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Issue	Date	Section affected	Change Description

APPLICABLE DOCUMENTS

Reference	Document Title	Document Number	Issue & Date
AD1			
AD2			
AD3			

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1. Introduction

This document describes the various CCD controller applications that can be run with ULTRACAM. All applications are downloaded to the SDSU timing board via the fibre link then executed with a 'GO' command. All applications reply to the 'GO' command with a 'RP' to indicate that the application has started, and all applications generate data. All *image* data packets are preceded by twelve 16-bit header words: 2 status words, 2 frame count words (24-bit count), and 8 words to hold time stamp information. Bit 0 of the first header word (status 1) is used to flag the last frame (or end of application), and bit 1 of same word is used to flag if the last frame was generated by a stop command 'ST'. All data packets include the two status words so that the end of the application can be flagged. For example Application 1 (power on) sends a packet of data that includes the status words only. Here, the 'last frame' flag is set to indicate that the application has finished.

Some of the applications have parameters, which can be passed to the timing board, e.g. the number of exposures or binning factors. All parameters are stored in the on-chip memory (location X:$005A to X:$0070) of the timing board's DSP56002. Note that this document will represent a hexadecimal number by preceding it with the symbol '$'.

All of the image data generating applications read out Ultracam's three chips in parallel, and parameters apply to all three CCDs. Furthermore, each chip has two readout channels that are always read out and sampled in parallel.

2. Application 1: *POWER ON*

This application causes the SDSU controller to switch power through to the video and clock boards in a controlled manner. After switching on the SDSU controller, the power on application must be downloaded and run once before any CCD readout application can be downloaded and executed. After a successful execution of the power on application all the LEDs on the power control board (at the back of the SDSU controller) should be on. This application has no parameters.

3. Application 2: *POWER OFF*

The execution of this application causes the SDSU to disable the voltages to the CCD and should be used at the end of an observation run. This application has no parameters.

4. Application 3: *FULL-FRAME READOUT*

4.1. Application 3: *Description*

This application is used to read out the entire CCD (1024 pixels x 1024 pixels).

4.2. Application 3: *Parameters*

There are six parameters for application 3, as described in Table 4.1 below.

0.0.0.0.1.1 Parameter	**0.0.0.0.1.2 Description**	**0.0.0.0.1.3 Default**
NO_EXPOSURES	The number of exposures taken each time the application is executed	1
EXPOSE_TIME	The frame exposure time in milliseconds	1000 (1s)
GAIN_SPEED	The gain and readout speed setting see Table 4.2 for various options	$CDD (gives approx. 1.2e/DN at 10us per pixel)
X_BIN_FAC	X binning factor. Bins the number of columns.	1
Y_BIN_FAC	Y binning factor. Bins the number of rows.	1
V_FT_CLK	Frame Transfer V Clock timing parameter (described in Appendix A)	$990000

Table 4.1: *Full-Frame Application Parameters*

Each parameter has limits on it and consequently invalid entries input by the user will be rejected and an error returned. The limits are described in Table 4.2.

0.0.0.0.1.4 Parameter	0.0.0.0.1.5 Limits	0.0.0.0.1.6 Comments
NO_EXPOSURES	NO_EXPOSURES ≥ -1, NO_EXPOSURES ≠ 0, NO_EXPOSURES ≤ 65535	When this parameter is set to **–1** the camera is put into “continual readout mode”, i.e. infinite number of exposures. This can only be terminated with a stop command ‘ST’ to the timing board.
EXPOSE_TIME	EXPOSE TIME ≥ 0	The exposure time is expressed in milliseconds
GAIN_SPEED	GAIN_SPEED = $CEE, or **GAIN_SPEED = $CDD,** or GAIN_SPEED = $CBB, or GAIN_SPEED = $C77, or GAIN_SPEED = $FEE, or **GAIN_SPEED = $FDD**, or GAIN_SPEED = $FBB, or GAIN_SPEED = $F77	As shown this parameter can only have one of 8 values. The gain refers to a variable gain stage setting on the SDSU video board. GAIN SPEED x 9.5 SLOW (10us/pix) **x 4.75 SLOW** x 2.0 SLOW x 1.0 SLOW x 9.5 FAST (2us/pix) **x 4.75 FAST** x 2.0 FAST x 1.0 FAST It is recommended that $CDD or $FDD be used. Both yield a system gain of approx. **1.2e/DN**.
X_BIN_FAC	512 % X_BIN_FAC = 0	The number of columns (per channel) must exactly dividable by the X binning factor.
Y_BIN_FAC	1024 % Y_BIN_FAC = 0	The number of rows must exactly dividable by the Y binning factor.
V_FT_CLK	V_FT_CLK > $260000 V_FT_CLK < $FF0000 V_FT_CLK ≠ $800000 16 least significant bits (0-15) of V_FT_CLK must equal 0	The most significant byte of this parameter determines the period of the V clocks used to perform a frame transfer. The two least significant bytes must both be $00. See Appendix A full description

Table 4.2: *Full-Frame Application Parameter Limits*

4.3. Application 3: *Readout Timing.*

This full-frame readout application clears the CCD before every exposure. Immediately after the CCD is cleared the DSP generates a timestamp interrupt to mark the **beginning** of the next exposure. The CCD is then exposed for the time provided by parameter EXPOSE_TIME. A frame transfer is then performed to shift the image area into the storage area. The cycle is then repeated for the number of times specified in parameter, 'NO_EXPOSURES'. This cycle is illustrated in Figure 4.1 below. Note that because the CCD is cleared before each exposure, the exposure time is exactly that specified by the parameter EXPOSE_TIME.

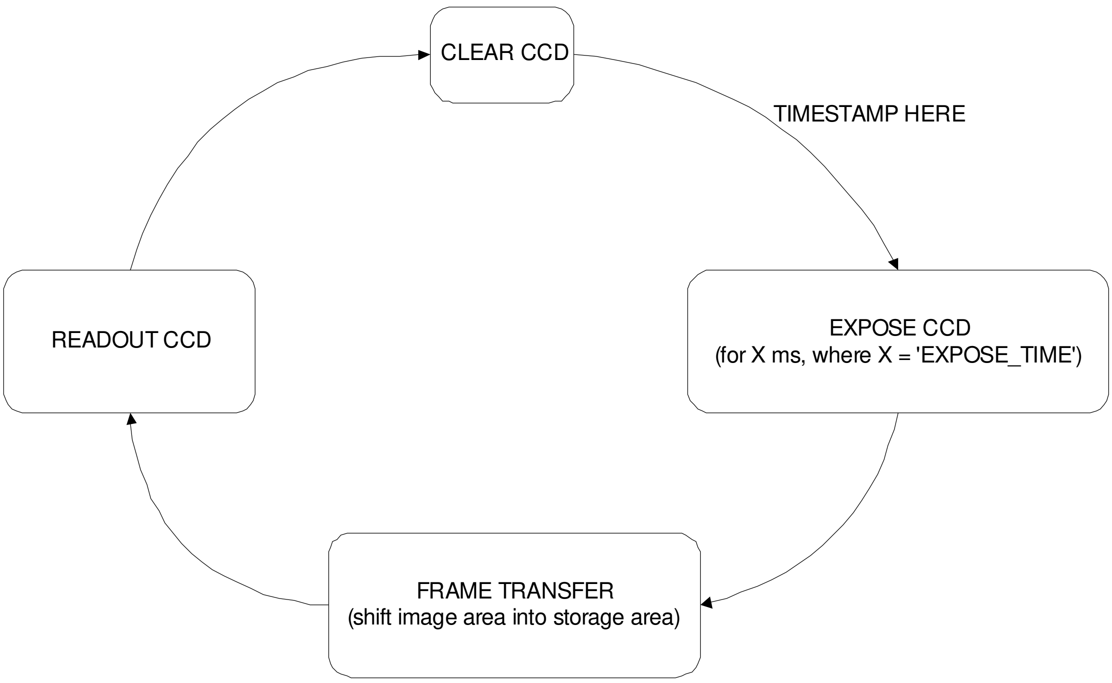

Figure 4.1:*Full Frame Readout Sequence*

As shown, this application clears the CCD before each exposure. Reading out a full frame takes several seconds, therefore, without clearing each time the minimum exposure time would be in the order of seconds. Therefore, to permit quicker exposure times the Clear CCD is included. However, this does mean there is a significant 'dead-time' in each cycle, where the CCD is integrating on unused signal. A second full-frame readout application without a clear CCD between successive frames is also available as is described in Section 10.

5. Application 4: *FULL-FRAME READOUT with OVERSCAN*

5.1. Application 4: *Description*

A full-frame contains 1024x1024 image pixels. However, in addition to this the CCD47-20 has 24 under-scan columns (8 blank element columns and 16 dark reference columns), 24 over-scan column (16 dark reference columns and 8 blank element columns) and 3 over-scan rows (dark reference rows). This yields a frame size of 1072 x 1027. Application 4 can be executed to obtain a full frame image with under-scan and over-scan rows and columns. In order to aid binning options an additional 8 blank over-scan columns and 5 over-scan rows will be clocked to yield a total frame size of **1080 x 1032**. A typical image (with no binning) is pictorially illustrated in Figure 5.1. As indicated, the additional 8 columns will appear in the centre of the chip since it is being readout from both outputs.

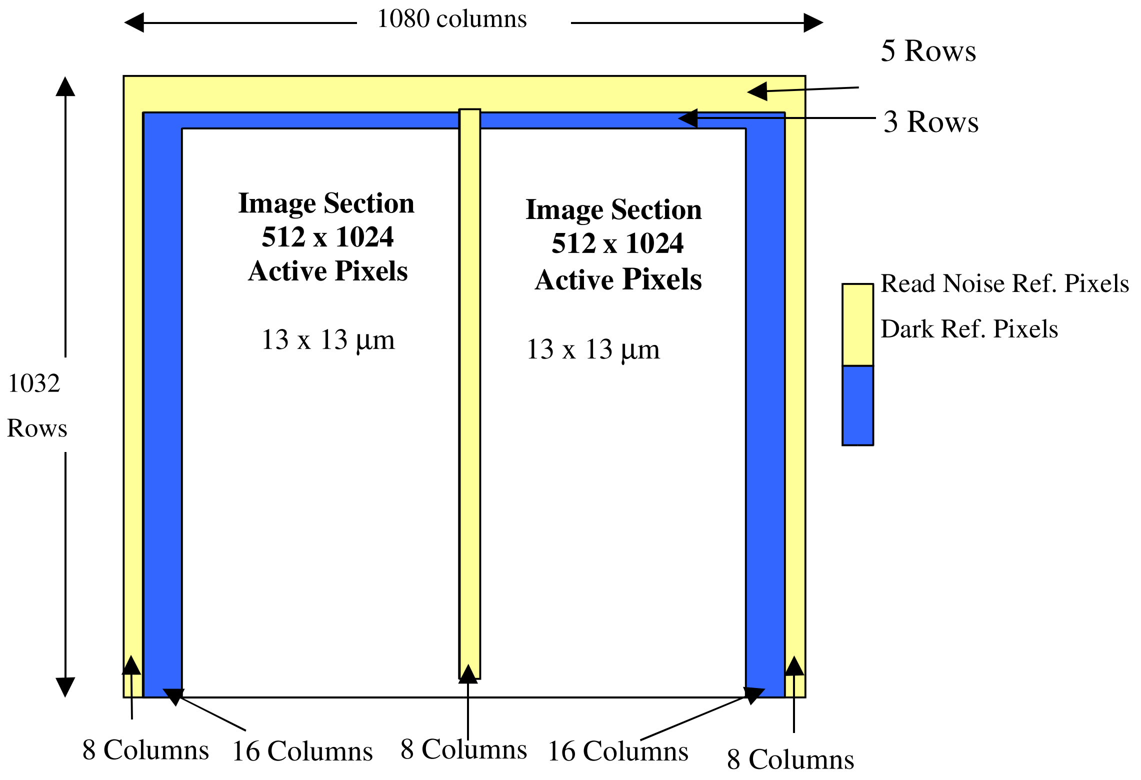

Figure 5.1: *Full Frame Readout*

5.2. Application 4: *Parameters*

The parameters for this application are the same as that of Application 3, and are listed in Tabled 4.1. The limits on these parameters are also the same as Application 3 (see Table 4.2), with the exception of X_BIN_FACTOR and Y_BIN_FACTOR, detailed in Table 5.1.

X_BIN_FAC	**540** % X_BIN_FAC = 0	The number of columns (per channel) must exactly dividable by the X binning factor.
Y_BIN_FAC	**1032** % Y_BIN_FAC = 0	The number of rows must exactly dividable by the Y binning factor.

Table 5.1: *Application 4 parameter limits*

5.2. Application 4: *Readout Timing*

As Application 3, see Figure 4.1.

6. Application 5: *WINDOW READOUT – 1PAIR*

6.1. Application 5: *Description*

This application allows 2 windows to be defined and readout per CCD frame. Window locations are specified from the first pixel in the image area. That is location 1,1 is the bottom left of the image area and location 1024,1024 is the top right of the image area. Again, under-scan and over-scan columns and rows are disregarded. The two windows should be thought of a window pair, with one window in each half of the CCD image area. That is one window (window 1L) in the left half of the chip (X = 1 to 512) and the other window (window 1R) in the right half of the chip (x = 513 to 1024). The windows will have the same starting position in Y and the same X and Y size dimensions.

6.2. Application 5: *Parameters*

In addition to the parameters described for application 3 (in Table 4.1) this application has various parameters that describe the window sizes and locations. The parameters are detailed below in Table 6.1.

0.0.0.0.1.7 Parameter	0.0.0.0.1.8 Description	0.0.0.0.1.9Default
NO_EXPOSURES	The number of exposures taken each time the application is executed	1
EXPOSE_TIME	The frame exposure time in milliseconds	1000 (1s)
GAIN_SPEED	The gain and readout speed setting see Table 3.2 for various options	$CDD
X_BIN_FAC	X binning factor. Bins the number of columns.	1
Y_BIN_FAC	Y binning factor. Bins the number of rows.	1
V_FT_CLK	Frame Transfer V Clock timing parameter (described in Appendix A)	$990000
X1L_START	The x-axis starting position of window 1 Left.	100
X1R_START	The x-axis starting position of window 1 Right.	600
Y1_START	The y-axis starting position of window pair 1	200
X1_SIZE	The size in x-axis of window pair 1	60
Y1_SIZE	The size in y-axis of window pair 1	60

Table 6.1: *Window Application (1 Pair) Parameters*

As before, each parameter has limits on it and the camera object will generate an error when the user inputs an invalid value. The limits for this application's parameters are described in Table 6.2.

0.0.0.0.1.10Parameter	0.0.0.0.1.11Limits	0.0.0.0.1.12Comments
NO_EXPOSURES	As Table 3.2	
EXPOSE_TIME	As Table 3.2	
GAIN_SPEED	As Table 3.2	
X_BIN_FAC	X1_SIZE % X_BIN_FAC = 0	The X bin factor is the same for both windows.
Y_BIN_FAC	Y1_SIZE % Y_BIN_FAC = 0	The Y bin factor is the same for both windows.
V_FT_CLK	As Table 3.2	
X1L_START	X1L_START≥ 1, AND X1L_START≤ 512	
X1R_START	X1R_START ≥ 513, AND X1R_START≤ 1024	
Y1_START	Y1_START ≥ 1 Y1_START ≤ 1024	Influences both Left and Right windows
X1_SIZE	X1_SIZE ≥ 1, AND X1_SIZE ≤ 513 – X1L_START, AND X1_SIZE ≤ 1025 – X1R_START	Influences both Left and Right windows
Y1_SIZE	Y1_SIZE ≥ 1 AND Y1_SIZE ≤ 1025 – Y1_START	Influences both Left and Right windows

Table 6.2: *Window Application Parameter Limits*

6.3. Application 6: *Readout Timing*

Unlike the previously described full frame applications, the window mode applications do not clear the CCD between successive readouts. In fact, the CCD is only cleared once, before the first exposure. Following this, each frame is exposed for the time specified by parameter EXPOSE_TIME, then shifted from the image area into the storage area to complete the exposure stage. It is here that the timestamp interrupt is performed marking the **end** of the current exposure and the beginning of the next exposure. The current frame is then readout of the storage area, during which time the next frame's exposure has begun. Once the readout is complete the cycle is repeated, as illustrated in Figure 6.1. Therefore, although the first frame has an exposure time equal to that specified by the parameter EXPOSE_TIME, all other frames have an exposure time equal to EXPOSE_TIME plus the time it takes to readout the previous frame T(Readout), as stated in Equation 6.1. Consequently, the first frame should be ignored in any observing run sequence.

$$\text{Exposure Time} = \text{EXPOSE\_TIME} + T(\text{Readout}) \qquad \textbf{(6.1)}$$

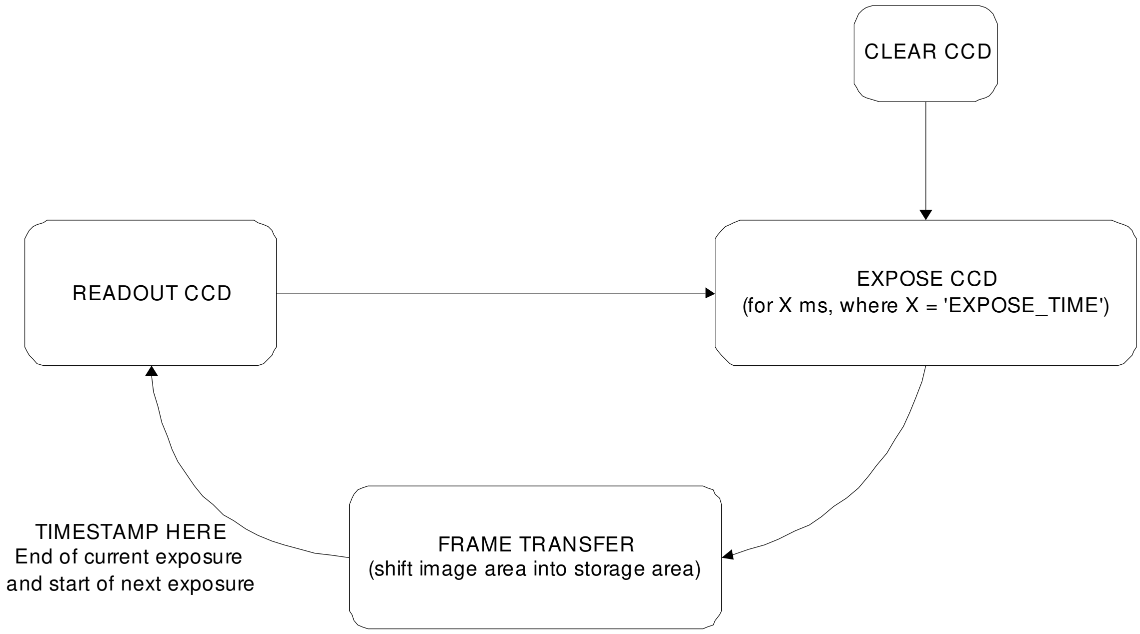

Figure 6.1: Window Mode Readout Sequence

7. Application 6: *WINDOW READOUT – 2PAIR*

7.1. Application 6: *Description*

This Application is similar to Application 6, except four windows are specified. Again windows should be though of in pairs, therefore, 2 window pairs are defined. A window pair must have one window in the left half of the chip (X = 1 to 512) and the other window in the right half of the chip (x = 513 – 1024), the same starting position in the Y-axis, and the same X and Y dimensions. Windows cannot overlap in Y.

7.2. Application 6: *Parameters*

The available parameters for this application are described in Table 7.1.

0.0.0.0.1.13Parameter	**0.0.0.0.1.14Description**	**0.0.0.0.1.15Default**
NO_EXPOSURES	The number of exposures taken each time the application is executed	1
EXPOSE_TIME	The frame exposure time in milliseconds	1000 (1s)
GAIN_SPEED	The gain and readout speed setting see Table 3.2 for various options	$CDD
X_BIN_FAC	X binning factor. Bins the number of columns.	1
Y_BIN_FAC	Y binning factor. Bins the number of rows.	1
V_FT_CLK	Frame Transfer V Clock timing parameter (described in Appendix A)	$990000
X1L_START	The x-axis starting position of window 1 Left.	100
X1R_START	The x-axis starting position of window 1 Right.	600
Y1_START	The y-axis starting position of window pair 1	200
X1_SIZE	The size in x-axis of window pair 1	120
Y1_SIZE	The size in y-axis of window pair 1	120
X2L_START	The x-axis starting position of window 2 Left.	200
X2R_START	The x-axis starting position of window 2 Right.	700
Y2_START	The y-axis starting position of window pair 2	600
X2_SIZE	The size in x-axis of window pair 2	120
Y2_SIZE	The size in y-axis of window pair 2	120

Table 7.1: *Window Application (2 Pairs) Parameters*

The limits for this application's parameters are described in Table 7.2.

0.0.0.0.1.16Parameter	**0.0.0.0.1.17Limits**	**0.0.0.0.1.18Comments**
NO_EXPOSURES	As Table 3.2	
EXPOSE_TIME	As Table 3.2	
GAIN_SPEED	As Table 3.2	
X_BIN_FAC	X1_SIZE % X_BIN_FAC = 0 AND X2_SIZE % X_BIN_FAC = 0	The X bin factor is the same for all the windows.
Y_BIN_FAC	Y1_SIZE % Y_BIN_FAC = 0 AND Y2_SIZE % Y_BIN_FAC = 0	The Y bin factor is the same for all windows.
0.0.0.0.1.19V_FT_CLK	As Table 3.2	
X1L_START	X1L_START≥ 1, AND X1L_START≤ 512	
X1R_START	X1R_START ≥ 513, AND X1R_START≤ 1024	
Y1_START	Y1_START ≥ 1 Y1_START ≤ 1024	Influences both Left and Right windows
X1_SIZE	X1_SIZE ≥ 1, AND X1_SIZE ≤ 513 – X1L_START, AND X1_SIZE ≤ 1025 – X1R_START	Influences both Left and Right windows
Y1_SIZE	Y1_SIZE ≥ 1 AND Y1_SIZE ≤ 1025 – Y1_START	Influences both Left and Right windows
X2L_START	X2L_START≥ 1, AND X2L_START≤ 512	
X2R_START	X2R_START ≥ 513, AND X2R_START≤ 1024	
Y2_START	Y2_START ≥ Y1_START+Y1_SIZE, AND Y2_START ≤ 1024	Influences both Left and Right windows
X2_SIZE	X2_SIZE ≥ 1, AND X2_SIZE ≤ 513 – X2L_START X2_SIZE ≤ 1025 – X2R_START	Influences both Left and Right windows
Y2_SIZE	Y2_SIZE ≥ 1 AND Y2_SIZE ≤ 1025 – Y2_START	Influences both Left and Right windows

Table 7.2: *Window Application (2 Pairs) Parameter Limits*

7.3. Application 6: *Readout Timing*

This follows the same model as Application 5 (see Section 6.1) except a frame now consists of four windows.

8. Application 7: *WINDOW READOUT – 3PAIR*

8.1. Application 7: *Description*

This Application can be used to read out 6 windows per frame. As before, windows should be though of in pairs, therefore, three window pairs are defined here. A window pair must have one window in the left half of the chip (X = 1 to 512) and the other window in the right half of the chip (x = 513 – 1024), the same starting position in the Y-axis, and the same X and Y dimensions. Windows cannot overlap in Y.

8.2. Application 7: *Parameters*

The available parameters for this application are described in Table 8.1.

0.0.0.0.1.20Parameter	0.0.0.0.1.21Description	0.0.0.0.1.22Default
NO_EXPOSURES	The number of exposures taken each time the application is executed	1
EXPOSE_TIME	The frame exposure time in milliseconds	1000 (1s)
GAIN_SPEED	The gain and readout speed setting see Table 3.2 for various options	$CDD
X_BIN_FAC	X binning factor. Bins the number of columns.	1
Y_BIN_FAC	Y binning factor. Bins the number of rows.	1
V_FT_CLK	Frame Transfer V Clock timing parameter (described in Appendix A)	$990000
X1L_START	The x-axis starting position of window 1 Left.	290
X1R_START	The x-axis starting position of window 1 Right.	750
Y1_START	The y-axis starting position of window pair 1	150
X1_SIZE	The size in x-axis of window pair 1	80
Y1_SIZE	The size in y-axis of window pair 1	80
X2L_START	The x-axis starting position of window 2 Left.	270
X2R_START	The x-axis starting position of window 2 Right.	730
Y2_START	The y-axis starting position of window pair 2	540
X2_SIZE	The size in x-axis of window pair 2	80
Y2_SIZE	The size in y-axis of window pair 2	80
X3L_START	The x-axis starting position of window 3 Left.	4
X3R_START	The x-axis starting position of window 3 Right.	750
Y3_START	The y-axis starting position of window pair 3	675
X3_SIZE	The size in x-axis of window pair 3	80
Y3_SIZE	The size in y-axis of window pair 3	80

Table 8.1: *Window Application (3 Pairs) Parameters*

The limits for this application's parameters are described in Table 8.2.

0.0.0.0.1.23Parameter	0.0.0.0.1.24Limits	0.0.0.0.1.25Comments
NO_EXPOSURES	As Table 3.2	
EXPOSE_TIME	As Table 3.2	
GAIN_SPEED	As Table 3.2	
X_BIN_FAC	X1_SIZE % X_BIN_FAC = 0, AND X2_SIZE % X_BIN_FAC = 0, AND X3_SIZE % X_BIN_FAC = 0, AND	The X bin factor is the same for all the windows.
Y_BIN_FAC	Y1_SIZE % Y_BIN_FAC = 0, and Y2_SIZE % Y_BIN_FAC = 0, and Y3_SIZE % Y_BIN_FAC = 0, and	The Y bin factor is the same for all the windows
0.0.0.0.1.26V_FT_CLK	As Table 3.2	
X1L_START	X1L_START≥ 1, AND X1L_START≤ 512	
X1R_START	X1R_START ≥ 513, AND X1R_START≤ 1024	
Y1_START	Y1_START ≥ 1 Y1_START ≤ 1024	Influences both Left and Right windows
X1_SIZE	X1_SIZE ≥ 1, AND X1_SIZE ≤ 513 – X1L_START, AND X1_SIZE ≤ 1025 – X1R_START	Influences both Left and Right windows
Y1_SIZE	Y1_SIZE ≥ 1 AND Y1_SIZE ≤ 1025 – Y1_START	Influences both Left and Right windows
X2L_START	X2L_START≥ 1, AND X2L_START≤ 512	
X2R_START	X2R_START ≥ 513, AND X2R_START≤ 1024	
Y2_START	Y2_START ≥ Y1_START+Y1_SIZE, AND Y2_START ≤ 1024	Influences both Left and Right windows

X2_SIZE	X2_SIZE ≥ 1, AND X2_SIZE ≤ 513 – X2L_START X2_SIZE ≤ 1025 – X2R_START	Influences both Left and Right windows
Y2_SIZE	Y2_SIZE ≥ 1 AND Y2_SIZE ≤ 1025 – Y2_START	Influences both Left and Right windows
X3L_START	X3L_START≥ 1, AND X3L_START≤ 512	
X3R_START	X3R_START ≥ 513, AND X3R_START ≤ 1024	
Y3_START	Y3_START ≥ Y2_START+Y2_SIZE, AND Y3_START ≤ 1024	Influences both Left and Right windows
X3_SIZE	X3_SIZE ≥ 1, AND X3_SIZE ≤ 513 – X3L_START X3_SIZE ≤ 1025 – X3R_START	Influences both Left and Right windows
Y3_SIZE	Y3_SIZE ≥ 1 AND Y3_SIZE ≤ 1025 – Y3_START	Influences both Left and Right windows

Table 8.2: *Window Application (3 Pairs) Parameter Limits*

8.3. Application 7: *Readout Timing*

This follows the same model as Application 5 (see Section 6.1) except a frame now consists of four windows.

9. Application 8: *Drift-scan Mode*

9.1. Application 8: *Description*

Driftscan mode is used for high-speed readout operation. It continuously reads out two similar windows with the same Y_START position, one from each half of the chip. The CCD storage area is used to pipeline a stack of exposed windows before they are readout, thereby minimising the readout 'dead-time'. Typically, a window pair is exposed then quickly shifted from the CCD's image area into the top of its storage area for the next exposure to begin. Consequently, for optimum temporal performance the window pair should be located as close to the image/storage area boundary as possible (i.e. have a small Y1_START parameter). During a given exposure the window pair at the end of the storage area pipeline is readout. On reading out a window pair all the windows in the storage area are shifted down the chip by the number of rows in a window (Y1_SIZE). Consequently, when the next window pair is shifted into storage area it will have Y1_SIZE rows between it and the previous window pair. The number of window pairs (NO_WINS) permitted in the pipeline is dependant on the size of the window and the size of the storage area. . Unfortunately, the CCD47-20 has 1033 rows in its storage area, which means an exact number of windows (and separations) cannot be stacked in the pipeline (since 1033 is a prime number). To overcome this extra shifts are required once the pipeline is full to shunt the stack of window pairs to the bottom of the storage area. For a given window size (Y1_SIZE), the number of window pairs that can be stacked in the pipeline is calculated from Equation 9.1.

$$NO\_WINS = floor\left(\frac{\frac{1033}{Y1\_SIZE} - 1}{2}\right), \qquad \textbf{(9.1)}$$

(Floor returns the nearest integer value below the calculated real number.)

Therefore, the extra number of required shifts (once the pipeline is full) is given by:

$$Pipe\_Shift = 1033 - \left[\left(2 \times NO\_WINS\right) + 1\right] \times Y1\_SIZE \qquad \textbf{(9.2)}$$

This additional number of shifts is performed before every Nth window readout, where N = NO_WINS.

9.3. Application 8: *Parameters*

The parameters used by this application are detailed in Table 9.1.

0.0.0.0.1.27Parameter	0.0.0.0.1.28Description	0.0.0.0.1.29Default
NO_EXPOSURES	The number of exposures taken each time the application is executed	1
EXPOSE_TIME	The frame exposure time in milliseconds	1000 (1s)
GAIN_SPEED	The gain and readout speed setting see Table 3.2 for various options	$CDD
X_BIN_FAC	X binning factor. Bins the number of columns.	1
Y_BIN_FAC	Y binning factor. Bins the number of rows.	1
V_FT_CLK	Frame Transfer V Clock timing parameter (described in Appendix A)	$990000
X1L_START	The x-axis starting position of window 1 Left.	100
X1R_START	The x-axis starting position of window 1 Right.	600
Y1_START	The y-axis starting position of window pair 1	1
X1_SIZE	The size in x-axis of window pair 1	49
Y1_SIZE	The size in y-axis of window pair 1	49

Table 9.1: *Window Application (1 Pair) Parameters*

As before, each parameter has limits on it and the camera object will generate an error when the user inputs an invalid value. The limits for this application's parameters are described in Table 9.2.

0.0.0.0.1.30Parameter	**0.0.0.0.1.31Limits**	**0.0.0.0.1.32Comments**
NO_EXPOSURES	As Table 3.2	
EXPOSE_TIME	As Table 3.2	
GAIN_SPEED	As Table 3.2	
X_BIN_FAC	X1_SIZE % X_BIN_FAC = 0	The X bin factor is the same for both windows.
Y_BIN_FAC	Y1_SIZE % Y_BIN_FAC = 0	The Y bin factor is the same for both windows.
V_FT_CLK	As Table 3.2	
X1L_START	X1L_START≥ 1, AND X1L_START≤ 512	Left Hand of Chip
X1R_START	X1R_START ≥ 513, AND X1R_START≤ 1024	Right Hand of Chip
	Y1_START ≥ 1 Y1_START ≤ 1024	Influences both Left and Right windows
X1_SIZE	X1_SIZE ≥ 1, AND X1_SIZE ≤ 513 – X1L_START, AND X1_SIZE ≤ 1025 – X1R_START	
Y1_SIZE	Y1_SIZE ≥ 1 AND Y1_SIZE ≤ 1025 – Y1_START	**See Table 9.3 for optimum values. Recommended values are 24, 49, 54, 79 114, and 147**

Table 9.2: *Window Application Parameter Limits*

9.3. Application 8: *Driftscan mode example detailing readout sequence*

Consider a window pair with 160 rows each (Y1_SIZE=160). This is a rather large window for Driftscan mode but is used here for example purposes. From Equation 9.1 the number of permitted window pairs in the pipeline is:

NO_WINS = floor (3.73) = 3

Consequently, from Equation 9.2 the Pipe-shift required before every N^{th} readout is:

Pipe_shift = 233

Therefore, an extra 233 Vertical clocks are required on the storage area before every 3^{rd} window is readout. This is pictorially illustrated in Figure 9.1. Step one shows an exposure being taken on window pair 1. After a specified exposure time (specified by parameter EXPOSE_TIME) the window pair is shifted into the top of the storage area. This is only shown as one step here, however it is actually done in two stages: firstly the window pair is shifted to the bottom of the image area using the Image V clocks only, then the window pair is shifted into the storage area using the Storage and Image V clocks. Consequently, everything in the storage area is shifted downwards by the number of rows in the window (160 for this case). As soon as window pair 1 has been shifted into the Storage area the exposure begins on window pair 2. It is at this stage that window pair 1 is time-stamped. While the exposure on window pair 2 is taking place, the window pair at the end of the pipeline is readout. At this stage the end of the pipeline does not contain any real image data, and step 3 of Figure 1 illustrates this with 'garbage' window pair A being readout. This cycle continues until the pipeline is full, i.e. step 8 of Figure 1, at this point the pipeline needs to be shifted (in this case 233 times) to get window pair 1 to the bottom of the Storage area ready for readout. Window pair 1 is then readout while exposing window pair 4, and the cycle continues.

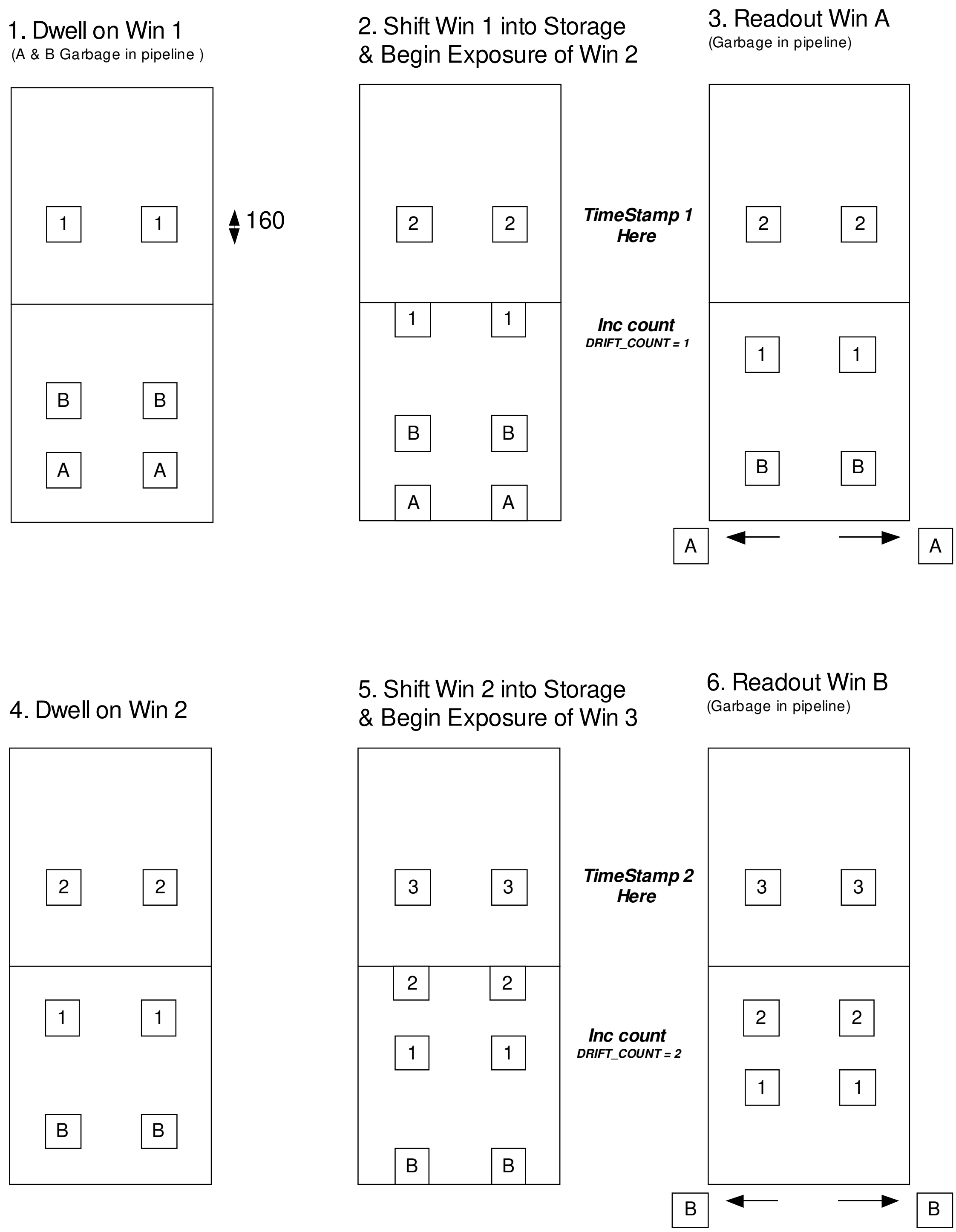

Figure 1: *Driftscan Readout with 3 windows in Pipeline*

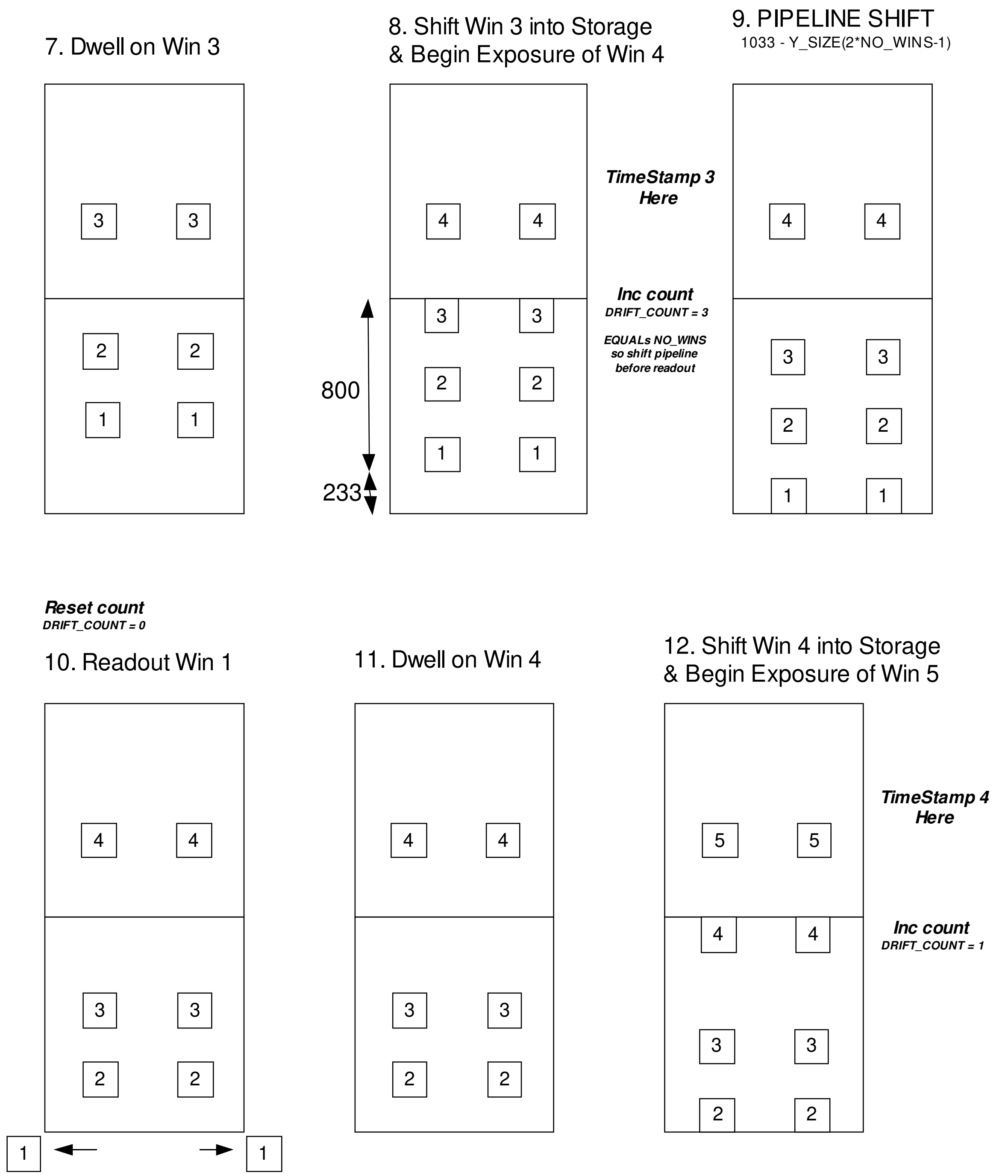

Figure 1 (cont.): *Driftscan Readout with 3 windows in Pipeline*

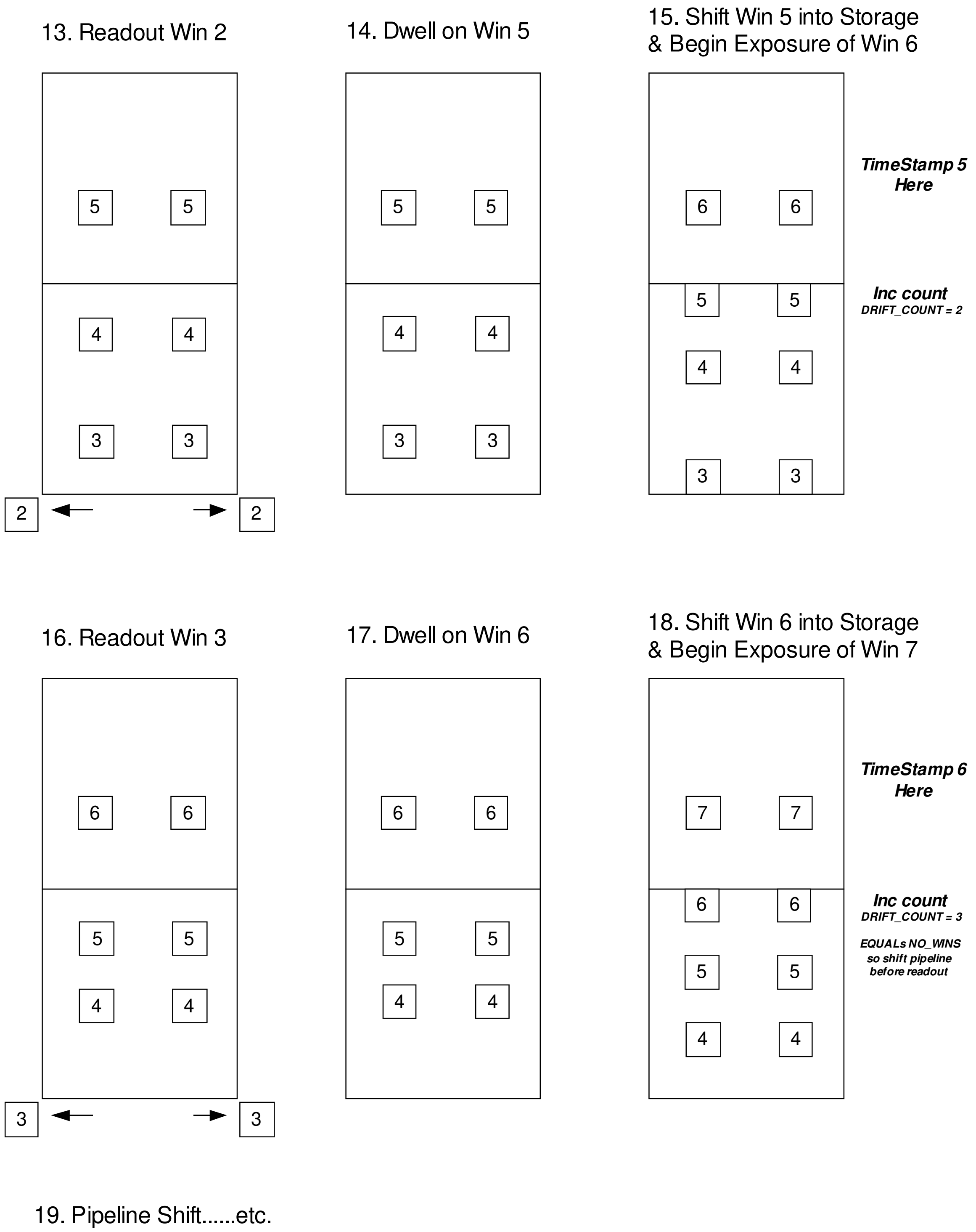

Figure 9.1 (cont.): *Driftscan Readout with 3 windows in Pipeline*

It can be seen from this example that at the beginning of any run the first few window pairs will contain garbage. The number of garbage windows, NWIN(Garbage), is equal to the number of windows that can be stacked in the pipeline, N_WINS, minus one, as stated in Equation 9.3. Solving Equation 9.3 for the above example yields NWINS(Garbage) = 2, which were represented by window pairs A and B. Note that NWINS(garbage) also provides the offset between the timestamp and the associated window. For example window pair 1 is readout just after timestamp 3 is generated.

$$\begin{aligned} \text{NWINS(Garbage)} &= \text{N\_WINS} - 1 \\ &= \text{Timestamp Offset} \end{aligned} \quad \textbf{(9.3)}$$

9.3. Application 8: *Optimisation of windows*

In the previous example an extra 233 V clocks were required before every third readout. This represents a significant overhead, for example, with V clocks of 24us this extra shift would take 5.6ms, thereby crippling the fastest readout speeds. Moreover, this additional delay will add to the exposure time of the window in the image area during the shift time, and so every third window would have a 5.6ms extended exposure time. Ideally, this number should be zero, however this could only be the case if an exact number of windows (and separations) could be stacked in the storage area, which is impossible for this CCD size. A plot of window size versus required shift is provided in Figure 9.2 revealing that careful choice of window size will minimise the amount of extra shifts required. The minima of the plot are presented in Table 9.1.

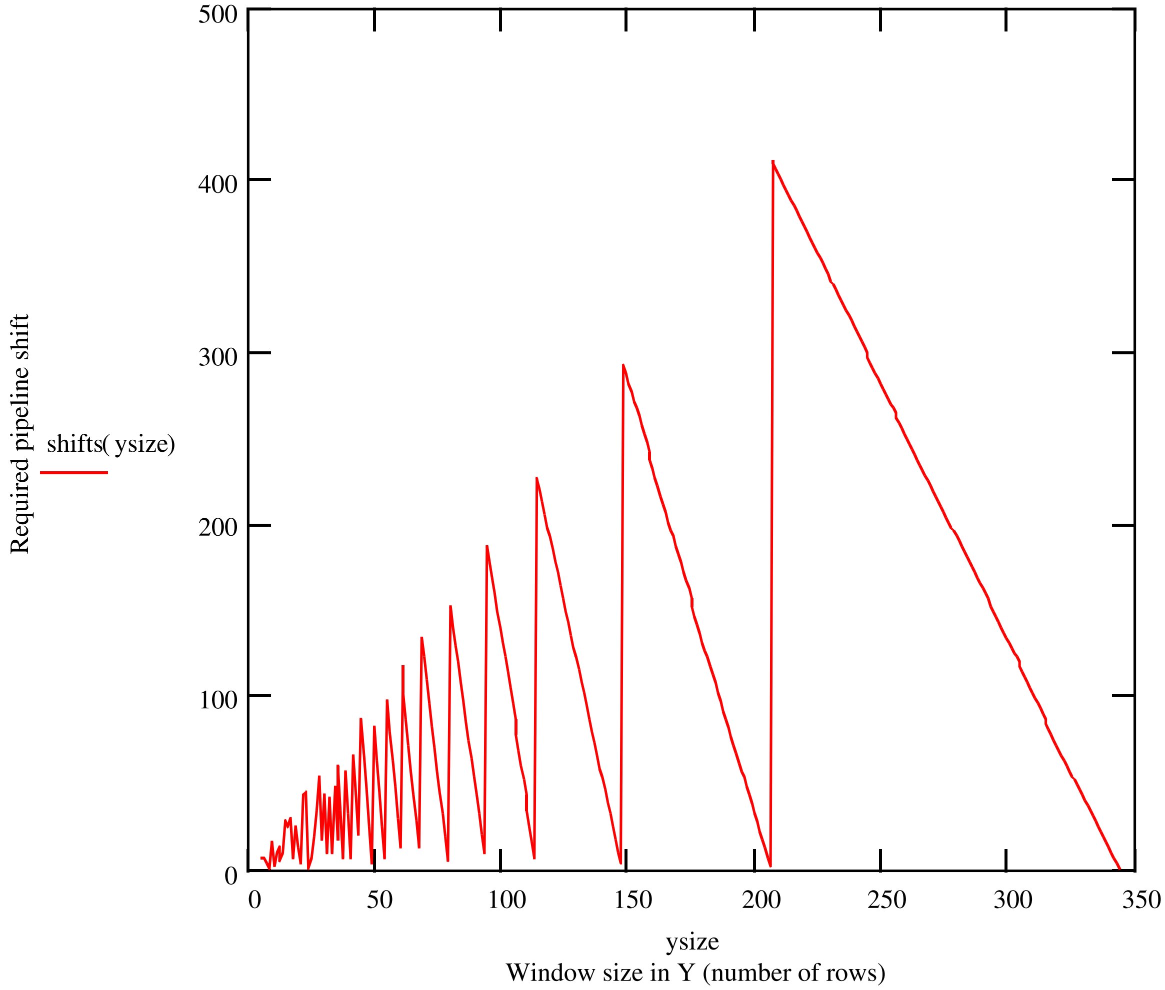

Figure 9.2: *Pipeline shifts vs. window Y1_SIZE*

Y1_SIZE	N_WINS (N)	Pipe_Shift (before Nth readout
8	65	1
10	52	3
13	40	6
18	29	7
21	25	4
24	**22**	**1**
31	17	10
38	14	7
41	13	8
49	**11**	**4**
54	**10**	**7**
60	9	13
68	8	13
79	**7**	**6**
93	6	10
114	**5**	**7**
147	**4**	**4**
206	3	3
344	2	1

Table 9.1: *Minimum Pipe Shifts*

Consequently, for minimum extra shift times these minima values should be selected for the Y1_SIZE parameter. It is recommended that that the following six window values be used: **24, 49, 54, 79 114, and 147**, providing a reasonable range of window size options, and a maximum pipe shift time of 168us (with the current V clock rate of 24us/pix). Consequently, the maximum increase in exposure time every Nth window would be approximately 1.6% at a 100Hz readout rate. However, for faster readout speeds even this small delay could become significant yielding an erroneous signal in the power spectrum of the measured light curve. In order to overcome this, an additional delay equal to the shift time will be added to all other exposures, resulting in all frames having an equal exposure time. The readout sequence diagram detailed in Figure 9.3 illustrates this. Consequently, all frames have an exposure time equal to that specified (in ms) by the parameter EXPOSE_TIME, plus the time it takes to readout a window pair T(Readout), plus the shunt pipeline delay T(Pipe_Shunt), as stated in Equation 9.4.

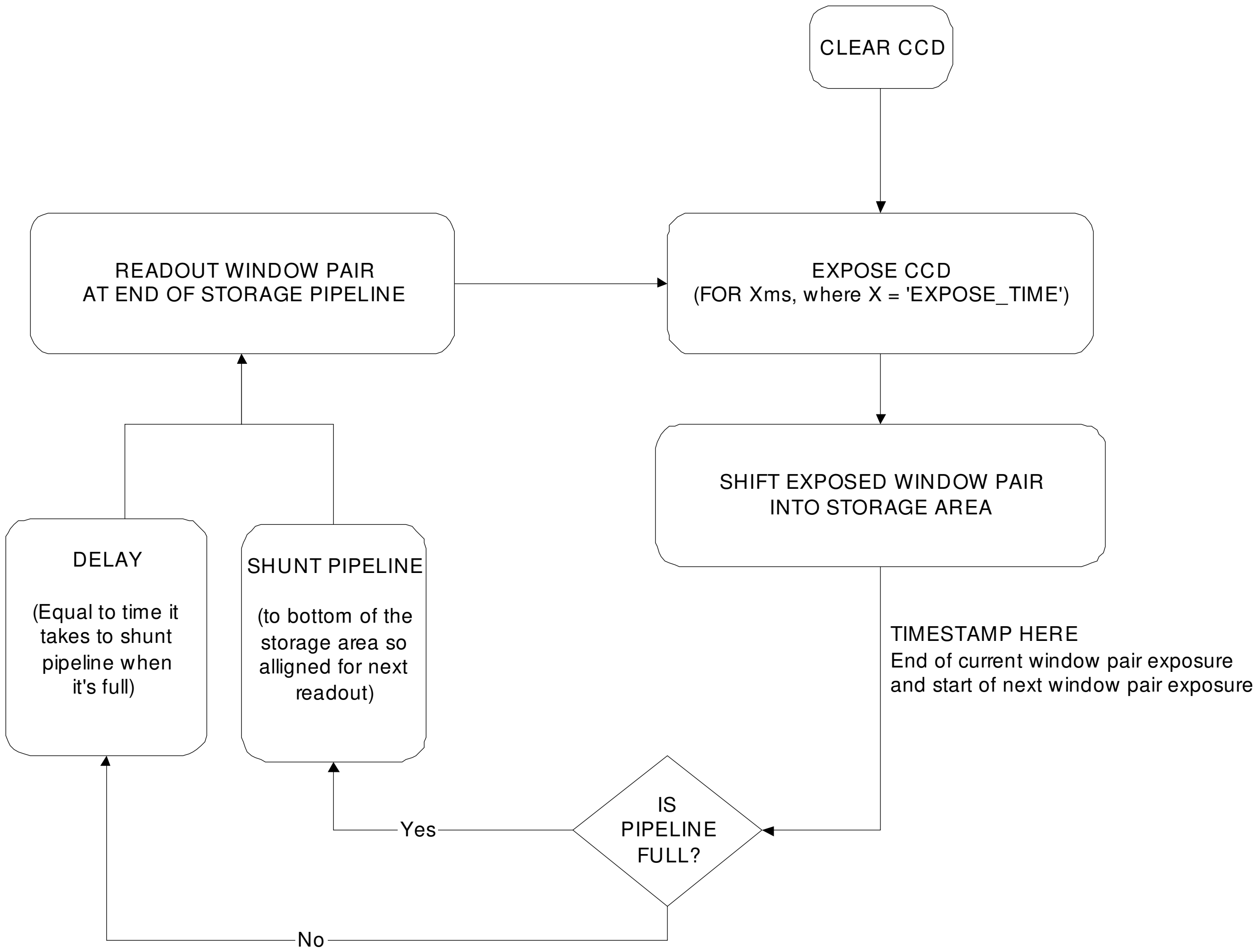

Figure 9.3: *Driftscan mode Readout Sequence*

Exposure Time = EXPOSE_TIME + T(Readout) + T(Pipe_Shunt) **(9.4)**

Where, T(Pipe_Shunt) = Pipe_Shift * T(V_Clock).

= Pipe_Shift * 24us.

Pipe_Shift is calculated from Equation 9.2, and the minima are listed in Table 9.2.

Note on window location in Y-axis

Recall that for optimum readout speeds the window pair location should be chosen to be as close the bottom of the image area as possible so that it can be quickly shifted into the storage area.

10. Application 9: *Full Frame with Minimum Dead-time*

10.1. Application 9: *Description*

As with Application 3, this mode reads out the entire CCD without overscan (1024 pixels x 1024 pixels). However, in this mode the CCD is only cleared once at the beginning of the run. Consequently, it follows a similar timing model to Applications 5, 6, and 7 (window modes), as illustrated in Figure 6.1. Essentially, this results in a full frame readout mode with minimum 'dead-time' since the chip is integrating on the next frame while reading out the current frame. However, it does limit the minimum total exposure time to that of a full frame readout.

10.2. Application 9: *Parameters*

The parameters are the same as those for Application 3 as described in Section 4. re are five parameters for application 3, as described in Table 4.1 below.

10.3. Application 9: *Readout Timing*

As with the window readout modes the total exposure time includes the time it takes to readout the previous frame. Consequently, the readout time is given by Equation 10.1. Note that the frame transfer time is ignored since is negligible compared with T(Readout) for full frame.

$$\text{Exposure Time} = \text{EXPOSE\_TIME} + T(\text{Readout}) \qquad \textbf{(10.1)}$$

Appendix A: *Frame Transfer V Clock Parameter*

The 24-bit parameter 'V_FT_CLK' is used to set a delay, which determines the period of the Vertical Clocks used to perform a frame transfer (FT). The period of the FT clocks is exactly 6 times the delay specified by V_FT_CLK.

The value of this delay is calculated from the most significant byte of the parameter and is equal to:

Delay = 80ns + (fine/course adjustment) x multiplier

Where the most significant bit (bit 23) determines the fine/course adjustment and bits 16-22 give the multiplier.

If bit 23 = 0, then the fine/course adjust is 20ns.
If bit 23 = 1, then the fine/course adjust is 160ns.

Note that the two least two significant bytes (bits 0 to 15) of V_FT_CLK must both be $00.

Some example parameter values and equivalent delays and clock periods are provided in Table A.1.

V_FT_CLK	Delay	FT V Clock Period
$260000	80ns+20ns*38 = 840ns	5.0µs
$360000	80ns+20ns*54 = 1160ns	7.0µs
$4F0000	80ns+20ns*79 = 1680ns	10.0µs
$790000	80ns+20ns*121 = 2500ns	15.0µs
$990000	80ns+160ns*25 = 4080ns	24.5µs
$800000	NOT PERMITTED	NOT PERMITTED

Table A.1: *Example values of V_FT_CLK*