TIME-TAG mode of STIS observations using the MAMA detectors

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ABSTRACT:

We summarize the time-tag mode of STIS observations using the MAMA detectors, both in imaging and spectroscopic modes. After a brief outline on the MAMA detector characteristics and the astronomical applications of the time-tag mode, the general philosophy and the details of the data management strategy are described in detail. The GO specifications, and the consequent different modes of data transfer strategy are outlined. Restrictions on maximum data rates, integration times, and BUFFER-TIME requirements are explained. A few cases where the subarray option would be useful are outlined.

1. Introduction:

STIS has two MAMA (Multi Anode Microchannel plate Array) detectors for imaging and spectroscopy in the UV wavelengths. The two detectors, known as the FUV-MAMA (Band I in the STIS IDT nomenclature) and the NUV-MAMA (Band II) detectors, cover the wavelength ranges 1150-1700 Å and 1650-3100 Å, respectively.

The MAMA detectors can be used either in “accum” mode, accumulating counts at each pixel, analogous to a CCD, or they can be used in “time-tag” mode, where the detector registers the x,y location of the events and time tags each event. The MAMA detector does not have any read-noise like the CCD, which makes the time-tag mode an attractive option with the MAMA detector. This document provides the details of the time-tag mode, some astrophysical applications, various restrictions on data acquisition/transfer rate, and the data management strategies.

2. Astronomical Applications:

The time-tag mode is particularly useful for obtaining time resolved data, in either imaging or spectral format, of variable phenomena. The time-tag mode provides time
resolution of 150 microsec. Examples of astronomical objects which may be studied in this mode are:

(i) Time variation of flare stars;
(ii) Study of pulsars;
(iii) Monitoring of X-ray/gamma-ray bursters in the ultraviolet;
(iv) Study of nova/supernova outbursts; and
(v) Cataclysmic variables.

Note that in all of the subsequent discussions, the counts refer to the actual recorded events, which necessarily implies that the throughput of the spectrometer and the detector efficiency, etc., are already taken into account. For the purpose of illustration, the variability characteristics of a few typical astronomical applications where the time-tag mode may be used are summarized in Table 1. (Note that these count rates are very approximate and can vary by a large factor depending on the particular source, its distance etc.)

Table 1. Expected count rates and variabilities for various astronomical applications

<table>
<thead>
<tr>
<th>Object type</th>
<th>Time resolution</th>
<th>Integration time</th>
<th>Count rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsating WDs</td>
<td>~50 millisecond</td>
<td>~1 orbit</td>
<td>~30,000</td>
<td>Continuum obs., both imaging and spectral mode. Observed with HSP</td>
</tr>
<tr>
<td>AM-Her stars</td>
<td>~50 millisecond</td>
<td>~1 orbit</td>
<td>~30,000</td>
<td>Both imaging and spectroscopic mode</td>
</tr>
<tr>
<td>Pulsars</td>
<td>1-10 millisecond</td>
<td>~1 orbit</td>
<td>few thousand</td>
<td>Dramatic rise at pulse. Crab was observed with HSP</td>
</tr>
<tr>
<td>Flare stars</td>
<td>~1 sec</td>
<td>~12 orbits</td>
<td>~3,000 (in flare)</td>
<td></td>
</tr>
<tr>
<td>CVs</td>
<td>few sec</td>
<td>~8 orbits</td>
<td>~&lt;10,000</td>
<td></td>
</tr>
</tbody>
</table>

3. Detector Performance

The STIS MAMA detectors can be used in two spatial resolution modes, known as “low res” and “high res”. These modes come about due to the way the anode array encodes the data. In the “low res” mode the detector has 1024 x 1024 pixels and each pixel measures 25 x 25 microns. In the “high res” mode the data are subsampled and the detector effectively has 2048 x 2048 pixels, each “low res” pixel having been divided into four 12.5 x 12.5 micron pixels. The data are always taken in the “high res” mode, but in the “accum” mode are rebinned onboard to 1024 x 1024. The time-tag data, on the other hand, are recorded and downlinked in the full 2048 x 2048 “high res” mode. There is a spatial resolution gain in going to the 2048 x 2048 format, which is approximately 10%. However, since the flat fields are more variable in the high-res mode and the gain in spatial resolu-
tion is modest, the pipeline converts them to the low-res mode before flat fielding the re-
constituted image, although the original, high-res, time-tag data are still available. Baum
et al (1995, STIS ISR 95-13) describe the processing of data in the STScI pipeline.

The MAMA is a photon counting detector, and when used in time tag-mode some restric-
tions on the maximum permissible count rate apply. These restrictions come from two
separate categories: one from the pixel (local) performance and the other from overall
(global) performance of the detector. The local restriction is due to the dynamic range
which is the range over which the detector behaves linearly. This corresponds to 100 c/
(sec.pixel), which is the limit at which the linearity deviates by 10%. Tests show that a
count rate of 50 c/(sec.pixel) corresponds to the point where the deviation from linearity is
well within 5%. This is same in time-tag and accum modes. The global limit comes from
the post detector electronics which limit the “total” or “global” count rate to a maximum
of 50,000 c/sec. This is specific to time-tag mode, and is much higher (>the bright-object-
protection limit discussed later) in the accum mode. Clearly, if the whole field is uniformly
illuminated, the maximum allowed count rate per pixel will be close to 0.05 c/(sec.pixel),
which is far below the local count rate limit of 50 c/(sec.pixel). But for spectra which
cover a small portion of the detector, or for images where there are a few bright stars in the
field, some pixels may record data at 50c/(sec.pixel) or larger, without exceeding the glo-
bal rate of 50,000 c/sec. And finally, there is the bright object protection limit, which
corresponds to about 300,000c/sec over the whole area of the detector. The relevant detec-
tor performance characteristics are given in Table 2.
Table 2. The Detector performance characteristics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Resolution</td>
<td>150 microsec</td>
</tr>
<tr>
<td>Maximum Global count rate in Time-tag mode</td>
<td>50,000 counts/sec</td>
</tr>
<tr>
<td>Maximum Local count rate</td>
<td>50 counts/sec/low res pixel (after which non-linearity effects set in).</td>
</tr>
<tr>
<td>Bright Object Protection limit</td>
<td>300,000 c/s</td>
</tr>
<tr>
<td>Memory size of the internal buffer:</td>
<td>16 Mbytes</td>
</tr>
<tr>
<td>Data transfer rate</td>
<td>1Mbit/sec</td>
</tr>
<tr>
<td>SSR (Solid State Recorder) capacity</td>
<td>12 Gbits</td>
</tr>
<tr>
<td>Available SSR storage space per visit</td>
<td>2.4 Gbits (20% of total SSR capacity)</td>
</tr>
<tr>
<td>Coarse time rate</td>
<td>32 millisec</td>
</tr>
<tr>
<td>Minimum time to transfer 8Mbytes in continuous mode</td>
<td>~77sec</td>
</tr>
<tr>
<td>Minimum time to transfer 8Mbytes in non-continuous mode</td>
<td>~98sec (subject to change depending on recorder overhead)</td>
</tr>
<tr>
<td>Background FUV-MAMA</td>
<td>&lt;6.25 x 10^{-5}/(pixel,sec) (spec value)</td>
</tr>
<tr>
<td>background NUV-MAMA</td>
<td>&lt;1.25 x 10^{-4}/(pixel,sec) (spec value)</td>
</tr>
</tbody>
</table>

4. Data management:

Each MAMA has its own dedicated MCE (MAMA Control electronics) which contains the electronics required to operate it. A separate MAMA Interface Electronics (MIE) processes data output from both MAMAs and dumps it to the CS (Control Section) buffer memory.

In the time-tag mode, each detected event is recorded in the CS as a separate entry. This entry contains both position (x, y) and time (t) information. Each qualified event from the MAMA detector creates a 32 bit word, 11 bits each for x and y and 10 bits for time (which is broken down as 8 bits for (fine) time data, 1 bit for fine/course flag and 1 spare bit). At the start of every exposure and every 32 millisec thereafter, a 32 bit time of day (coarse time) word is written to the CS memory until the end of the exposure. To avoid unnecessary use of the memory and recorder space, no coarse time is recorded if no events are recorded during this time interval.
Two pointers are used to describe the condition of the CS memory in use, namely the fill and dump pointers. The dump pointer indicates the position in the CS buffer memory from which the next dump will start. The fill pointer indicates the position up to which the buffer is filled with data. The CS buffer has a capacity of 16 Mbytes, and is a truly circular buffer as shown in Fig. 1. As will be explained later, the data transfer modes are designed such that at least half the buffer memory (i.e. 8 Mbytes) are always available for acquiring data.

At the start of the timetag exposure, the buffer memory must be empty. Before making an exposure, a set-up instruction is given which requests the allocation of the full CS buffer memory, and sets the fill and dump pointers to the beginning of the memory assigned. Then the exposure is started.

Both the CS and the MIE keep track of the fill and dump pointer locations. The CS controls the dump pointer and the MIE controls the fill pointer. When a dump is requested, the data are dumped from the dump pointer memory position to the fill pointer memory position at the time the dump was requested. Meanwhile, the new dump pointer moves to the old fill position and the new fill pointer continues to move ahead to indicate the current fill position. This is schematically shown in Fig. 1.

Dumps will be always commanded in units of 8 or 16 Mbytes.

Consider the case where there is only 1MByte of data in memory and a dump of 8Mbytes is requested. The dump will then contain 8Mbytes which will consist of 1 Mbyte of real data and 7 Mbytes of fill data (5569 hex). Meanwhile, the fill pointer progresses on and at the end of the dump, the dump pointer is assigned to the position where the fill pointer was at the beginning of the dump. Should the fill pointer catch up with the dump pointer (within a small pad), then the MIE will stop taking data, an overflow word (FAAA AAAA hex) will be written, and subsequent data will be lost, resulting in a “data drop out”. The CS now waits for the commanded data dump from the NSSC1, and the MIE continues taking data only after the dump is complete.

The full buffer memory containing 16Mbytes of data is dumped at the end of any visit. Thus the last dump in any visit is 16Mbytes, which implies that at least 16 Mbytes of data are dumped to the SSR in any single visit. If the count rate is too low, a large fraction of this may be fill data.

**Brightness Protection:**

The time-tag mode has all the same brightness protection as that of the “accum” mode, which is 300,000 c/s over the whole detector. If for instance the brightness protection creates a TDF (take data flag) down, the data taking will stop. During the next dump, the FSW will output fill data to tape just as if the count rate was lower than expected. The fill pointer will not move after all real data has been sent.
4.1 Header

Time-tag data has an internal header, identifying the exposure and other programmatic information. The header also contains information on the time when the first coarse time was inserted (start_time) and number of lines of data to expect. The timetag header contains the same engineering information and snapshot data as the accumulate mode; no special information is appended. (There will be two engineering snapshots for every dump. However, the first engineering snapshot is populated at the beginning, and the second at the end; thus the second ‘real’ engineering snapshot is available only at the end of
the exposure. As a result, the two engineering snapshots will be identical until the last dump. In other words, the structure of the science data header will be the same in all dumps; and in order to do this, redundant data will be included in all but the last dump). The commanded Doppler correction keywords will be present in the header but will not be used by the FSW. The data will not be ‘chopped’ in dispersion direction in a subarray when observing in Doppler corrected mode (in contrast to the accum mode, where the data will be ‘chopped’ in dispersion direction). If data is scheduled for multiple dumps, each dump has the same header with the exception of the time dependent parameters such as the total words in the dump. There are currently no direct indications of sequence in the science headers.

5. Modes of data transfer:

There are 3 restrictions which govern the data transfer strategy:

- The data transfer rate is limited to 1 Mbit/sec. This poses limitations on the rate at which data can be collected before the buffer becomes full.
- The CS buffer memory is 16 Mbytes. This implies that, if the data were to exceed 16 Mbytes, the data arrival rate cannot be faster than the data transfer rate. This would limit the count rate to < 26,000 c/sec (more details later).
- The maximum volume of data that can be acquired in any single visit (where a visit is a set of exposures at a single pointing which must be scheduled together), is about 2.4Gbits (20% of the solid-state recorder capacity). This imposes a limit on the exposure duration which can be sustained at a given count rate.

Considering these restrictions, the data transfer is handled in three different modes as follows:

(i) Mode A: Dump-at-end mode:

In this mode, the data from the internal buffer will be dumped to the Solid State Recorder (SSR) at the end of the exposure. Since the memory size of the internal buffer is 16 Mbytes, the maximum counts in each exposure are limited to ~4E6 counts (1 count = 32 bits = 4 bytes).

This mode would be useful in 2 cases:

- when the total amount of data is expected to be less than the CS buffer memory of 16 Mbytes, and
- when the data arrival rate is faster than the data transfer rate. In this case, there is the inevitable limit on the total amount of data to 16Mbytes, and the consequent limit on the total integration time, details of which are described later.
(ii) Mode B: Continuous mode

In the continuous mode, the data are dumped in blocks of 8 Mbytes from the internal buffer to the SSR. The decision to dump data in blocks of 8 Mbytes was driven by two reasons: (1) Since 8 Mbytes of memory are always available for data acquisition, this allows the maximum rate of data acquisition at any given time. This would allow observing a source which varies by a large factor in brightness. (2) This works satisfactorily for most astronomical applications.

The command for each dump is issued as soon as the transfer of the previous 8 Mbyte block is complete. There is no overhead for starting/stopping of the recorder in this mode. Including the overhead involved in the ‘packetisation’ and the error-correction, the time for each dump of 8 Mbytes is about 77 sec. (For a more precise calculation of the time to dump in different modes, interested readers may refer to the Appendix).

This mode is currently not available, and may be available after Cycle 7.

(iii) Mode C: Non-continuous mode

In this mode, the data are transferred in a discrete fashion in blocks of 8 Mbytes. A separate dump command is issued for each dump, the time between successive dumps will be the same as the GO parameter BUFFER-TIME. The extra overhead involved in the start/stop of the SSR and the commanding is ~21 sec at present, thus the time needed to dump 8 Mbytes is about 98 sec. The overhead may be reduced in the future, but is likely to remain ~19sec for the beginning of cycle 7.

This mode would be useful when the total amount of expected data is larger than 16Mbytes, and the maximum expected count rate is less than about 21,000 c/s (details in the next section).

5.1 GO specification: BUFFER-TIME

The only GO requirement needed in the time-tag data management mode is the BUFFER-TIME, which will be used as the time between successive dumps. The responsibility of the GO is to take all the sources in the (sub)array and the dark current (the exact value of which will be available later) into account. Since data will be transferred in blocks of 8 MBytes, the GO specified BUFFER-TIME must necessarily be the minimum time estimated to fill 8 Mbytes (~2e6 counts) by the source and the background. In many astronomical applications, the expected count rate will not change by a large factor during an integration. In that case, the maximum count rate is a good approximation to determine the value of BUFFER-TIME, which can be simply calculated as

\[ \text{BUFFER-TIME} = \frac{2E6}{(\text{expected maximum count rate})} \]

(where we have ignored the value of the background which is expected to be small).
However, in special applications where the count rate can vary by a large factor during an integration, this simple scheme may not be an efficient way to transfer data. Examples of this kind would be flare stars or pulsars, where there would be times during the exposure when the count rates may exceed the maximum data transfer rate, yet the average count rate for an entire exposure (total_counts/exposure time) might be quite low. Taking these into account, BUFFER-TIME can be best estimated by the observer and hence the value of BUFFER-TIME needs to be specified by the GO.

An underestimate of BUFFER-TIME would result in a large amount of fill data (zeros) and unnecessary use of the valuable SSR and downlink resources. An overestimation of BUFFER-TIME, on the other hand, will result in loss of data. Thus the GO is expected to make a good estimation of BUFFER-TIME so that no data are lost, but at the same time there is no unwanted (over)use of the SSR. In the next section, the average count rates are given for illustration purposes which are applicable only to sources which do not vary by a large factor within the integration. For sources which do have such variation, BUFFER-TIME has to be evaluated by the GO taking the variation characteristics of the source into account. Taking the GO specified BUFFER-TIME and other factors such as the background and the recorder overhead into account, the mode of data transfer will be decided by the Institute.

5.2 Calculations of and restrictions on BUFFER-TIME

The first restriction, which would be applicable only for bright objects, comes from the highest global count rate restriction of 50,000 counts/sec. The local maximum count rate can be up to 50 counts/(sec.pixel) beyond which the detector response can be non-linear.

\[ 40 \text{ sec} < \text{BUFFER-TIME} < 77\text{sec} : \]

Going down the ladder in brightness scale, let us consider BUFFER-TIME < 77sec, which will be the case for objects with average count rates >~ 26,000 counts/sec. In that case, the data rate is too fast to be continuously transferred to the SSR and can be dumped only at the end of the exposure (mode A). The exposure time is thus limited by the memory size of the internal buffer, which is approximately 4E6 counts. The maximum supported integration time in such a case will thus be (4E6/expected average count rate, or 2*BUFFER-TIME), which is always less than 2.5 minutes. There is also an absolute minimum buffer-time, which comes from the fact that the global count rate cannot be larger than 50,000 c/sec. This corresponds to a buffer-time of (2e6/50,000 =) 40sec.
A value of BUFFER-TIME between 77 and 98 sec corresponds to average count rates between about 21,000 and 26,000 counts/sec. Greater data acquisition rates will result in data drop outs. In this case, the data are dumped in 8 Mbyte blocks in a continuous mode (i.e. time between dumps will be ~77sec). The the recorder is used at its maximum rate, and 32 dumps can be performed. Consequently, the total integration time per visit cannot be more than 40 minutes. Note that this is the maximum integration time in this mode (mode B), regardless of the exact value of BUFFER-TIME. To get a longer integration time, BUFFER-TIME must currently be > 98 sec, in which case the SSR will be used in mode C. This may change slightly, if the recorder overhead changes.

Note that this mode will not be available in the beginning of Cycle 7. Until this mode is available, BUFFER-TIME in this range will use ‘Mode A’ data transfer.

**BUFFER-TIME > 98sec:**

A value of BUFFER-TIME > 98 sec corresponds to average count rates <~21,000 counts/sec, in which case the data will be dumped in the non-continuous mode (mode C). In this mode, there is some extra overhead caused by the start/stop of the SSR and the commanding. Since the SSR is used during a small portion of this overhead time, a maximum of 29
dumps can be supported in this mode. The maximum allowed integration time per visit is 29*BUFFER-TIME.

* A special case: BUFFER-TIME > 0.5 exp_time:*

If BUFFER-TIME is larger than half the exposure time, the expected data during the whole exposure will be less than 16Mbytes. Hence the data will be dumped only at the end of the exposure (mode A). Note that the first case (BUFFER-TIME < 77sec) always satisfies this criterion.

6. Wavecal:

If time-tag data is taken in the spectroscopic mode, wavecal data will be taken in the accum mode either before or after the time-tag observation.

7. Parallel observations:

Parallel observations with other instruments are not prohibited in timetag mode. However, the data from the parallel observations can be dumped only when there is enough time between successive dumps of the timetag data. This will severely restrict parallel observation opportunities during timetag mode.

8. Bright objects:

For bright objects, there is the possibility of using a neutral density filter to reduce the flux of exceptionally bright sources. Note that these filters are unsupported and therefore not calibrated.

9. Subarrays

Subarrays are ‘Engineering Only’ parameters, which are useful in situations where a bright source in the field may exceed the 50,000 c/sec global rate. A subarray allows the electronics to pre-screen (“qualify”) an area on the MAMA detector so that only those events inside the subarray will reach the MIE. Thus the global limit of 50,000 c/s applies only to the subarray, and not the whole detector. The advantage of the subarray will however be limited to the bright object protection limit of ~300,000 c/sec over the entire (not subarrayed) detector. Thus in subarray mode, there would be a global limit of 50,000 c/sec for the subarray and another global limit of 300,000 c/sec for the entire detector. Subarrays also solve limiting cases where the count rate is close to the maximum value of 26,000 in mode B (since mode B will not be available in the beginning of Cycle 7, this maximum value is currently 21,000 corresponding to mode C) since any additional light will change the maximum allowed integration time from 40 min to less than 2.5 min. This may be a particular concern in crowded fields such as open or globular clusters, or close to the
galactic plane where the number density of bright stars is expected to be large. There are no restrictions on subarrays specifications on size and position; the only restriction is that the subarray must fall within the array.

10. Appendix: Calculation of the time to dump:

The time to dump in different modes are calculated as follows.

\[ \text{Time\_To\_Dump} = \text{ceil} (\text{total\_lines} \times 0.017143 \text{ sec/line}) + \text{overhead}. \]

The total_lines to dump are 4348 for an 8 Mbyte dump, and 8694 for a 16 Mbyte dump. Mode B uses 8 Mbyte dumps and has a 2sec overhead for issuing the dump command, giving a minimum BUFFER-TIME of 77 sec. Mode C also uses 8 Mbyte dumps and currently has an overhead of 23sec giving a minimum BUFFER-TIME of 98 sec.