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HIGH SPEED SPECTROSCOPY USING THE FOS IN RAPID MODE

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Abstract

The HST Faint Object Spectrograph has the capability to record spectra with time resolution better than 0.1 seconds. This makes the FOS an extremely valuable tool for researchers studying rapid variability, and even more so with the loss of the HSP. In this Report we give formulae for computing live/dead times and present plots of duty cycle versus READ–TIME so that the user can make an optimal choice of time resolution. Various subtle points are noted to help the user obtain the highest quality data possible.

1 INTRODUCTION

Numerous objects of astrophysical interest exhibit pronounced variability on a timescale of seconds (e.g. flare stars, cataclysmic variables, X–ray binaries, pulsating degenerate stars, occultation events, etc.). Very often these fluctuations contain no preferred periodicity, so real–time phase folding using the FOS in PERIOD mode does not provide very useful information. Rather, one can use the FOS in RAPID mode to record high speed spectrophotometry.

With the default parameters, the FOS in RAPID mode can record spectra approximately every 6.2 seconds. By changing these default parameters, the FOS can record several spectra per second. However, as higher time resolution is demanded (i.e. shorter exposure times per spectrum), the ratio of live time to READ–TIME decreases. At some level the trade–off becomes so severe that *efficient* observing becomes impossible.

It is likely that once the FOS has been used several times in non–default RAPID mode, there will be a much greater demand for the high speed capabilities of the instrument, especially after the loss of the HSP. It is the purpose of this report to help the user take full advantage of the unique high speed spectroscopic capabilities of the FOS. The formulae given in section 2 should allow users to determine the live and dead time of their proposed observations, and in section 3 figures are given to assist in the assessing the duty cycle (i.e., efficiency) of the observing scheme. Section 4 gives a few vital suggestions on observing strategies that may be critical to the success of a RAPID mode observing run with the FOS.

2 LIVE AND DEAD TIME

Before attempting to compute live and dead times, one should always consult the current FOS Instrument Handbook for the general philosophy, definitions, defaults and details of using the FOS in RAPID mode. In addition, the FOS Handbook V1.1 (Ford & Hartig 1990) is of particular interest to those attempting non–default RAPID mode observations. We note that the formulae given in the FOS Handbook V4.0 (Kinney 1993) are accurate to roughly a few tenths of a second, but for high speed work this is not accurate enough.

For high speed observations with the FOS, the user defines the time resolution via the parameter READ–TIME. READ–TIME is the time in seconds between each recorded spectrum. READ–TIME consists of the sum of live time plus dead time (internal to the FOS) plus the readout time required to store the data,

$$\text{READ–TIME} = \text{READOUT time} + \{\ (\text{LT}+\text{DT}) \times \text{INTS} \times \text{SUB–STEP} \times \text{OVERSCAN} \times \text{YSTEPS} \times \text{NPATT}\ \},$$

where SUB–STEP≡NXSTEP, OVERSCAN≡COMB≡MUL, YSTEPS≡Y–SIZE and the other terms have their usual meaning. For high–speed RAPID mode observations, INTS, NPATT, and YSTEPS should be equal to one. The deadtime DT is by default 0.01 sec. Since there is relatively little penalty in keeping OVERSCAN at the default value of 5 we recommend the user do so. Only in cases where time resolution requirements exceed data quality requirements should OVERSCAN be changed. We assume throughout this *Report* that the minimum (LT+DT)=0.030 sec. Thus in effect, the only free parameters are in SUB–STEP and in READOUT time.

SUB–STEP controls the sampling of the diode array, and hence the spectral resolution. By default SUB–STEP=4 (quarter stepping). To satisfy the Nyquist sampling theorem SUB–STEP must be ≥ 2, though in some cases SUB–STEP=1 (single stepping) may be tolerated.

The READOUT time depends upon the amount of data to be read out and the speed at which it is read out. The READOUT time can be computed by:

READOUT time=
$(15/14)\times(1024/RATE) \times$ NSEG(WORDS) $\times$ SUB–STEP $\times$ YSTEPS.

The expression NSEG(WORDS) is evaluated as:

NSEG = 1 if WORDS $<$ 51
NSEG = 1 + $NINT\{$ 0.499 + ((WORDS – 50) / 61)$\}$ if WORDS $\geq$ 51

where WORDS = (NCHNLS + OVERSCAN – 1) and NCHNLS is the number of diodes to be read out (516 for full array with OVERSCAN=5). The $NINT\{\}$ function rounds to the *nearest* integer, e.g., $NINT\{0.499\}=0$, $NINT\{0.500\}=1$, $NINT\{0.515\}=1$, and $NINT\{8.138\}=8$. $RATE$ is the data telemetry rate and is either 32,000 or 365,000 bits/sec. The slower value (32 kbit/sec) is the default. If the amount of time spent on reading out data (READOUT time) exceeds 20% of READ–TIME, the high telemetry rate (365 kbit/sec) automatically is enabled. **Note that at the high telemetry rate, a maximum of ~ 18 minutes of data can be recorded due to onboard data storage capabilities.** NOTE: Previous FOS Instrument Handbooks claim a limit of 20 minutes, but due to overheads associated with starting and stopping the tape, the actual available time is only ~ 18 minutes. Once the onboard science data tape is filled, no more science can be done until the data is dumped to the ground (but see the last suggestion of section 4). While the telemetry rate cannot be specified by the user on the logsheet, a special request can be made to override the default telemetry rate. This is accomplished via a comment entry in the exposure logsheet. Be sure to explicitly state this request in the "description of special sheduling requirements" and also in the "description of proposed observations" sections of your proposal.

For SUB–STEP=4, OVERSCAN=5, NCHNLS=512 and the 32 kbit/sec telemetry rate, the minimum READOUT time is 1.2343 sec. This drops to 0.3086 sec for SUB–STEP=1. To remain at the 32 kbit/sec rate, the minimum READ–TIME for quarter stepping is 6.18 sec. For SUB–STEP=2 this drops to 3.09 sec and to 1.55 seconds for SUB–STEP=1. READ–TIMEs less than these will force the FOS to use the high telemetry rate.

For the high telemetry rate (called the 1MHz rate in the FOS Handbook), the READOUT times drop to 0.1082 and 0.02705 sec for SUB-STEP=4 and 1. The minimum READ-TIMES for the above parameters are then 0.7082 and 0.1771 sec for SUB-STEP=4 and 1, assuming a minimum (LT+DT)=0.030 sec. If OVERSCAN is set to 1, using SUB-STEP=1 can give a minimum READ-TIME of 0.057 sec.

By changing the number of diodes to be read out, substantially shorter READ-TIMEs can be used. For example, the absolute minimum READ-TIME possible can be obtained by reading out 50 or less diodes ($NCHNLS<50$), with OVERSCAN=1 and SUB-STEP=1. This results in a READOUT time of 0.0030 sec, and thus a a minimum READ-TIME of 0.033 sec. Note that reading out less than 50 diodes does not reduce the READ-TIME as NSEG cannot be less than 1. We caution that for very short exposures the amount time actually spent collecting data may be only a small fraction of the READ-TIME; one should compute the duty cycle.

3 DUTY CYCLE

We define the "duty cycle" as the amount of time spent actually accumulating data divided by the READ-TIME. (Note that this is not the same as LT/DT.) For many applications it is the optimization of the duty cycle rather than the S/N ratio per spectrum that will determine the READ-TIME.

For fixed NCHNLS and OVERSCAN the duty cycle will depend on the number of SUB-STEPs and the telemetry rate. Because there are 2 values of the telemetry rate and 3 SUB-STEP options, a total of 6 possible duty cycles exist for a given READ-TIME.

It is instructive to look at the functional form of the duty cycle equation for a moment. For a given set of optional parameters (i.e., holding SUB-STEP, OVERSCAN, NCHNLS, and telemetry rate fixed), the duty cycle has the form $f(x) = \frac{x - const.}{x}$, where x = READ-TIME and *const.* = READOUT time + total dead time. The constraint that (LT+DT)>0.030 sec manifests itself as a lower limit to the READ-TIME.

In figures 1 and 2 we show the duty cycle plotted as a function of READ-TIME. Six curves are plotted, each corresponding to a different value of SUB-STEP and telemetry rate. In each case NCHNLS=512, YSTEP=1, and OVERSCAN=5. The curve studded with dots represents the SUB-

STEP=4 case, the diamonds represent the SUB–STEP=2 case and the boxes are for the SUB–STEP=1 case. The lower three curves (dashed) are for the 32 kHz telemetry rate, the upper (dotted) curves represent the 1MHz rate. The default telemetry rates are shown as the dark curves. Sharp transitions occur when the default telemetry rate changes (when READOUT time exceeds 20% of the READ–TIME). (Note that the transition criterion does not account for the 0.01 seconds of DT, hence the transitions occur below the 80% duty cycle level.)

From the figures one can multiply the READ–TIME by the duty cycle fraction to get the true exposure time. For example, for SUB–STEP=4, using the default telemetry rate, and a READ–TIME=10 seconds, one can expect to be collecting photons for ~ 85% of the time, or about 8.5 seconds. Using the default telemetry rate for SUB–STEP=1 and a READ–TIME of 0.4 seconds, a duty cycle of ~ 80% can be achieved. One can also see that by forcing the telemetry to be at the slow rate, for SUB–STEP=2 and READ–TIME=2, the duty cycle is ~ 64%.

4 IMPORTANT USER CONCERNS

Below are a listing of various concerns to those using the FOS in RAPID mode for time series analysis.

- The STSDAS calibration software (calfos) is designed to work with data that has SUB–STEP=4, NCHNLS=512 and OVERSCAN=5. Other combinations are not fully supported and it is possible that the standard calibration pipeline will be inadequate. Users must be aware that they may need to calibrate the data themselves, and that calibration files for non–routine FOS observing modes may not be available. Likewise, we caution that in–orbit calibration of the internal stability of the FOS in rapid mode has not been established.
- In cases where the sampling rate (i.e. READ–TIME) needs to be exactly set *a priori*, one must be absolutely sure to specify a total exposure time (TIME_PER_EXP) that is an integral multiple of READ–TIME. If not, the READ–TIME (not the TIME_PER_EXP) will be altered to make this true.
- One should specify the NON–INTERRUPTIBLE special requirement if a continous data set is needed (i.e. no gaps). For example, an exposure may be broken up into two pieces due to an Earth occultation unless specifically prohibited.

- Avoid READ–TIMEs that are right on the transition from the 32kHz to 1MHz telemetry rates. Small roundoffs or adjustments to READ–TIME (see above) can have a drastic effect.

- To achieve maximum time resolution, the number of channels to be read out must be restricted. This is done by using the WAVELENGTH parameter in the exposure logsheet. Note that for the G130H, G160L, G190H, G650L, G780H, and PRISM dispersers, the background count rate can be directly determined from regions on the diode array beyond the area where the dispersed light falls. This ability is sacrificed if a wavelength range is specified. In the case of the G160L grating the order zero light is also lost – see below.

- Because of jitter in the spacecraft pointing induced by the light/dark terminator crossing, etc., it is wise to use the largest aperture possible, and perhaps omit data taken near the time of transition.

- The G160L grating is particularly useful because of its wide wavelength coverage ($\lambda\lambda$ 1150–2510Å) and the (undispersed) zero order light also falls on the diode array. For the blue camera, the order zero light corresponds roughly to the U band (Eracleous, et al. 1994; note: this supersedes Horne & Eracleous 1993). For bright objects, one must be careful not to exceed the count rate limit per diode, since most of the order zero light falls on one or two diodes (see Hartig 1988, also the tables of Kinney 1993). Note that if a wavelength range is specified, the zero order data will not be recorded. The maximum wavelength coverage possible with the FOS is achieved via the PRISM and RED camera ($\lambda\lambda$ 1850 to ~8600Å), though the calibration of the (highly non–linear) wavelength scale is considerably worse than for the gratings, especially in the optical (Sirk & Bohlin 1986).

- It may be possible to collect more than 18 minutes of data at the high telemetry rate because an additional science tape recorder has become available. There is still the physical limit of ~ 18 minutes on each tape recorder. However, one may be able to take 18 minutes of data in one exposure, then on the next exposure switch to the other tape recorder giving an additional 18 minutes. You must discuss this with an FOS instrument scientist before attempting to do this as the full details have not been worked out at this time. Note that in the event that HST goes into a safemode situation, data on one of the science tape recorders may be lost.

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5 REFERENCES

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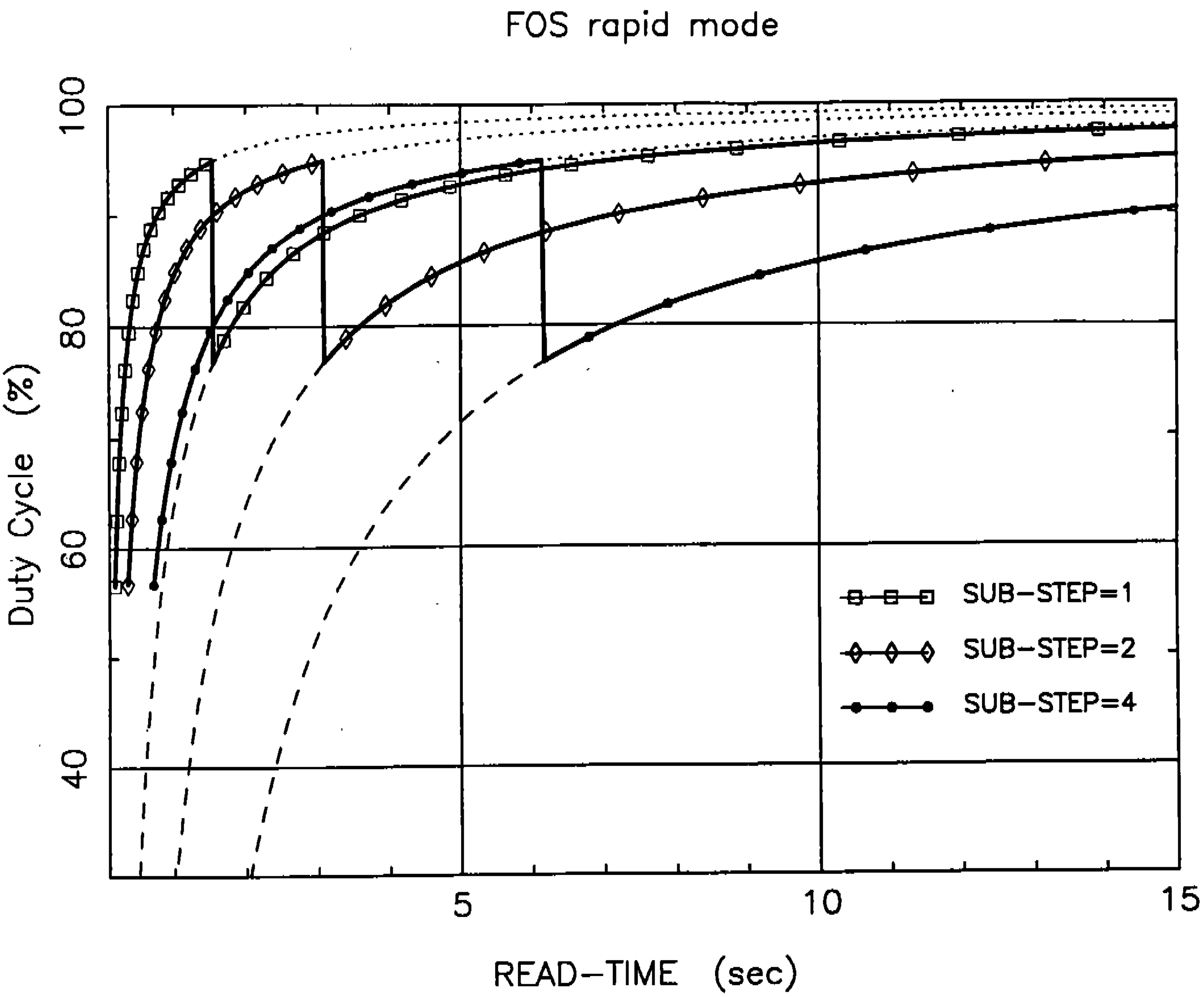

Fig. 1. Duty cycle versus READ-TIME.
The boxes mark the SUB-STEP=1 case, the diamonds mark the SUB-STEP=2 case and the dots mark the SUB-STEP=4 case. The upper three curves (dotted) are for the high telemetry rate and the dashed curves are at the low rate. The thick curves correspond to the default telemetry rate. In all cases OVERSCAN=5 and NCHNLS=512.

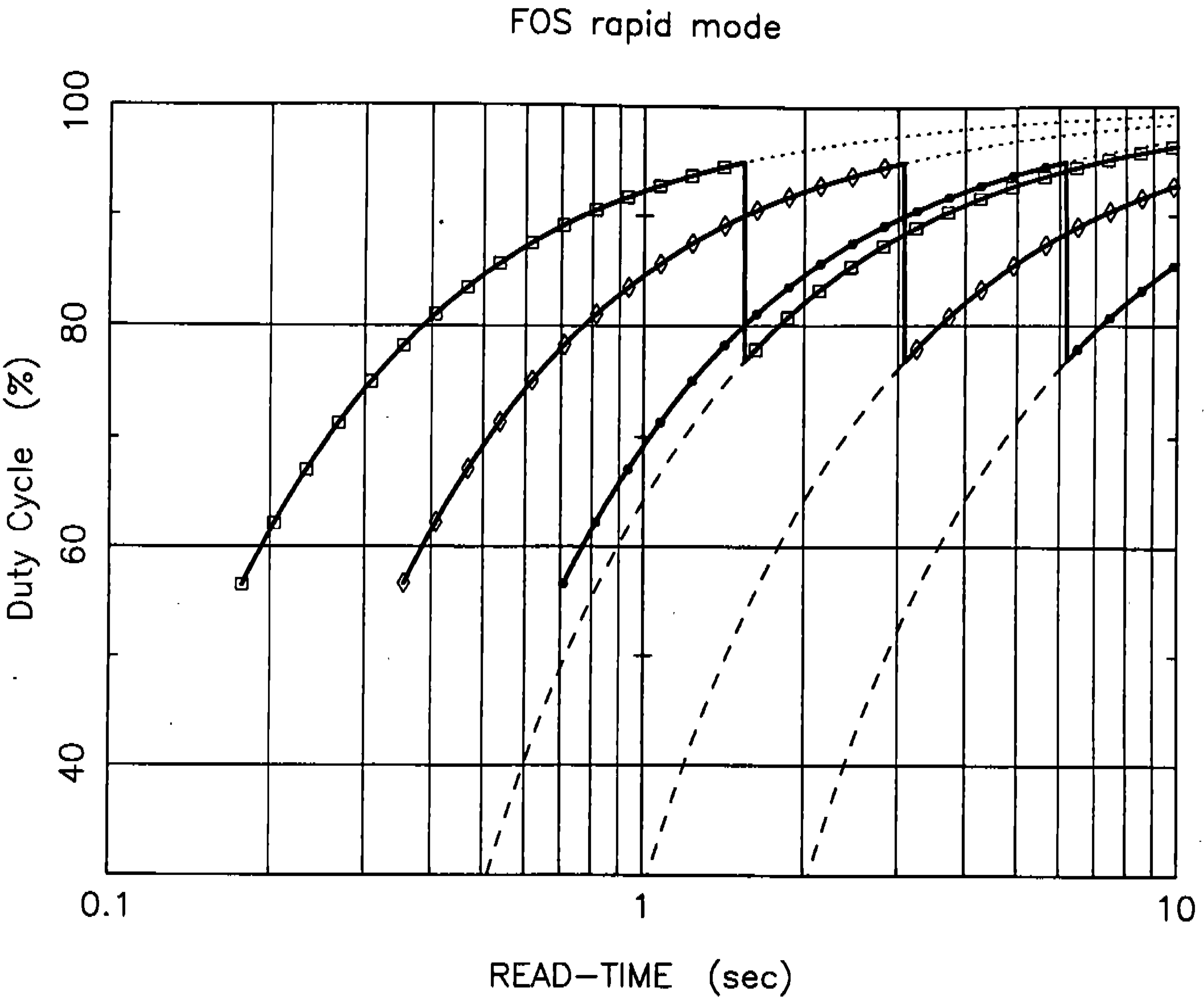

Fig. 2. Duty cycle versus log READ–TIME.
Similar to Fig. 1, except now the abscissa is plotted on a log scale.