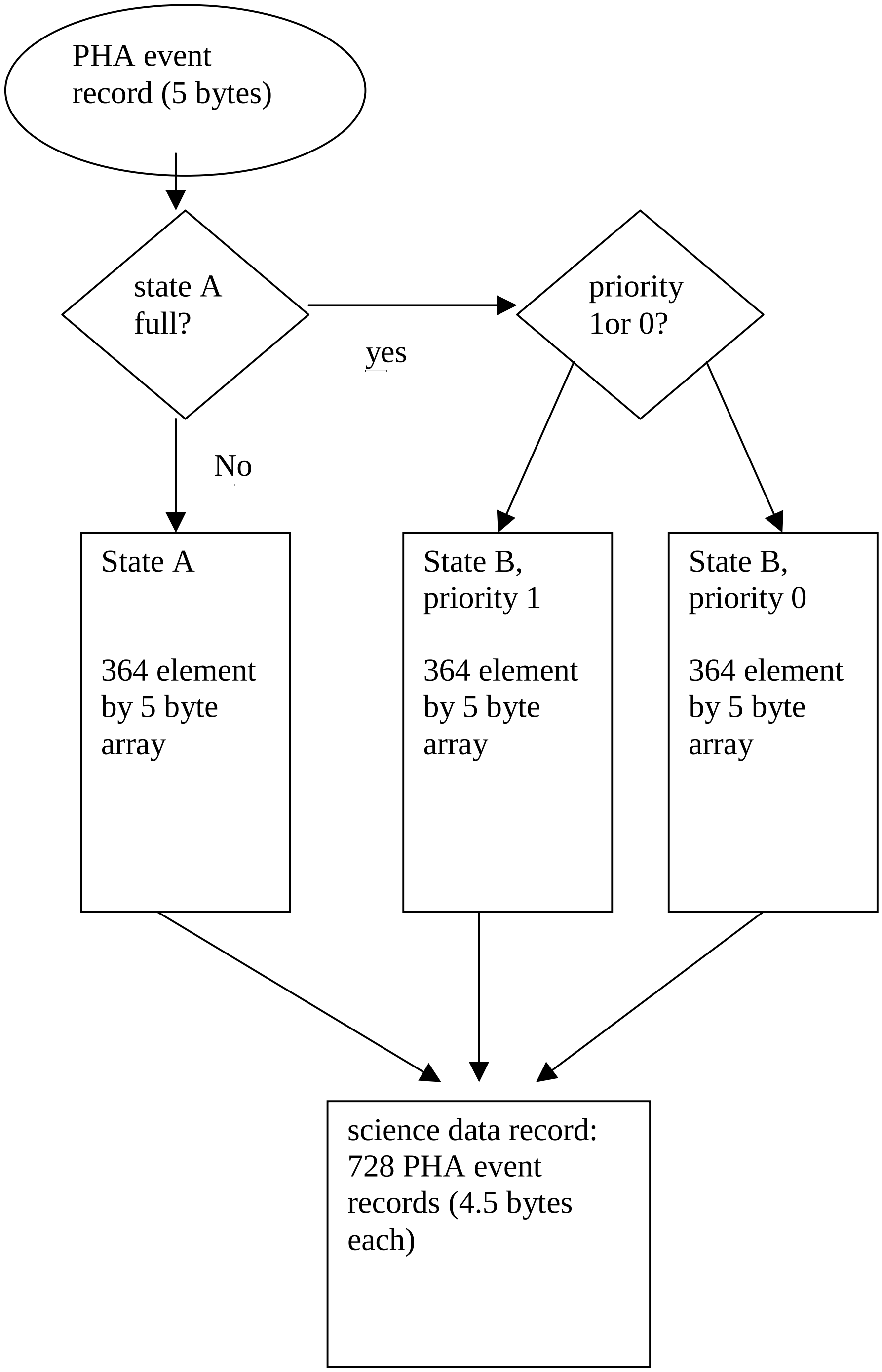
Figure 5.


PHA event
record (5 bytes)
state A
full?
yes
priority
1or 0?
No
State A
364 element
by 5 byte
array
State B,
priority 1
364 element
by 5 byte
array
State B,
priority 0
364 element
by 5 byte
array
science data record:
728 PHA event
records (4.5 bytes
each)