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## KAI-1003 Image Sensor Evaluation Timing Specification

### EVAl BOARD USER'S MANUAL

#### Altera Code Version Description

The Altera code (Firmware Version 1.1) described in this document is intended for use in the AD9945 Timing Board. The code is developed specifically for use with the following system configuration:

**Table 1. SYSTEM CONFIGURATION**

Evaluation Board Kit	PN 4Hxxxx
Timing Generator Board	3F5592 (AD9945 20 MHz)
KAI-1003 Imager Board	3E8214
Framegrabber Board	National Instruments PCI-1424

The 3F5592 Timing Generator Board features the KSC-1000 Timing Generator chip. The KSC-1000 provides all of the signals necessary for an imaging system using Full Frame (KAF) or Interline (KAI) family of image

sensors. It also provides the signals necessary for operation of 2 Analog Front-End (AFE) chips, enabling independent optimization of the AFE chips for dual channel readout devices.

#### ALTERA CODE FEATURES/FUNCTIONS

The Altera Programmable Logic Device (PLD) serves as a state machine, which performs a variety of functions. Three basic functions are required, common to all CCD image sensor configurations: serial input steering, AFE default programming, and KSC-1000 default programming. In addition, certain other functions specific to the KAI-1003 Image Sensor is implemented.

#### Serial Input Steering

The 3-wire serial interface enters the Timing Board through the DIO Interface connector, and is routed to the

PLD. The Altera PLD decodes the addressing of the serial input, and steers the datastream to the correct device. The serial input must be formatted so that the Altera PLD can correctly decode and steer the data to the correct device.

The serial interface can be used to dynamically change the operating conditions of the AFE or KSC-1000 chips by reprogramming the appropriate registers. Reprogramming these registers through the serial interface will have no effect on the default settings that are automatically programmed into these devices on power-up or board reset.

**Table 2. SERIAL INPUT DEVICE SELECT**

Device Select DS[2..0]	Serial Device
000	PLD
001	AFE1
010	AFE2
011	KSC-1000
100	(Not Used)
101	(Not Used)
110	(Not Used)
111	(Not Used)

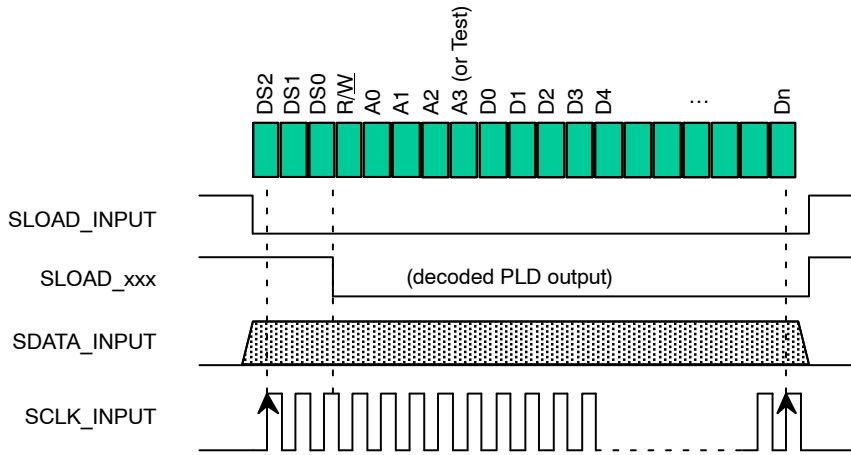


Figure 1. Serial Input Timing

The first 3 bits in the datastream are the Device Select bits DS[2..0], sent MSB first, as shown in Figure 1. The Device Select bits are decoded as shown in Table 2.

The next bit in the datastream is the Read/Write bit (R/W). Only writing is supported; therefore this bit is always LOW.

The definition of next four bits in the datastream depends on the device being addressed with the Device Select bits. For the KSC-1000 device, they are Register address bits A[0..3], LSB first. For the AD9945 AFE, they are Register Address bits A[0..2], LSB first, followed by a Test bit which is always set LOW.

The remaining bits in the bitstream are Data bits, LSB first, with as many bits as are required to fill the appropriate register.

**AFE Default Initialization**

Upon power up, or when the BOARD\_RESET button is pressed, the PLD programs the registers of the two AFE chips on the Timing Generator Board to their default settings via the 3-wire serial interface. See Table 9 for details. The AD9945 AFE must be reprogrammed on power-up, as it does not retain register settings when power is removed.

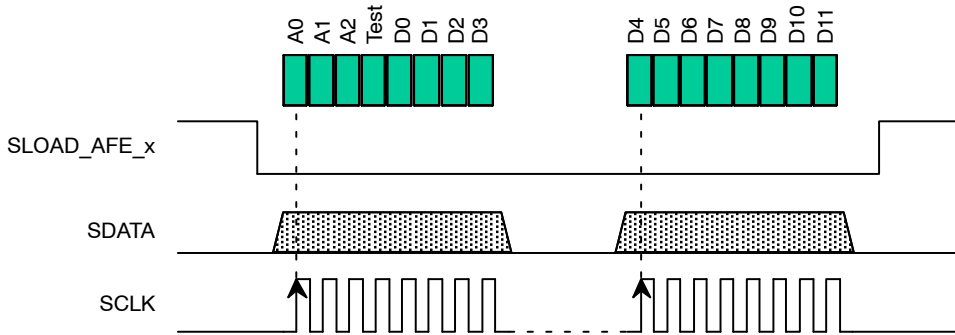


Figure 2. AFE Initialization Timing

The data for each AFE register is formatted into two bytes of data, as shown in Figure 2. The Test bit is always low, and the Address bits specify the register being programmed, as shown in Table 9. Each byte is read into an 8-bit shift register, and is shifted out as a serial stream of eight bits. Each register in the AFE is programmed in this fashion until the entire AFE is programmed.

**KSC-1000 Default Initialization**

Upon power-up, or when the BOARD\_RESET button is pressed, the Altera PLD programs the registers of the KSC-1000 chip on the AFE Timing Generator Board to their default settings via the 3-wire serial interface. The default settings are selected by the user through the PLD

inputs SW[4..1] and DIO[15..0] (See Table 10 through Table 25 for details). The KSC-1000 must be reprogrammed on power-up, as it does not retain register settings when power is removed.

The KSC-1000 default settings automatically programmed by the PLD allow the Evaluation Board Kit user to operate the CCD image sensor with minimal intervention and no programming. The default settings are chosen to comply with the appropriate CCD device specifications (See [References](#)). The registers, line tables and frame tables described in this document also serve as examples for those who wish to create their own KSC-1000 timing.

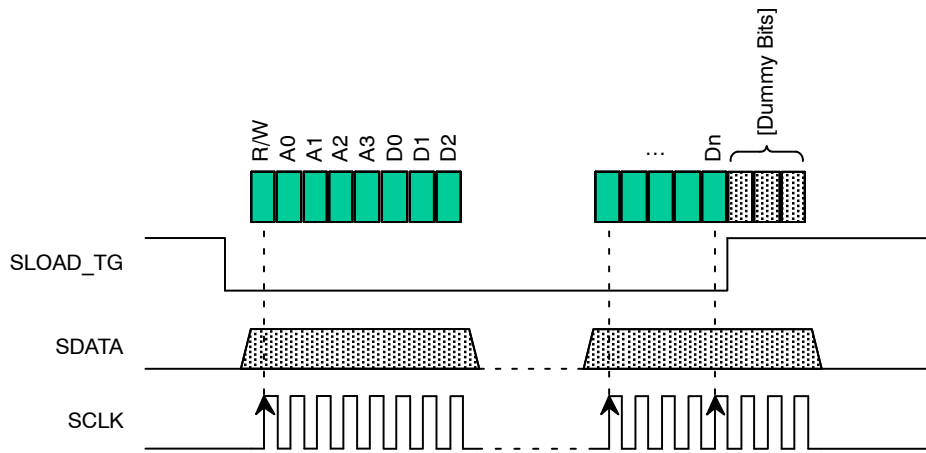


Figure 3. KSC-1000 Initialization Timing

The data for each KSC-1000 register is formatted into bytes of data, as shown in Figure 3. The Read/Write bit is always low, and the Address bits specify the register being programmed, as shown in Table 3. Each byte is read into an 8-bit shift register, and is shifted out of the PLD as a serial stream of eight bits. The last byte of data sent to a particular

register may need to be padded with extra “dummy” bits; the SLOAD\_TG signal is brought HIGH at the appropriate time so that the correct number of bits are streamed into each register, and the extra bits are ignored. Each register in the KSC-1000 is programmed in this fashion until the entire device is programmed.

Table 3. KSC-1000 REGISTERS

Register Address	Register Description	Data Bits
0	Frame Table Pointer	3
1	General Setup	202
2	General Control	2
3	INTG_STRT Setup	30
4	INTG_STRT Line	13
5	Signal Polarity	25
6	Offset	78
7	Width	65
8	Frame Table Access	(Variable)
9	Line Table Access	(Variable)

**PLD State Machine**

The Altera PLD contains a State Machine that parallels the operation of the KSC-1000. The PLD controls the KSC-1000 through the VD\_TG output, and monitors several of the KSC-1000 outputs, enabling it to track and control the operation of the Timing Generator.

**Remote Board Reset**

The DIO14 input is used as a remote Board Reset control line. The Altera PLD monitors this input, and when DIO14 goes HIGH, the ARSTZ (active low) output to the KSC-1000 is asserted, disabling and clearing the timing generator. When DIO14 goes LOW, the ARSTZ output is de-asserted, and the Power-up/Board Reset initialization sequence is executed. This allows programmable control of

the timing sequences to change the Electronic Shutter position, for example.

**Integration Clock**

The Altera PLD uses the System Clock and an internal counter to generate a 1.0 ms-period clock. This clock is used to generate an internal delay after power-up or Board Reset. It may also be used to control precise integration times for the image sensor.

**Output Channel Control**

PLD input SW1 is used to select one of the supported operation modes: Full Field Single Output, or Interlaced Dual Output. When making a change to the switch settings, the user must initiate a Board Reset for the change to take

effect, either by pressing the BOARD\_RESET button (S1) on the Timing Board, or by setting and resetting the Remote Reset (DIO14) input.

**Integration & Electronic Shutter Control**

The PLD inputs DIO[11..7] may be used to select the integration time. See Table 14 for timing details for each operating mode. In general, when making a change to the DIO[11..7] settings, the user must initiate a Board Reset for the change to take effect, either by pressing the BOARD\_RESET button (S1) on the Timing Board, or by setting and resetting the Remote Reset (DIO14) input.

**Binning Control**

PLD input SW3 is used to select between 2x2 Binning Single Output, and normal operation (no binning). When making a change to the switch settings, the user must initiate a Board Reset for the change to take effect, either by pressing the BOARD\_RESET button (S1) on the Timing Board, or by setting and resetting the Remote Reset (DIO14) input.

Dual channel output with binning is not supported in the board firmware. Therefore, if both SW1 and SW3 are high, the result will be single channel binning mode (i.e. binning will override 2 channel mode).

**ALTERA CODE I/O**

**Inputs**

The Altera PLD has multiple inputs that may be used to control certain functions. The inputs include: user selectable switches SW[4..1] on the Timing Board; remote digital inputs DIO[15..0] and a 3-wire serial interface through Timing Board connector TP6; Timing Board signals;

and various outputs from the KSC-1000 Timing Generator. The KSC-1000 outputs are monitored by the PLD to control auxiliary timing functions, and keep the KSC-1000 and Altera PLD synchronized. The remote digital inputs DIO[15..0] are optional, and are not required for KAI-1003 operation, but may be used to control integration time.

**Table 4. ALTERA INPUTS**

Symbol	Location	Description
BOARD_RESET	S1 (Board Reset)	The Rising Edge of this Signal Clears and Re-initializes the PLD
SYSTEM_CLK	U5	40 MHz Clock, 2X the Desired Pixel Clock Rate
PIXCLK_TG	-	20 MHz Pixel Rate Clock from the KSC1000TG (Not Used)
JMP1	S2-1	HIGH = Dual Output; LOW = Single Output, Full Image
JMP2	S2-2	(Not Used for KAI-1003 Operation)
JMP3	S2-3	Binning Mode: HIGH = 2 x 2 Binning, Single Output; LOW = No Binning
JMP4	S2-4	(Not Used for KAI-1003 Operation)
DIO[6..0]	J3	(Not Used for KAI-1003 Operation)
DIO[11..7]	J3	Integration Control See Table 14
DIO[13..12]	J3	(Not Used for KAI-1003 Operation)
DIO14	J3	Remote Board Reset (HIGH activates ARSTZ; Falling Edge Activates BOARD_RESET)
DIO15	J3	(Not Used for KAI-1003 Operation)
SLOAD_INPUT	TP6-2	3-wire Serial Interface LOAD Signal Input
SCLOCK_INPUT	TP6-3	3-wire Serial Interface CLOCK Signal Input
SDATA_INPUT	TP6-4	3-wire Serial Interface DATA Signal Input
EXT CLK INPUT	J11	(Not Used for KAI-1003 Operation; Not Populated)
Hx_TG	-	Pixel Rate Clock Inputs (from KSC-1000)
Vx_TG	-	Line Rate Clock Inputs (from KSC-1000)
RG_TG	-	Reset Clock Input (from KSC-1000)
SHx_TG		AFE Clamp and Sample Signal Inputs (from KSC-1000)
DATACLKx_TG	-	Data Clock Inputs (from KSC-1000)
PIXCLK_TG	P1-3	Pixel Valid Input (from KSC-1000)
LINE_VALID_TG	P1-2	Line Valid Input (from KSC-1000)
FRAME_VALID_TG	P1-1	Frame Valid Input (from KSC-1000)

**Table 4. ALTERA INPUTS** (continued)

Symbol	Location	Description
CLPDM_TG	-	Black Clamping Signal Inputs (from KSC-1000)
CLPOB_TG	-	Black Clamping Signal Inputs (from KSC-1000)
PBLK_TG	-	Pixel Blanking Signal Inputs (from KSC-1000)
AMP_EN_TG	-	Amplifier Enable Input (from KSC-1000)
INT_START_TG	-	Integration Start Signal Input (from KSC-1000)

**Outputs**

The Altera PLD outputs include: the 3-wire serial interface; control signals to and from the KSC-1000; the

INTEGRATE signal used for external monitoring and synchronization; the PLD internally generated 1 ms Integration Clock.

**Table 5. ALTERA OUTPUTS**

Symbol	Location	Description
PIX_VALID	P1-1	Used to Monitor KSC-1000 Pixel Clock
LINE_VALID	P1-2	Used to Monitor KSC-1000 Line Valid
FRAME_VALID	P1-3	Used to Monitor KSC-1000 Frame Valid
INTEGRATE_CLK	TP5	1 ms Integration Clock Output
INTEGRATE	J6	High During CCD Integration Time
VD_TG	TP7	Control Signal to KSC-1000
HD_TG	-	(Not Used for KAI-1003 Operation)
ARSTZ_TG	-	KSC-1000 Force-Reset Signal
AFE_CLK_PLD	TP13	AD9945 Analog-to-Digital Conversion Clock signal
SHPx_PLD	TP14, TP18	AD9945 CDS Sampling CCD Reference Clock Signal
SPDx_PLD	TP15, TP17	AD9945 CDS Sampling CCD Data Clock Signal
CLPDM_PLD CLPOB_PLD PBLK_PLD	-	AD9945 Clamping Control Signals
HD_AFE_x, VD_AFE_x	-	(Not Used for KAI-1003 Operation)
SLOAD_TG	TP9	KSC-1000 SLOAD
SLOAD_AFE <sub>x</sub>	TP12, TP24	AD9945 AFE SLOAD
SCLOCK	TP27	3-wire Serial Interface CLOCK Signal Output
SDATA	TP28	3-wire Serial Interface DATA Signal Output
SDAT, SCLK	TP30, TP31	(Not Used for KAI-1003 Operation)
SLOAD_DAC	TP29	(Not Used for KAI-1003 Operation)
SLOAD_LED_DAC	TP11	(Not Used for KAI-1003 Operation)
IMAGER_PWR_ENA	-	(Not Used for KAI-1003 Operation)
SYSTEM_CLK_TG	-	(Not Used for KAI-1003 Operation)
PLD_OUT[19..0]	J5	Timing Signals to Imager Board
SYSTEM_CLOCK_OUT	-	(Not Used for KAI-1003 Operation)

KAI-1003 TIMING CONDITIONS

System Timing Conditions

Table 6. SYSTEM TIMING

Description	Symbol	Time	Notes
System Clock Period	$T_{sys}$	25 ns	40 MHz System Clock
Unit Integration Time	$U_{int}$	1.0 ms	Generated by PLD
Power Stable Delay	$T_{pwr}$	125 ms	Typical
Default Serial Load Time	$T_{sload}$	1.2 ms	Typical
Integration Time	$T_{int}$		Operating Mode Dependent

CCD Timing Conditions

Table 7. CCD TIMING

Description	Symbol	Time	Pixel Counts	Notes
H1, H2, RESET Period	$T_{pix}$	50.0 ns	1	20 MHz Clocking of H1, H1L, H2, RESET
VCCD Delay	$T_{Vd}$	50.0 ns	1	Delay after Hclks Stop
VCCD Transfer Time	$T_V$	2.0 $\mu$ s	40	V2 Rising Edge to V2 Falling Edge
HCCD Delay	$T_{Hd}$	1.5 $\mu$ s	30	Delay before Hclks Resume
Vertical Transfer Period	$V_{period}$	3.55 $\mu$ s	71	$V_{period} = T_{Vd} + T_V + T_{Hd}$
Horizontal Pixels	HPIX	56.0 $\mu$ s	1120	1060 CCD Pixels + 60 Overclock Pixels
Vertical Pixels	VPIX		1056	1032 CCD Lines + 21 Overclock Lines
Line Transfer Time	$T_L$	9.55 $\mu$ s	1191	$T_L = V_{period} + HPIX$
Photodiode Transfer Time	$T_{Vh}$	18 $\mu$ s	360	V2 3rd Level
Photodiode Delay	$T_{rd}$	40 $\mu$ s	800	Delay before Vclks Begin
Shutter Pulse Setup	$T_{set}$	1.5 $\mu$ s	30	Delay after Hclks and Vclks Stop
Shutter Pulse Time	$T_{es}$	7.5 $\mu$ s	150	Shutter Pulse Width
Shutter Pulse Delay	$T_{hves}$	1 $\mu$ s	20	Delay before Hclks and Vclks Resume

PCI-1424 Timing Conditions

Table 8. PCI-1424 TIMING

Description	Symbol	Time	Pixel Counts	Notes
PIX Period	$T_{PIX}$	50.0 ns	1	20 MHz Clocking of DATACLK Sync Signal
FRAME Time	$T_{FRAME}$	59.1 ms	1182791	$T_{FRAME} = T_{PIX} * ((V_{period} + HPIX) * VPIX)$

**MODES OF OPERATION**

The following modes of operation are available to the user:

**Electronic Shutter Modes**

The Evaluation Board electronic shutter circuitry provides a method of precisely controlling the image exposure time without any mechanical components. Charge may be cleared from the CCD photodiodes at some time during the readout of the previous frame. This allows integration times of less than one frame time, to compensate for high light exposures that would otherwise saturate the CCD.

The default integration time can be set from 1x to 1/8x frame time via the digital inputs DIO[11..7]. See Table 14.

When changing the integration time, the user must initiate a Board Reset for the change to take effect, either by pressing the BOARD\_RESET button (S1) on the Timing Board, or by setting and resetting the Remote Reset (DIO14) input.

**Black Clamp Mode**

One of the features of the AD9945 AFE chip is an optical black clamp. The black clamp (CLPOB) is asserted during the CCD's dark pixels and is used to remove residual offsets in the signal chain, and to track low frequency variations in the CCD's black level. The location of these pulses is fixed in the default KSC-1000 settings, but can be adjusted dynamically through the 3-wire serial interface. The default settings are shown in Table 11.

**POWER-ON/BOARD RESET INITIALIZATION**

When the board is powered up, the Board Reset button is pressed, or the Remote Rest (DIO14) is toggled, the Altera PLD is internally reset. When this occurs, state machines in the PLD will first serially load the initial default values into the AFE registers, then will load the KSC-1000 frame tables, line tables, and registers.

Upon completion, the KSC-1000 will be ready to proceed according to its programmed configuration. In the

background, the Altera PLD monitors the activity of the KSC-1000, and the 3-wire Serial Interface.

**AFE Register Default Settings**

On power-up or board reset, the AFE registers are programmed to the default levels shown in Table 9. See the AD9945 specifications ([References](#)) for details of the AFE registers.

**Table 9. DEFAULT AD9945 AFE REGISTER PROGRAMMING**

Register Address	Description	Value (decimal)	Notes
0	Operation	0	
1	Control	0	
2	Clamp	96	The Output of the AD9945 will be Clamped to Code 96 during the CLPOB Period
3	VGA Gain	20	Corresponds to a VGA Stage Gain of 6.0 dB

**KSC-1000 Timing Generator Default Settings**

On power-up or board reset, The KSC-1000 is programmed to the default settings as detailed in Table 10 through Table 25. See the KSC-1000 Device Specification [1] for details of the KSC-1000 registers.

*Register 0: Frame Table Pointer*

Register 0 contains the Frame Table Pointer, which instructs the KSC-1000 to perform the timing sequence defined in that table. Frame Table 0 is used for Single or Dual Channel readout and Frame Table 1 is used for 2x2 Binning mode. The default setting depends on the position of SW1 and SW3.

**Table 10. REGISTER 0 DEFAULT SETTING**

Register Entry	Data (Single or Dual Channel)	Data (Binning 2x2)
Frame Table Address	0	1

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### Register 1: General Setup

The default settings written to Register 1 for the KAI-1003 are the same for all 1-channel and binning

operating modes. Some values are different in 2-channel mode. The entries for Register 1 are shown in Table 11.

**Table 11. REGISTER 1 DEFAULT SETTING**

Register Entry	Single Channel /Binning Data	Dual Channel Data
Pixels Per Line[0..12]	1120	560
Line Valid Pixel Start[0..12]	9	9
Line Valid Pixel Quadrature Start[0..1]	0	0
Line Valid Pixel End[0..12]	1119	559
CLPOB1_Pix_Start[0..12]	4	4
CLPOB1_Pix_End[0..12]	14	14
CLPOB2_Pix_Start[0..12]	6	6
CLPOB2_Pix_End[0..12]	1054	527
CLPDM1_Pix_Start[0..12]	0	0
CLPDM1_Pix_End[0..12]	0	0
CLPDM2_Pix_Start[0..12]	0	0
CLPDM2_Pix_End[0..12]	0	0
PBLK_Pix_Start[0..12]	1119	559
PBLK_Pix_End[0..12]	1	1
RG_Enable	1	1
H6_Enable	0	0
H4_Enable	1	1
H5_Enable	0	0
SH2_Enable	1	1
SH4_Enable	1	1
DATACLK1_Enable	1	1
DATACLK2_Enable	1	1
PIXCLK_Enable	1	1
H3_Enable	1	1
H1_Enable	1	1
H2_Enable	1	1
SH1_Enable	1	1
SH3_Enable	1	1
H6 24 mA Output Enable	0	0
H4 24 mA Output Enable	0	0
H5 24 mA Output Enable	0	0
RG 24 mA Output Enable	0	0
SH2 24 mA Output Enable	0	0
SH4 24 mA Output Enable	0	0
DATACLK1 24 mA Output Enable	0	0
DATACLK2 24 mA Output Enable	0	0
H3 24 mA Output Enable	0	0
H1 24 mA Output Enable	0	0
H2 24 mA Output Enable	0	0
SH1 24 mA Output Enable	0	0
SH3 24 mA Output Enable	0	0
DLL Frequency Range Select	8	8



*Register 2: General Control*

Register 2 controls the Power Management and Operation state of the KSC-1000. The Low Power Mode is not used on the KAI-1003, so this bit is always LOW. The Memory Table Mode bit is used to halt execution of the KSC-1000 timing sequences and to enable programming of

the registers. The KSC-1000 Initialization sequence begins with setting the Memory Table Mode bit in Register 2 to Program Mode, and ends by setting the bit to Execution Mode. See the KSC-1000 Device Specification ([References](#)) for more details.

**Table 12. REGISTER 2 SETTINGS**

Register Entry	Program Mode	Execution Mode
Low Power Enable	0	0
Memory Table Mode	0	1

*Register 3: INTG\_START Setup*

The default settings written to Register 3 establish the setup, pulsewidth, and hold timing of the Electronic Shutter pulse. The Shutter Pulse may occur on a particular line, as

controlled by Register 4, or may be asserted by setting the “Force INTG\_STRT” bit in the Frame Table (Register 8). In either case, the Electronic Shutter Pulse occurs before the vertical clocking interval of the Frame Table entry.

**Table 13. REGISTER 3 DEFAULT SETTING**

Register Entry	Data
Electronic Shutter Setup Clocks[0..9]	30
Electronic Shutter Pulse Width[0..9]	150
Electronic Shutter Hold Clocks[0..9]	20

*Register 4: INTG\_START Line*

Short integration times may be controlled through use of the Electronic Shutter. The default setting written to Register 4 controls the line number on which the Electronic Shutter will occur. The DIO[11..7] inputs are used to control the Integration time, by selecting pre-programmed line numbers, as shown in Table 14.

The Electronic Shutter pulse occurs during the previous frame readout. The values are chosen to allow integration times adjustable in increments of one-eighth the Frame time.

If the line number is greater than the number of lines specified in a Frame Table (Register 8), the Electronic Shutter will not occur. This is the method used to turn the Shutter off. In this case, the integration time is controlled by a counter in the Altera PLD (See Table 24).

**Table 14. REGISTER 4 DEFAULT SETTING**

DIO[11..7]	Frame/Flush Integration	Single and Dual Channel Modes Integrate Start Pulse Line Number[0..12]	Binning Mode Integrate Start Pulse Line Number[0..12]
0	1	1100 (Default – No Pulse)	1100 (Default – No Pulse)
1	1/8	924	462
2	1/4	792	396
3	3/8	660	330
4	1/2	528	264
5	5/8	396	198
6	3/4	264	132
7	7/8	132	66

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### Register 5: Signal Polarity

The default settings written to Register 5 depend on the position of SW3 on the Timing Board, used to select between Single Channel/Dual Channel and Binning modes of operation.

**Table 15. REGISTER 5 DEFAULT SETTING**

Register Entry	Evaluation Board Signal Name	Single Channel	Dual Channel	Binning
H5_IDLE_VAL	(Not Used)	0	0	0
H3_IDLE_VAL	H1A	1	1	1
H4_IDLE_VAL	H2A	0	0	0
H1_IDLE_VAL	H2B	1	0	1
H6_IDLE_VAL	(Not Used)	0	0	0
H2_IDLE_VAL	H1B	0	1	0
RG_IDLE_VAL	RESET	1	1	1
SH2_IDLE_VAL	SHP1	1	1	1
SH1_IDLE_VAL	SHP2	1	1	1
SH4_IDLE_VAL	SHD1	1	1	1
SH3_IDLE_VAL	SHD2	1	1	1
DATACLK1_IDLE_VAL	ADCLK (to AFEs)	0	0	0
DATACLK2_IDLE_VAL	DATACLK (to Framegrabber)	0	0	0
CLPOB_IDLE_VAL	CLPOB	1	1	1
CLPDM_IDLE_VAL	CLPDM (Not Used for AD9945)	0	0	0
AMP_ENABLE_IDLE_VAL	AMP_ENABLE	0	0	0
FRAME_VALID_IDLE_VAL	FRAME_VALID	0	0	0
LINE_VALID_IDLE_VAL	LINE_VALID	0	0	0
INTEGRATE_START_IDLE_VAL	INTG_START/VES	0	0	0
V1_IDLE_VAL	V3RD	0	0	0
V2_IDLE_VAL	V2B (Not Used)	0	0	0
V3_IDLE_VAL	V2	0	0	0
V4_IDLE_VAL	V1	1	1	1
V5_IDLE_VAL	INT (Not Used on KAI-1003 Imager Board)	0	0	0
V6_IDLE_VAL	FDG (Not Used)	0	0	0

### Register 6: Pixel-Rate Signal Offset

The default settings written to Register 6 are the same for all operating modes (1- and 2-Channel, and binning modes).

**Table 16. REGISTER 6 DEFAULT SETTING**

Register Entry	Evaluation Board Signal Name	Data
H6_OFFSET[0..5]	(Not Used)	0
H3_OFFSET[0..5]	H1A	2
H4_OFFSET[0..5]	H2A	2
H1_OFFSET[0..5]	H2B	3
H5_OFFSET[0..5]	(Not Used)	0
H2_OFFSET[0..5]	H1B	3
RG_OFFSET[0..5]	RESET	31
SH2_OFFSET[0..5]	SHD1	43
SH1_OFFSET[0..5]	SHD2	42
SH4_OFFSET[0..5]	SHP1	15
SH3_OFFSET[0..5]	SHP2	16
DATACLK1_OFFSET[0..5]	ADCLK (to AFEs)	5
DATACLK2_OFFSET[0..5]	DATACLK (to Framegrabber)	0

*Register 7: Pixel-Rate Signal Width*

The default settings written to Register 7 are the same for all operating modes (1-Channel, 2-Channel, and binning modes).

**Table 17. REGISTER 7 DEFAULT SETTING**

Register Entry	Evaluation Board Signal Name	Data
H6_WIDTH[0..5]	(Not Used)	0
H3_WIDTH[0..5]	H1A	16
H4_WIDTH[0..5]	H2A	16
H1_WIDTH[0..5]	H2B	16
H5_WIDTH[0..5]	(Not Used)	0
H2_WIDTH[0..5]	H1B	16
RG_WIDTH[0..5]	RESET	15
SH2_WIDTH[0..5]	SHD1	12
SH1_WIDTH[0..5]	SHD2	12
SH4_WIDTH[0..5]	SHP1	12
SH3_WIDTH[0..5]	SHP2	12
DATACLK1_WIDTH[0..5]	ADCLK (to AFEs)	16
DATACLK2_WIDTH[0..5]	DATACLK (to Framegrabber)	16

*Register 8: Frame Tables*

Two Frame Tables are written by default to the KSC-1000 Frame Table registers, but only one Frame Table is active at a time, as determined by the Frame Table Pointer (Register 0). Frame Table 0 is used for Single or Dual

Channel readout, and Frame Table 1 is used for Binning Mode (2x2). Note that the last row in Table 18 and Table 19 are the mnemonics associated with the Flag, Count, and Address bits. See the KSC-1000 Device Specification ([References](#)) for more details.

**Table 18. FRAME TABLE 0 DEFAULT SETTING**

Bit Location	Frame Table Data	0	1	2	3
0	Check and Increment Line Counter	0	0	1	0
1	Clear Line Counter	1	1	0	0
2	Force INTG_STRT	0	0	0	0
3:04	Horizontal Binning Factor	0	0	0	0
5	HCLK_V Enable	0	0	0	0
6	LINE_VALID Enable	0	0	1	0
7	FRAME_VALID Enable	0	0	1	0
8	Video Amplifier Enable	0	0	0	0
9	AFE Clock Enable	1	1	1	1
10	CLPDM2 Enable	0	0	0	0
11	CLPDM1 Enable	0	0	0	0
12	CLPOB2 Enable	0	0	0	0
13	CLPOB1 Enable	0	0	1	0
14	PBLK Enable	0	0	1	0
15	Pblk_Idle_Val	1	1	1	0
16	Flag	1	0	0	0
17:29	Count	0	1	1056	0
30:32:00	Address 2:0	0	1	2	0
33	Address 3	0	0	0	0
-	Mnemonic	ExLTNVD	ExLT	ExLT	JmpFT

**Table 19. FRAME TABLE 1 DEFAULT SETTING**

Bit Location	Frame Table Data	0	1	2	3
0	Check and Increment Line Counter	0	0	1	0
1	Clear Line Counter	1	1	0	0
2	Force INTG_STRT	0	0	0	0
3:04	Horizontal Binning Factor	0	0	1	0
5	HCLK_V Enable	0	0	0	0
6	LINE_VALID Enable	0	0	1	0
7	FRAME_VALID Enable	0	0	1	0
8	Video Amplifier Enable	0	0	0	0
9	AFE Clock Enable	1	1	1	0
10	CLPDM2 Enable	0	0	0	0
11	CLPDM1 Enable	0	0	0	0
12	CLPOB2 Enable	0	0	0	0
13	CLPOB1 Enable	0	0	1	0
14	PBLK Enable	0	0	1	0
15	Pblk_Idle_Val	1	1	1	0
16	Flag	1	0	0	0
17:29	Count	0	1	528	0
30:32:00	Address 2:0	0	1	3	1
33	Address 3	0	0	0	0
-	Mnemonic	ExLTNVD	ExLT	ExLT	JmpFT

*Register 9: Line Tables*

There are four Line Tables written by default to the KSC-1000 Line Table registers.

Line Table 0 is the Integration sequence. Both the Vertical and Horizontal clocks are inactive. See Figure 4.

**Table 20. LINE TABLE 0 DEFAULT SETTING**

Line Table Data Name	CCD Signal	0
Count[0..12]		1
HCLK_H Enable		0
V6	FDG (Not Used)	0
V5	INT	1
V4	V1	0
V3	V2	0
V2	V2B (Not Used)	0
V1	V3RD	0

Line Table 1 the Photodiode Transfer sequence, transfers charge from the photodiodes to the vertical registers.

The Horizontal Clocks are not active during this sequence. See Figure 5.

**Table 21. LINE TABLE 1 DEFAULT SETTING**

Line Table Data Name	CCD Signal	0	1	2	3	4	5	6
Count[0..12]		1	800	1	358	1	300	800
HCLK_H Enable		0	0	0	0	0	0	0
V6	FDG (Not Used)	0	0	0	0	0	0	0
V5	INT	0	0	0	0	0	0	0
V4	V1	0	0	0	1	0	0	0
V3	V2	0	1	1	1	1	1	0
V2	V2B (Not Used)	0	0	0	0	0	0	0
V1	V3RD	0	0	1	1	1	0	0

Line Table 2 is the Line Transfer sequence. See Figure 6.

**Table 22. LINE TABLE 2 DEFAULT SETTING**

Line Table Data Name	CCD Signal	0	1	2	3	4
Count[0..12]		1	1	38	1	30
HCLK_H Enable		0	0	0	0	1
V6	FDG (Not Used)	0	0	0	0	0
V5	INT	0	0	0	0	0
V4	V1	0	0	1	0	0
V3	V2	0	1	1	1	0
V2	V2B (Not Used)	0	0	0	0	0
V1	V3RD	0	0	0	0	0

Line Table 3 is used to implement the 2x2 Binning Mode Line Transfer sequence. The Vertical clocks are pulsed twice

to perform a 2x binning into the horizontal register. See Figure 7.

**Table 23. LINE TABLE 3 DEFAULT SETTING**

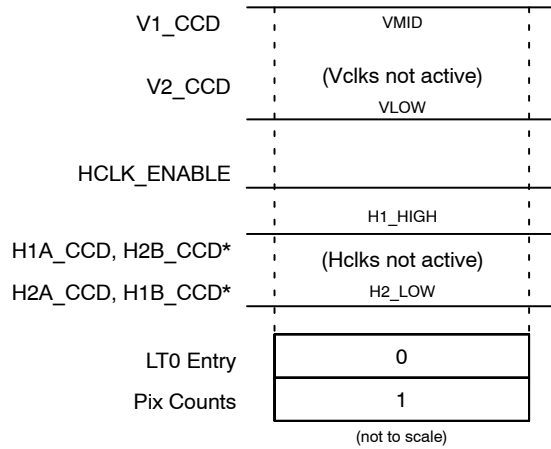
Line Table Data Name	CCD Signal	0	1	2	3	4	5	6	7	8
Count[0..12]		1	1	38	1	40	1	38	1	30
HCLK_H Enable		0	0	0	0	0	0	0	0	1
V6	FDG (Not Used)	0	0	0	0	0	0	0	0	0
V5	INT	0	0	0	0	0	0	0	0	0
V4	V1	0	0	1	0	0	0	1	0	0
V3	V2	0	1	1	1	0	1	1	1	0
V2	V2B (Not Used)	0	0	0	0	0	0	0	0	0
V1	V3RD	0	0	0	0	0	0	0	0	0

KAI-1003 TIMING

**Line Table 0 (Integration)**

Line Table 0 is the Integration timing sequence, during which both the Vertical and Horizontal clocks are inactive.

This sequence runs until Integration is complete, signaled by the assertion of the VD\_TG signal from the Altera PLD.



\* In Single Channel Mode

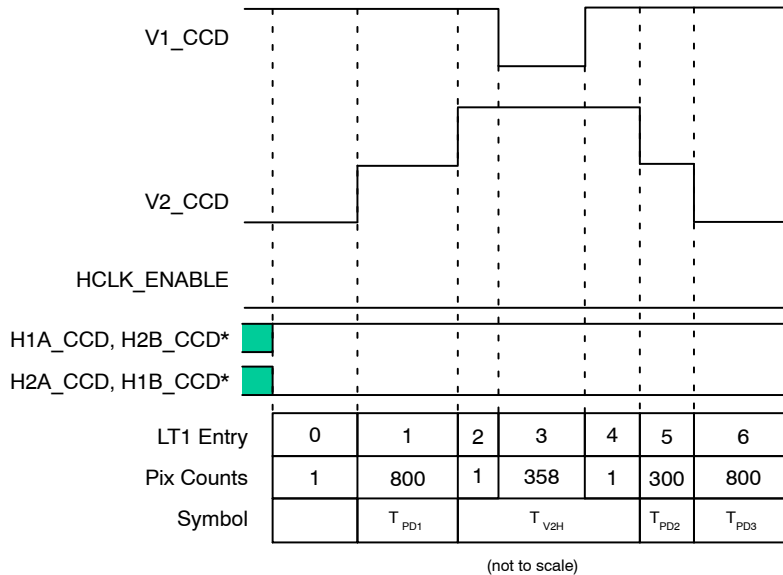
Polarity is reversed for H2B\_CCD and H1B\_CCD for Dual Channel Mode

**Figure 4. Line Table 0 Default Timing**

**Line Table 1 (Diode Transfer)**

Line Table 1 is the Photodiode Transfer timing, in which the V2 clock 3rd-level shifts charge from all the photodiodes into the vertical CCD registers. The V1 and V2 clocks have

overlap adjustability to compensate for the clock driver rise and fall times. Horizontal Clocks are inactive during the Diode Transfer sequence.



\* In Single Channel Mode

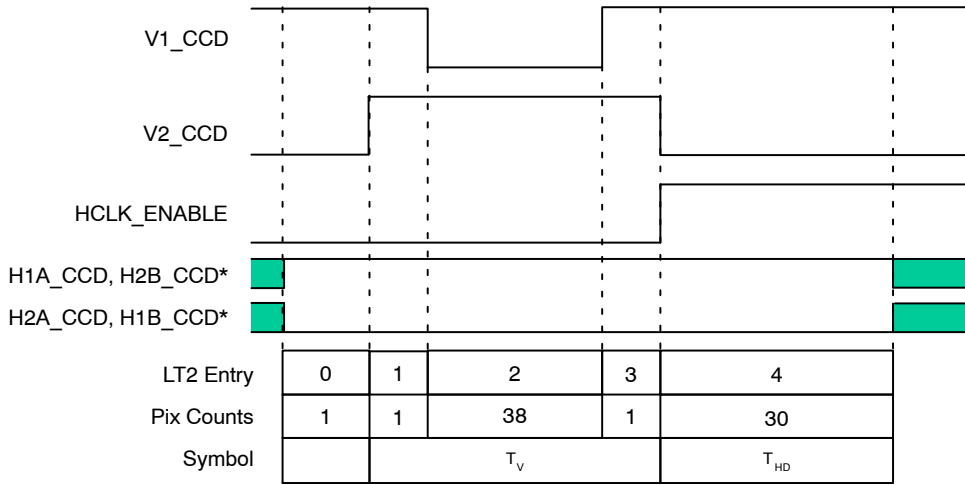
Polarity is reversed for H2B\_CCD and H1B\_CCD for Dual Channel Mode

**Figure 5. Line Table 1 Default Timing**

**Line Table 2 (Line Transfer)**

Line Table 2 is the Line Transfer timing sequence that transfers one entire row of charge toward the horizontal register. V1 and V2 are asserted, with overlap adjustability to compensate for the clock driver rise and fall times. Charge

is moved down the vertical CCD registers, and the last row of charge is dumped into the horizontal register. The VCCD clocking interval is followed by the Horizontal clocks, which shift one line out through the output amplifier.



(not to scale)

\* In Single Channel Mode

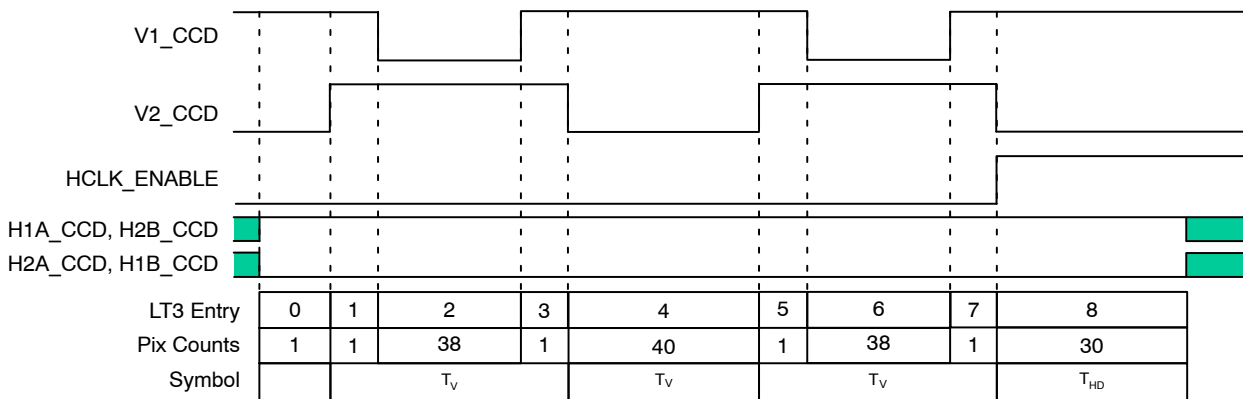
Polarity is reversed for H2B\_CCD and H1B\_CCD for Dual Channel Mode

**Figure 6. Line Table 2 Default Timing**

**Line Table 3 (Binning Mode Line Transfer)**

Line Table 3 is the Binning Mode Transfer sequence, during which the Vertical clocks are asserted twice. Pulsing the Vertical Clocks twice dumps two lines of charge onto the Horizontal CCD, thus providing a 2x vertical binning factor. The Horizontal clocks are run in Binning Mode as the pixels

are shifted out. Horizontal Binning is controlled within the Frame Table (Frame Table 1). Binning by 2 in the Horizontal direction is achieved by clocking the Reset gate at half the rate of the Horizontal clocks, thus transferring two horizontal pixels onto the floating diffusion for every one Reset pulse.



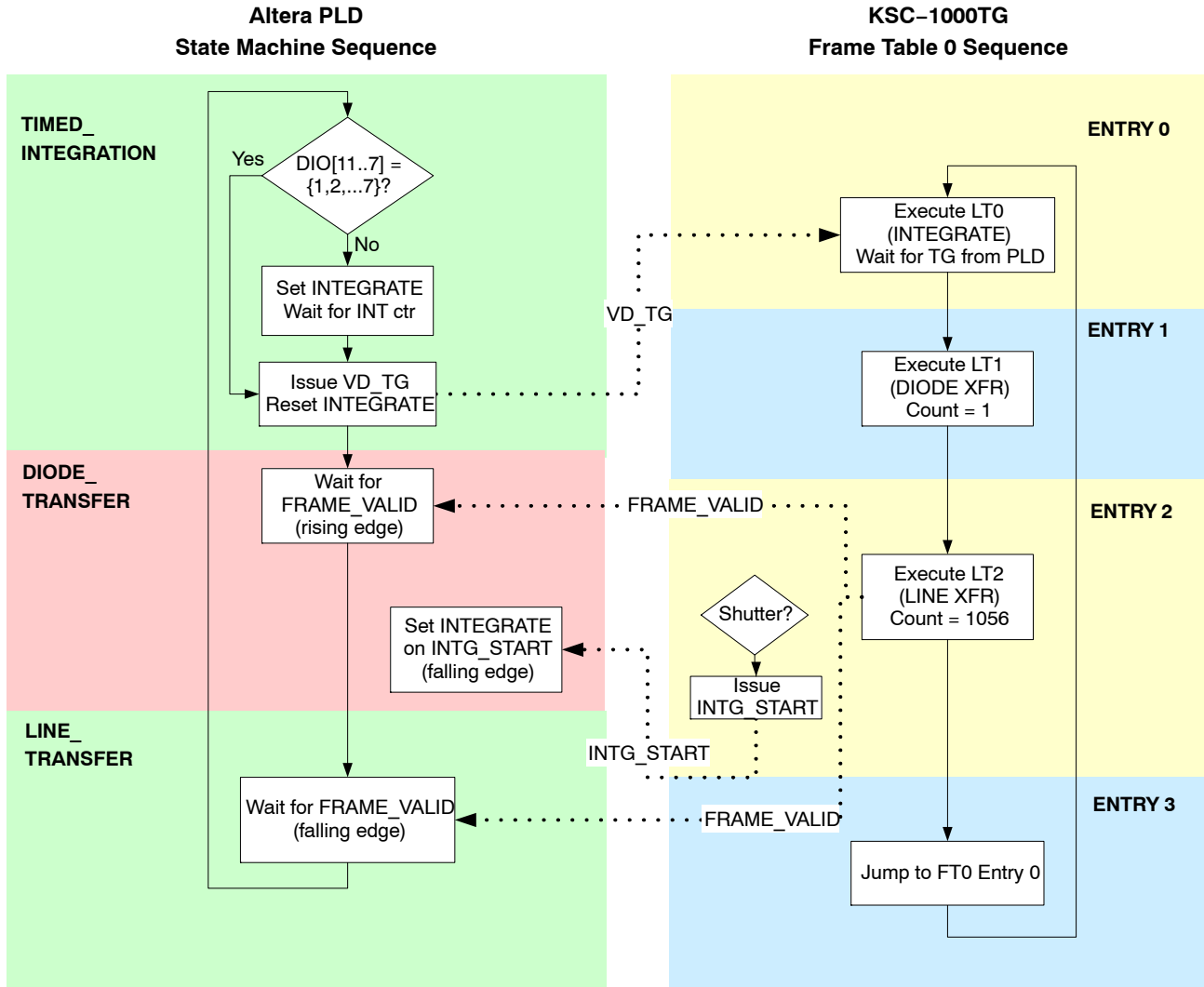
(not to scale)

**Figure 7. Line Table 3 Default Timing**

**Frame Table 0 Sequence**

Frame Table 0 contains the Single or Dual Channel timing sequence used to continuously read out all rows of the CCD. The sequence begins with the Integration sequence. Upon receiving the VD\_TG pulse, the Diode Transfer sequence moves charge from the photodiodes into the light shielded vertical CCDs. Once charge is in the vertical CCDs, the Line

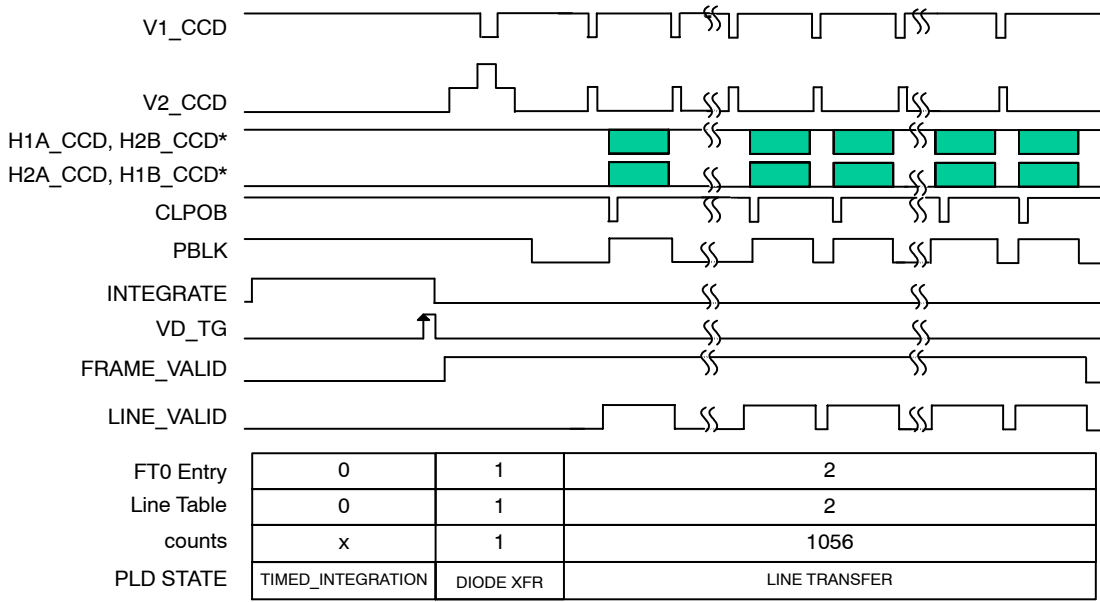
Transfer sequence clocks out all lines of the CCD imager array. Once a full frame read out is complete, the KSC-1000 returns to Integration and waits for the Altera PLD to assert the VD\_TG signal to indicate the end of integration. Frame Table 0 is used for both Single and Dual Channel readout, as the sequence is exactly the same for both modes and only the polarity of H1B and H2B are reversed.



**Figure 8. Single and Dual Channel Mode Timing Sequence**



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(not to scale)

\* In Single Channel Mode

Polarity is reversed for H2B\_CCD and H1B\_CCD for Dual Channel Mode

**Figure 9. Frame Table 0 Default Timing**

## Frame Table 1 Sequence

Frame Table 1 contains the 2x2 Binning Mode timing sequence used to sum the charge collected in four photosites into one CCD pixel. The sequence is essentially the same as that of Frame Table 0, except that the Vertical Clocks are asserted twice per line. This dumps charge from two vertical CCD pixels into each Horizontal register CCD pixel. The Horizontal CCD is clocked out using a binning readout routine (See Figure 14). Since the Vertical Clocks are pulsed twice for every Horizontal readout period, the entire CCD is read with half the number of Vertical intervals. This evaluation kit only supports Single Channel output when in the Binning mode.

It is important to note that the KAI-1003 Device Performance Specification illustrates a horizontal Binning mode different than the one implemented in this Evaluation Kit. In the device specification, binning is performed as charge is shifted to Phase H22. Due to hardware limitations on the KAI-1003 Imager Board, it is not possible to clock Phase H22 as defined in the device specification, but binning is still possible at the floating diffusion. The Reset pulse is suspended every other pixel clock, thereby allowing two packets of charge to be dumped onto the floating diffusion before it is sampled and then reset.

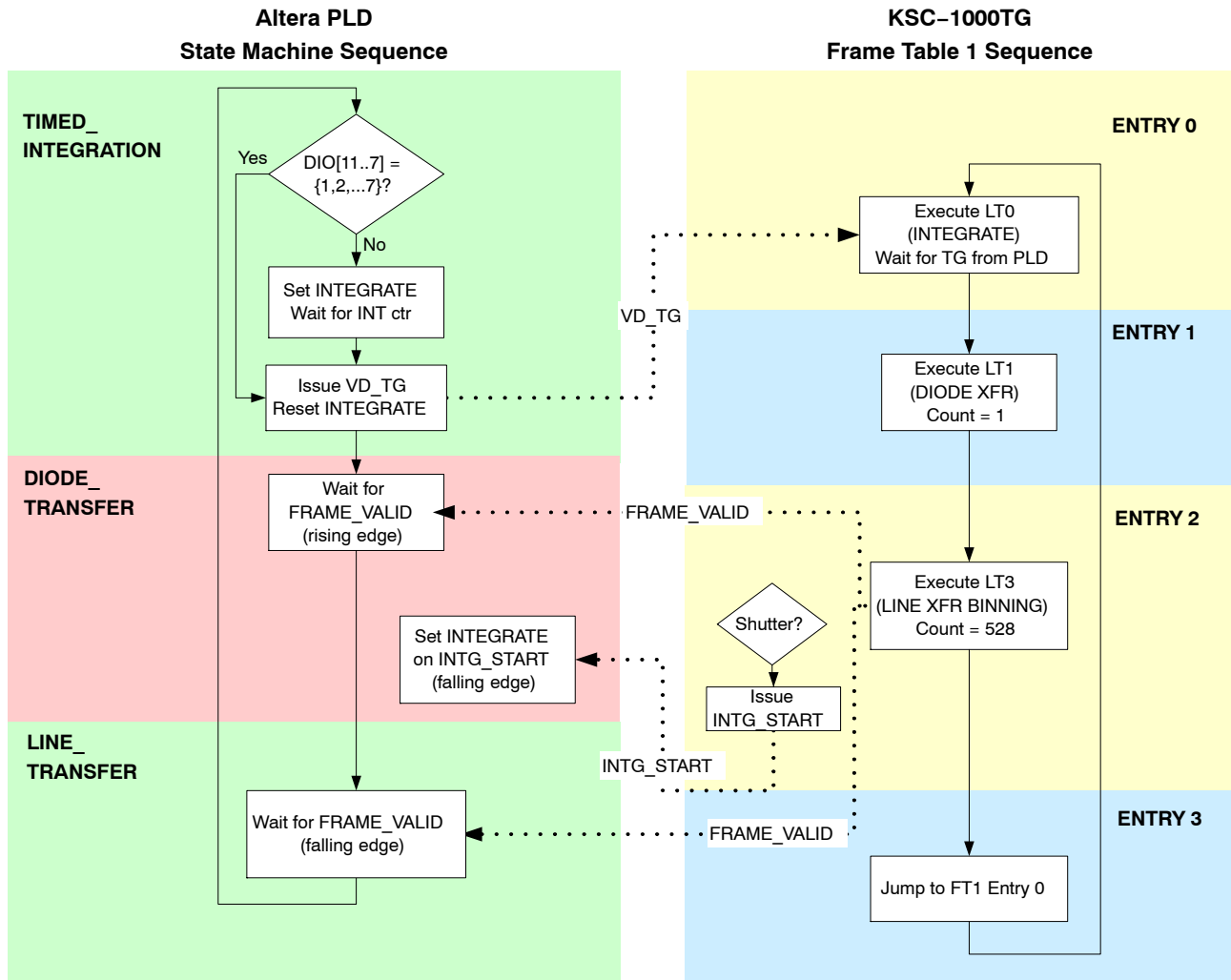


Figure 10. Dual Channel Mode Timing Sequence

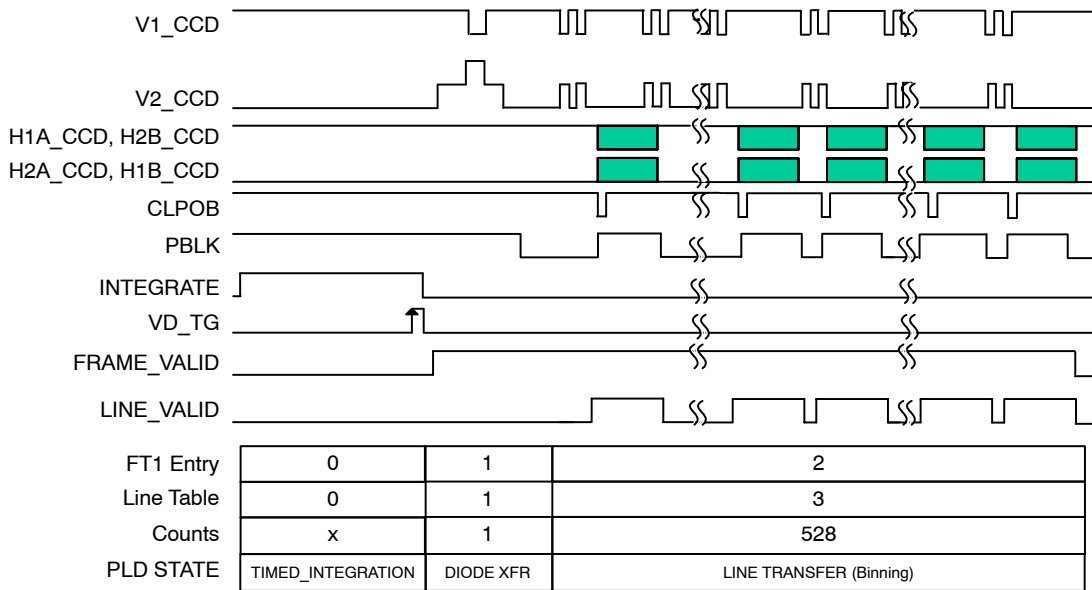


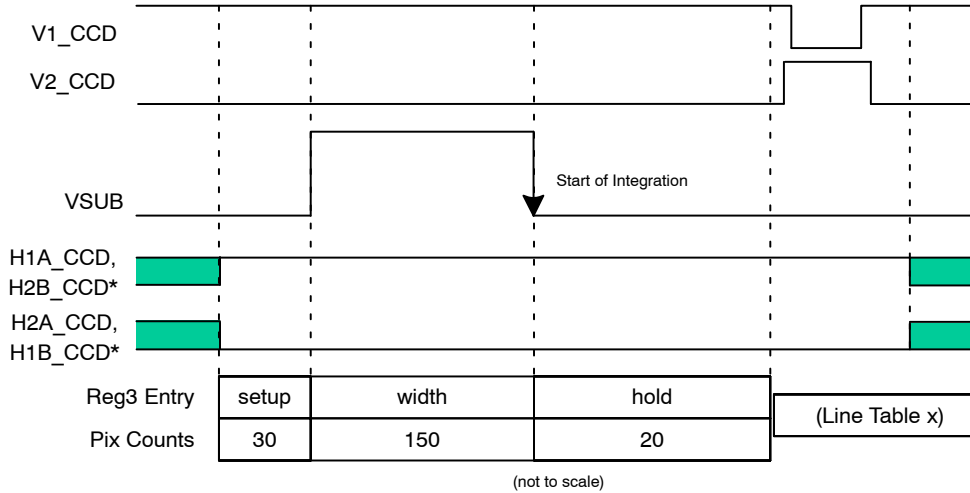
Figure 11. Frame Table 1 Default Timing

**Electronic Shutter Timing**

The electronic shutter timing is controlled by the values in Register 3 of the KSC-1000. There are two methods of actuating the Electronic Shutter pulse: by setting the Integrate Start Pulse Line Number value in Register 4 so that the pulse occurs on a specific line, or by setting the Force INTG\_START bit in a Frame Table entry. In either case, the Electronic Shutter pulse setup, width, and hold times are determined by the values in Register 3. The shutter sequence

is inserted before the specified line, causing that particular line time to be extended accordingly.

If the Integrate Start Pulse Line Number value in Register 4 is set to 0, the Electronic Shutter will occur immediately following the Diode Transfer sequence, before the first line is read out. If the Integrate Start Pulse Line Number value is greater than the number of vertical lines in the Frame Table, there will be no Electronic Shutter. This is the method used to disable the Electronic Shutter.



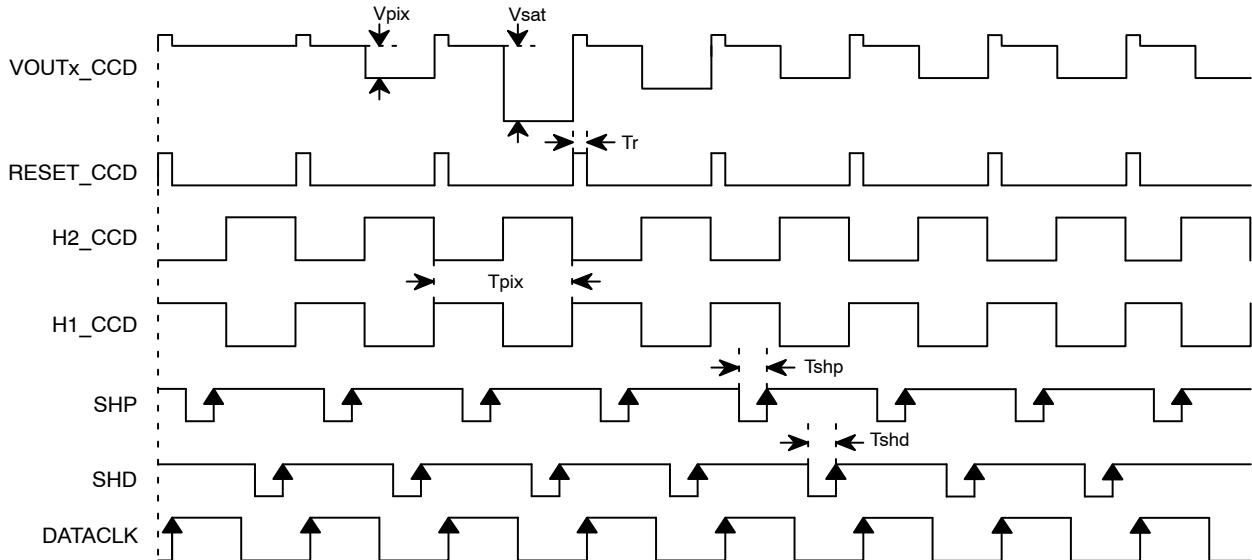
\* In Single Channel Mode  
Polarity is reversed for H2B\_CCD and H1B\_CCD for Dual Channel Mode

**Figure 12. Electronic Shutter Timing**

**Horizontal Timing**

Figure 13 depicts the basic theoretical relationship between the pixel-rate clocks to the CCD, the Video output of the CCD, and the pixel-rate clocks to the AFE. Note that the states of H1B and H2B are dependent on the operating

mode. In Single Channel and Binning output modes, H1B runs in phase with H2A while H2B is in phase with H1A. In Dual Channel operation, the phases of H1B and H2B are reversed, such that H1B clocks in phase with H1A and H2B is in phase with H2A.



\* In Single Channel Mode  
Polarity is reversed for H2B\_CCD and H1B\_CCD for Dual Channel Mode

**Figure 13. Horizontal Timing**

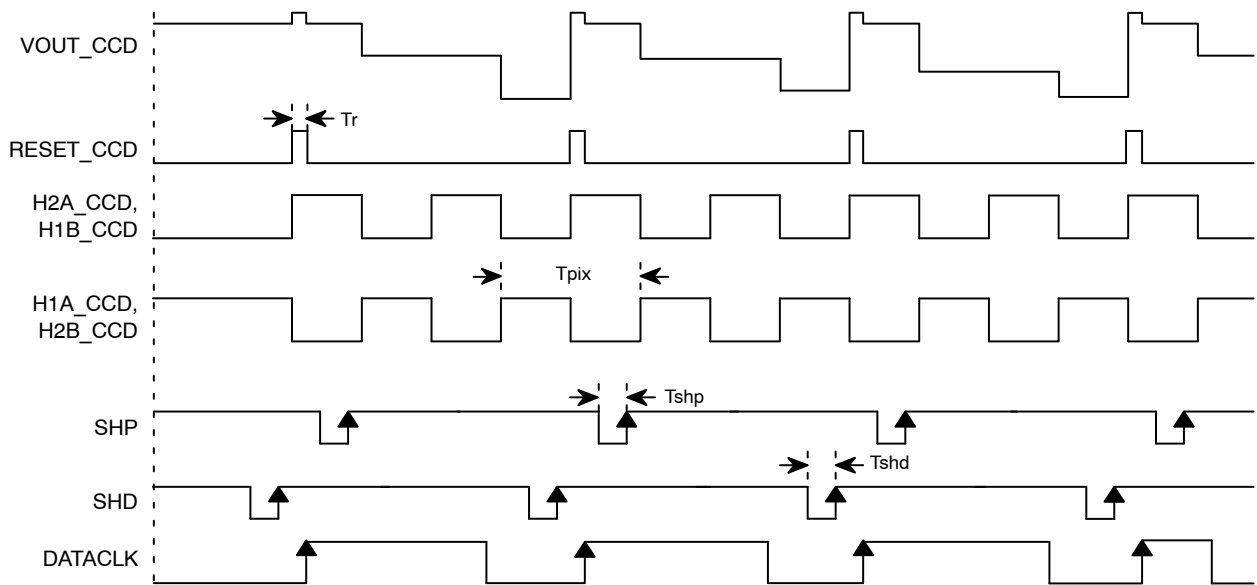
**Binning Mode Horizontal Timing**

In order to sum the charge from two Horizontal CCD pixels into one, the Reset clock is suspended on alternating Horizontal clock cycles. In this way, two pixels of charge are dumped onto the floating diffusion of the output amplifier before this node is reset to VRD, the Reset Drain voltage. See the KAI-1003 Device Specification [1] for further details.

In order to correctly convert the output amplifier voltage to digital data, the AFE clocks must be adjusted accordingly. The Clamp pulse (SHP) samples the output after the Reset pulse has been issued, but before the Horizontal clocks have moved charge onto the floating diffusion. The Sample pulse (SHD) samples the output after two Horizontal clock cycles have moved two charge packets onto the floating diffusion. The DATACLK then clocks the AFE to perform the

conversion. The KSC-1000 has the capability of implementing the Horizontal Timing necessary to bin up to four pixels. Horizontal Binning is controlled by setting bits 3:4 of the active Frame Table (Register 8) in the KSC-1000. Figure 17 depicts the basic theoretical relationship between the pixel-rate clocks to the CCD, the Video output of the CCD, and the pixel-rate clocks to the AFE in 2x Horizontal Binning Mode.

The Altera PLD default KSC-1000 settings contain 2x2 Binning Mode timing in Frame Table 1 (See Figure 12). In order to activate the 2x2 Binning Mode, the Frame Table Pointer (Register 0) must be changed to a value of 1. Setting SW3 HIGH and pressing the BOARD\_RESET button (S1 on the Timing Board) will load the binning mode default values.



**Figure 14. Binning Mode Horizontal Timing**

**Integration & Shutter Timing**

The default Integration Time in Single Channel Mode is approximately one Frame Time, or the time between Diode Transfers, during which the photodiodes are collecting charge. This time may be decreased by use of the Electronic Shutter, and may be increased by lengthening the Frame Time. The user may control the Integration Time through the DIO connector bits DIO[11..7]. This connector is optional, and when disconnected, all bits are pulled LOW. The available pre-programmed Integration Times are detailed in Table 24.

The Electronic Shutter is controlled by changing the Integrate Start Pulse Line Number value of the KSC-1000 Register 4. The Altera PLD has 8 pre-programmed Shutter settings, controlled through the DIO[11..7] bits, as shown in Table 14. These settings result in Integration times of one Frame Time or less, in increments of 1/8 of the Frame Time (See Figure 12). When the Integrate Start Pulse Line

Number value is set to 1280 the Shutter is never pulsed, as this value exceeds the number of lines in a frame. The BOARD\_RESET switch must be pressed after changing the DIO[11..7] bits in order for the change to the KSC-1000 to take effect.

The Altera PLD controls the Integration time. The KSC-1000 waits for a trigger signal (VD\_TG) before beginning the Diode Transfer sequence (See Figure 16). The Altera PLD issues this trigger pulse when the Integration Counter has reached a pre-programmed value, as shown in Table 24. The Integration counter is clocked by an internally generated 1 ms clock. The default value of 0 means that the VD\_TG trigger is issued on the next rising edge of the 1 ms clock after the frame readout is complete. A value greater than 0 adds that many milliseconds to the Integration Time, allowing Integration times greater than 8 seconds (Figure 18).

For any DIO[11..7] configuration, integration time for Dual Channel and Binning modes are approximately half that of the Single Channel mode. The shutter and integration line numbers in Figure 16, Figure 17, and Figure 18 can be

generalized to represent Binning (Frame Table 1) mode by replacing 1056 lines with 528 lines and dividing electronic shutter line numbers by 2.

**Table 24. PROGRAMMED INTEGRATION TIMES**

DIO[11..7]	Int Count	1 Ch Mode Reg 4 Entry	1 Ch Mode Tint	2 Ch/Bin Mode Reg 4 Entry	2 Ch/Bin Mode Tint
0 (Default)	0	1100 (Default – No Pulse)	63.00 ms	1100 (default – no pulse)	34.00 ms
1	0	924	7.86 ms	462	4.25 ms
2	0	792	15.75 ms	396	8.50 ms
3	0	660	23.63 ms	330	12.75 ms
4	0	528	31.50 ms	264	17.00 ms
5	0	396	39.38 ms	198	21.25 ms
6	0	264	47.25 ms	132	25.50 ms
7	0	132	55.13 ms	66	29.75 ms
8	1	1100 (Default – No Pulse)	64.0 ms	1100 (Default – No Pulse)	35.0 ms
9	3	1100 (Default – No Pulse)	66.0 ms	1100 (Default – No Pulse)	37.0 ms
10	5	1100 (Default – No Pulse)	68.0 ms	1100 (Default – No Pulse)	39.0 ms
11	10	1100 (Default – No Pulse)	73.0 ms	1100 (Default – No Pulse)	44.0 ms
12	25	1100 (Default – No Pulse)	88.0 ms	1100 (Default – No Pulse)	59.0 ms
13	50	1100 (Default – No Pulse)	113.0 ms	1100 (Default – No Pulse)	84.0 ms
14	70	1100 (Default – No Pulse)	133.0 ms	1100 (Default – No Pulse)	104.0 ms
15	100	1100 (Default – No Pulse)	163.0 ms	1100 (Default – No Pulse)	134.0 ms
16	200	1100 (Default – No Pulse)	263.0 ms	1100 (Default – No Pulse)	234.0 ms
17	300	1100 (Default – No Pulse)	363.0 ms	1100 (Default – No Pulse)	334.0 ms
18	400	1100 (Default – No Pulse)	463.0 ms	1100 (Default – No Pulse)	434.0 ms
19	500	1100 (Default – No Pulse)	563.0 ms	1100 (Default – No Pulse)	534.0 ms
20	600	1100 (Default – No Pulse)	663.0 ms	1100 (Default – No Pulse)	634.0 ms
21	700	1100 (Default – No Pulse)	763.0 ms	1100 (Default – No Pulse)	734.0 ms
22	800	1100 (Default – No Pulse)	863.0 ms	1100 (Default – No Pulse)	834.0 ms
23	900	1100 (Default – No Pulse)	963.0 ms	1100 (Default – No Pulse)	934.0 ms
24	1000	1100 (Default – No Pulse)	1.063 s	1100 (Default – No Pulse)	1.034 s
25	2000	1100 (Default – No Pulse)	2.063 s	1100 (Default – No Pulse)	2.034 s
26	3000	1100 (Default – No Pulse)	3.063 s	1100 (Default – No Pulse)	3.034 s
27	4000	1100 (Default – No Pulse)	4.063 s	1100 (Default – No Pulse)	4.034 s
28	5000	1100 (Default – No Pulse)	5.063 s	1100 (Default – No Pulse)	5.034 s
29	6000	1100 (Default – No Pulse)	6.063 s	1100 (Default – No Pulse)	6.034 s
30	7000	1100 (Default – No Pulse)	7.063 s	1100 (Default – No Pulse)	7.034 s
31	8000	1100 (Default – No Pulse)	8.063 s	1100 (Default – No Pulse)	8.034 s

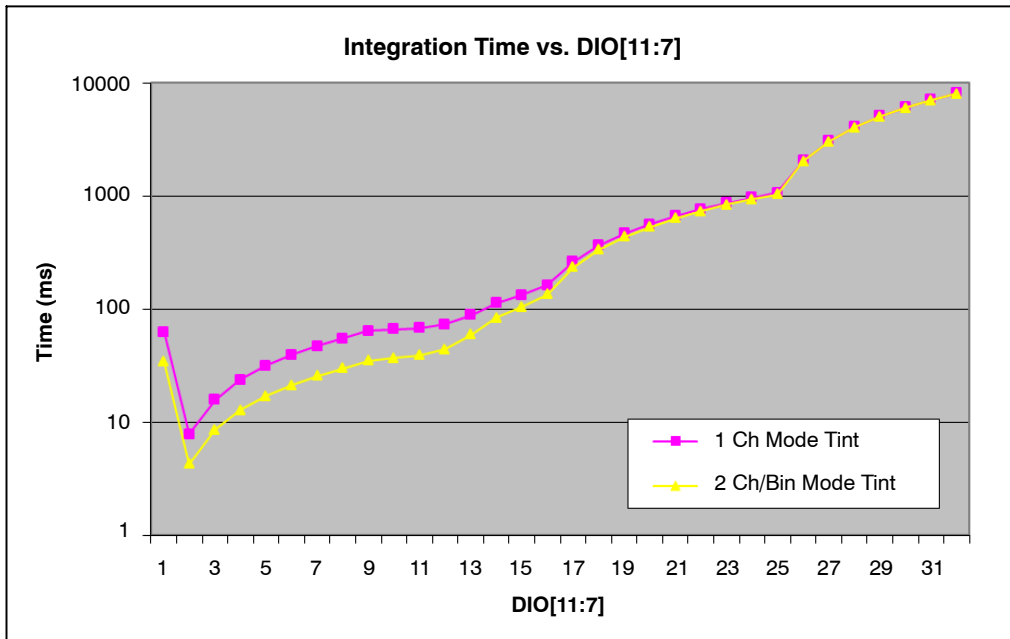


Figure 15. Programmed Integration Times

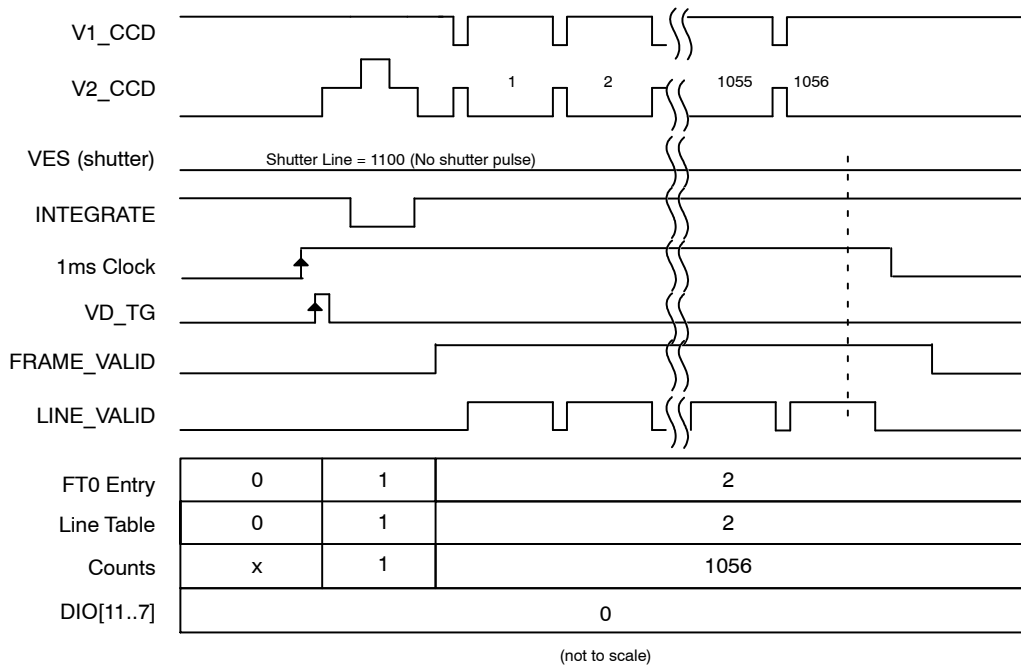
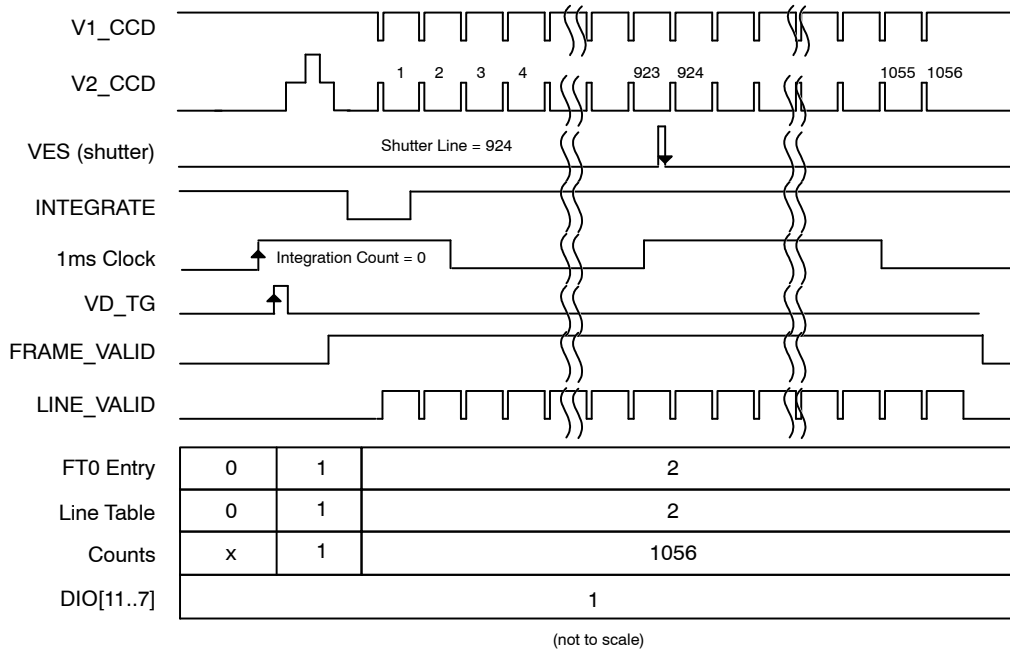
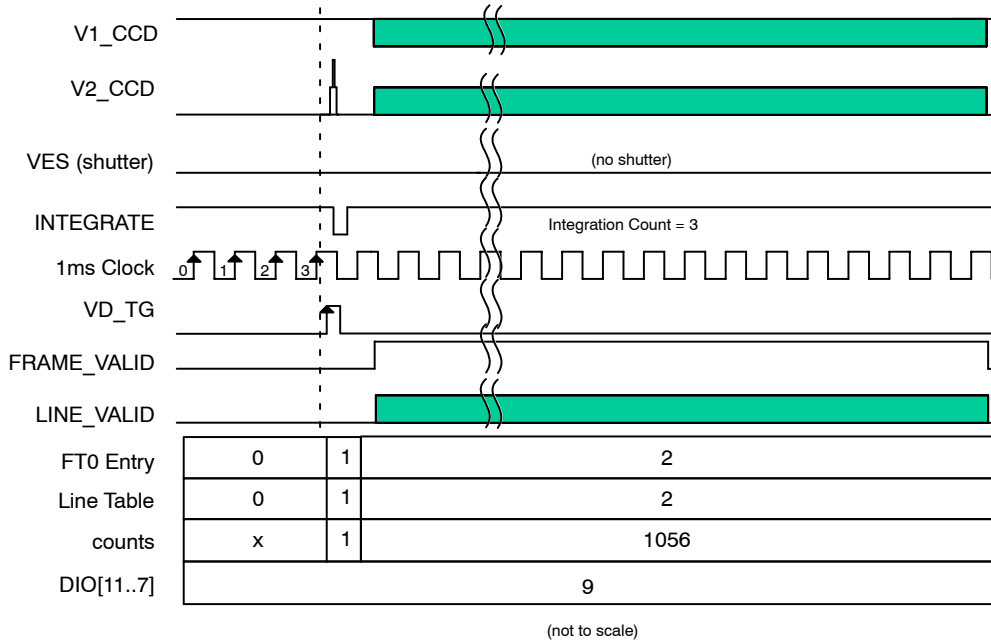


Figure 16. Single and Dual Channel Mode Default Integration Timing

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**Figure 17. Single and Dual Channel Mode Integration Timing with Shutter**



**Figure 18. Single and Dual Channel Mode Extended Integration Timing**

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## BOARD INTERFACE CONNECTOR SIGNAL MAP

For reference, the board interface timing signals from the 3F5054 Timing Board to the 3E8214 Imager Board are

shown in Table 25. Note that the power connections are not shown here.

**Table 25. TIMING BOARD/IMAGER BOARD SIGNAL MAP**

AD9945 KSC-1000 Timing Board			KAI-1003 Imager Board		
KSC-1000 Signal Name	LVDS Interface Signal Name	3F5592 J5 Pins	3E8214 J3 Pins	LVDS Interface Signal Name	Imager Board Signal Name
	TIMING_OUT0	1/2	1/2		
INTG_START	TIMING_OUT1	5/6	5/6	VES ±	VES
V6	TIMING_OUT2	9/10	9/10	FDG ±	FDG (Not Used)
V1	TIMING_OUT3	13/14	13/14	V3RD ±	V3RD
V2	TIMING_OUT4	17/18	17/18	V2B ±	V2B (Not Used)
V3	TIMING_OUT5	21/22	21/22	V2 ±	V2
V4	TIMING_OUT6	25/26	25/26	V1 ±	V1
RG	TIMING_OUT7	29/30	29/30	R ±	RESET
H1	TIMING_OUT8	33/34	33/34	H2B ±	H2B
H4	TIMING_OUT9	37/38	37/38	H2A ±	H2A
H2	TIMING_OUT10	41/42	41/42	H1B ±	H1B
H3	TIMING_OUT11	45/46	45/46	H1A ±	H1A
	TIMING_OUT12	51/52	51/52		
	TIMING_OUT13	55/56	55/56		
	TIMING_OUT14	59/60	59/60		
	TIMING_OUT15	63/64	63/64		
	TIMING_OUT16	67/68	67/68		
	TIMING_OUT17	71/72	71/72		
	TIMING_OUT18	75/76	75/76		
	TIMING_OUT19	79/80	79/80		



VIDEO SIGNAL PATH

The entire video signal path through the Imager Board and Timing Board is represented in Figure 19. The individual blocks are discussed in the Imager Board User Manual and the Timing Board User Manual.

The hardware gain for the entire pre-AFE signal path can be calculated by multiplying the gains of the individual stages:

$$0.96 \times 1.25 \times 0.5 \times 1.25 = 0.75 \quad (\text{eq. 1})$$

The gain of the hardware signal path is designed so that the saturation output voltage of the KAI-1003 will not overload the AFE input. The AFE default VGA gain is set to 2.0 (6.0 dB) using a gain code of 20 to maximize the dynamic range of the AFE (See Table 9 and [References](#)).

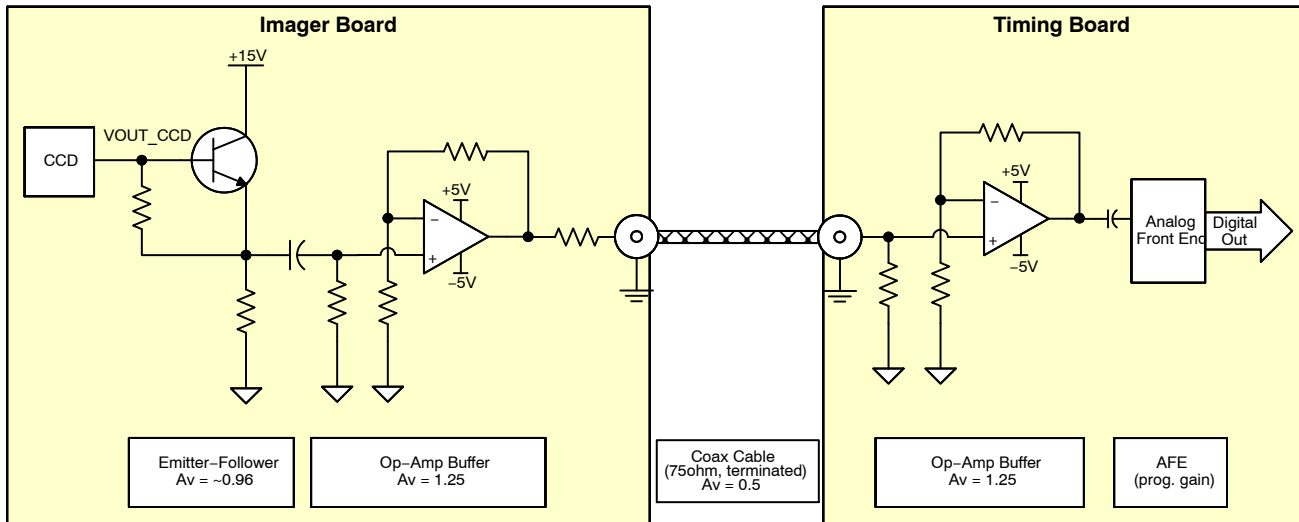


Figure 19. Video Signal Path Block Diagram

WARNINGS AND ADVISORIES

When programming the Timing Board, the Imager Board must be disconnected from the Timing Board before power is applied. If the imager Board is connected to the Timing Board during the reprogramming of the Altera PLD, damage to the Imager Board will occur.

Purchasers of a ON Semiconductor Evaluation Board Kit may, at their discretion, make changes to the Timing

Generator Board firmware. ON Semiconductor can only support firmware developed by, and supplied by, ON Semiconductor. Changes to the firmware are at the risk of the customer.

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ON Semiconductor reserves the right to change any information contained herein without notice. All information furnished by ON Semiconductor is believed to be accurate.

**REFERENCES**

- [1] KAI-1003 Device Specification
- [2] KAI-1003 Imager Board User Manual
- [3] KAI-1003 Imager Board Schematic
- [4] AD9945 Timing Generator Board User Manual
- [5] AD9945 Timing Generator Board Schematic
- [6] Analog Devices AD9945 Product Data Sheet

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