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Spec No: 001-16627

Spec Title: MULTIPLE SLOPE INTEGRATION WITH IBIS5B-1300-AN4081

Sunset Owner: Evelyn Beard (EYB)

Replaced by: None

Multiple Slope Integration with IBIS5B-1300

AN4081

Application Note Abstract

This document describes the working of multiple slope integration. It demonstrates the implementation of this method with the IBIS5B-1300 sensor for both synchronous and rolling shutters.

Introduction

The multiple slope integration method is used to compress a wide optical dynamic range on a limited voltage output range. This method is implemented in several Cypress image sensors including the IBIS5B-1300. Essentially, the light power [W/m2] to voltage [V] relation is made piece-wise linear. Both the relative slopes and knee points (voltages at which the slopes change) are programmable, although they are fixed in certain image sensors. Figure 1 is an example of the 4-slope power-voltage relationship.

The double or multiple mode combines, in each individual pixel and without external control, the sensor's transfer curve, which holds at nominal integration time (steep slope, high sensitivity) with the transfer curve obtained by using the electronic shutter (shorter exposure time, lower sensitivity). This is done in a single exposing operation, without combining two different images. The 'knee' in the resulting bilinear electro-optical transfer can be positioned by programming in the analog domain.

Figure 2 compares the response of long integration (high sensitivity), short integration (low sensitivity), and the double slope response as a combination of the previous two. The pink curve is a steep, high sensitive or long integration time curve that reaches saturation with a small percentage of relative light intensity ideal for dark scenes. The yellow curve is a low sensitive or small integration time curve, which reaches saturation for a much higher percentage of relative light intensity and is ideal for bright scenes. The blue line is the double slope response, which combines the high sensitivity for dark scenes and the low sensitivity for bright scenes.

Figure 1. Multiple Slope Response

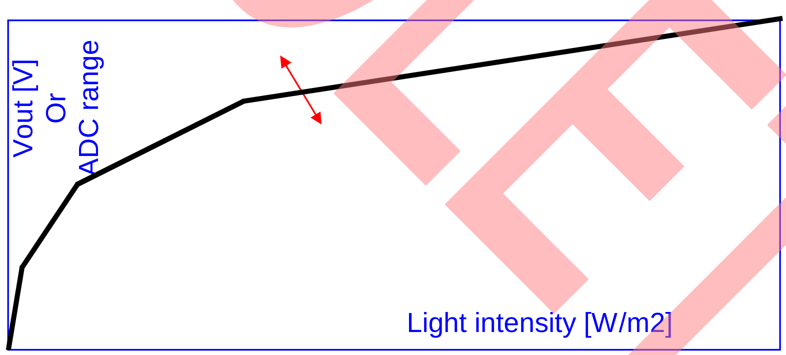
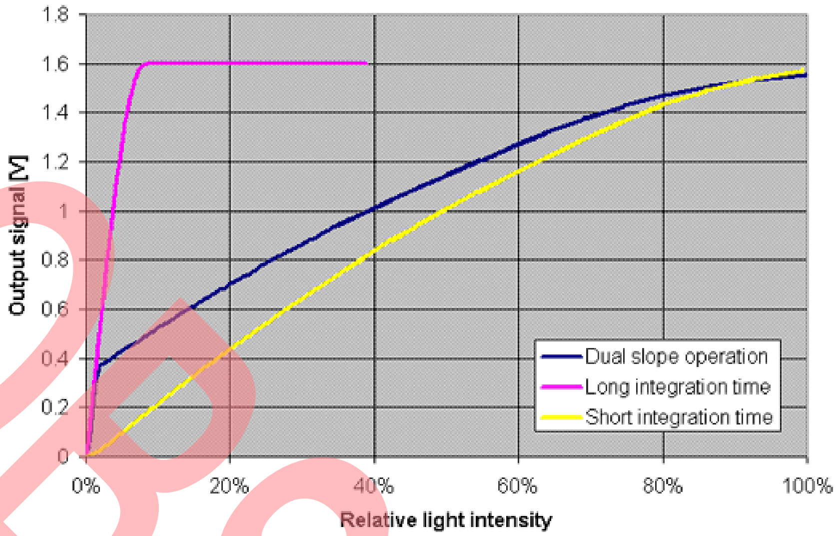


Figure 2. Double and Single Slope Response Curves



Dual Slope Operation

Definitions

The output of a pixel with a linear response is given by:

$V_{out} = V_0 - APT_{int}$

With: V_{out}: pixel output voltage (V)
V_0: pixel reset voltage (V)
A: pixel sensitivity (V/J)
P: light intensity on the pixel (J/s = W)
T_{int}: integration time (s)

Consider that T_{int} and A are fixed and the same for every pixel on the imaging array. P varies from pixel to pixel. For each pixel there is also a minimum V_{out} defined as V_{min}. Assume that $V_{min} = 0$. From the moment V_{out} reaches $V_{min} = 0$, the pixel is saturated. So in linear mode, the maximum signal $P_{maxsingle}$ before saturation is:

$P_{maxsingle} = V_0/AT_{int}$

Reducing T_{int} and/or A can increase $P_{maxsingle}$. In practice, this is done only for the pixels that see a high enough light intensity, resulting in a signal clearly above the noise. This is realized in the dual slope as described here.

Dynamic Range

The purpose of dual slope is to increase the intra-scene dynamic range. The dynamic range (DR) is defined as:

$DR = P_{max}/P_{min}$

P_{max} is the maximum light intensity detected by the pixel before going in saturation, this means reaching V_{min}.

P_{min} is the minimum light intensity detected by the pixel; this means, the intensity that results in a signal above the pixel noise signal. P_{min} is determined by the noise of the pixel signal. If the noise signal is V_{noise}, the minimum signal P_{min} that can be detected is:

$P_{min} = V_{noise}/AT_{int}$

Single Slope

$DR_{single} = P_{maxsingle}/P_{min} = (V_0/AT_{int})/(V_{noise}/AT_{int})$

$DR_{single} = V_0/V_{noise}$

So in the linear mode, maximizing the output signal swing or minimizing the noise can only optimize the DR.

Dual Slope

In the dual slope mode, all pixels for which $V_{out} < V_{reset}$ is reset to V_{reset} at the T_{reset}. With $V_{min} < V_{reset} < V_0$ and $0 < T_{reset} < T_{int}$. This means that pixels that see an intensity larger than:

$P_{reset} = (V_0 - V_{reset})/AT_{reset}$

Have an output voltage equal to:

$V_{out} = V_{reset} - AP(T_{int} - T_{reset})$

In that case $P_{maxdual}$ before reaching saturation is:

$P_{maxdual} = V_{reset}/A(T_{int} - T_{reset})$

Therefore:

$DR_{Dual} = P_{maxdual}/P_{min} = [V_{reset}/A(T_{int} - T_{reset})] / (V_{noise}/AT_{int})$
$DR_{Dual} = T_{int}V_{reset}/V_{noise}\ (T_{int} - T_{reset})$

$DR_{Dual} = [T_{int} / (T_{int} - T_{reset})]\ (V_{reset}/V_{noise})$

or with $V_{reset} = aV_0$ with $0 < a < 1$

$DR_{Dual} = T_{int} / (T_{int} - T_{reset})\, aDR_{single}$

$\Rightarrow DR_{dual}/DR_{single} = a\, T_{int} / (T_{int} - T_{reset})$

$\Rightarrow T_{reset}/T_{int} = 1 - aDR_{single}/DR_{dual}$

In the dual slope mode, it is possible to distinguish a certain minimum contrast, ΔP_{min}. ΔP_{min} is defined by V_{noise}, A and $T_{int} - T_{reset,min}$ as:

$\Delta P_{min} \geq V_{noise}/A(T_{int} - T_{reset,\ min})$

$\Rightarrow T_{reset,min} \leq T_{int} - V_{noise}/A.\Delta P_{min}$

Multiple Slope

Multiple slope is obtained by applying this process two ore more times for different V_{reset} and T_{reset}.

In that case, $T_{reset2} > T_{reset1}$.

Figure 3 shows the pixel output signals for two different double slope reset voltages ($V_{reset} > V_{reset}$) and one multiple slope voltage (V_{reset}) with various double slope reset times. Depending on the reset time and voltage the dynamic range and intra-scene contrast will vary. The optimal settings are a good tradeoff between an acceptable intra-scene contrast and a high optical dynamic range.

Multiple Slope Operation with Synchronous Shutter

The green lines in Figure 3 are the analog signal on the photo diode, which decreases as a result of exposure. The slope is determined by the amount of light at each pixel (the more light the steeper the slope). When the pixels reach the saturation level, the analog signal does not change despite further exposure. Without any multiple slope pulse, pixels p3 and p4 reach saturation before the sample moment of the analog values, a saturated signal is acquired without multiple slope. When multiple slope is enabled, a second and/or more reset pulse(s) is given (blue line) at a certain time before the end of the exposure time. This multiple slope reset pulses reset the analog signal of the pixels below this level to the reset level. After reset, the analog signal starts to decrease with the same slope as before the multiple slope reset pulse. If the multiple slope reset pulse is placed at the end of the integration time (80 to 90 percent, for instance), the analog signal that reaches the saturation levels are not saturated anymore at read out. This increases the optical dynamic range. Note that pixel signals above the multiple slope reset level are not influenced by these reset pulses (pixels p1 and p2).

The times when the multiple slope resets are asserted are set with the assertion of the SS_START pulses, as shown in Figure 4. The position of the multiple slope resets influence the ratio between the successive slopes (see Figure 1). A good relation between dynamic range and contrast in the image has to be found. The level of the multiple slope pulse is set by changing the KNEEPOINT MSB/LSB register setting (bits 8,9 register 0) or by applying an external voltage on VDDR_RIGHT.

Figure 3. Pixel Output Signal as Function of Double Slope Reset Level and Time

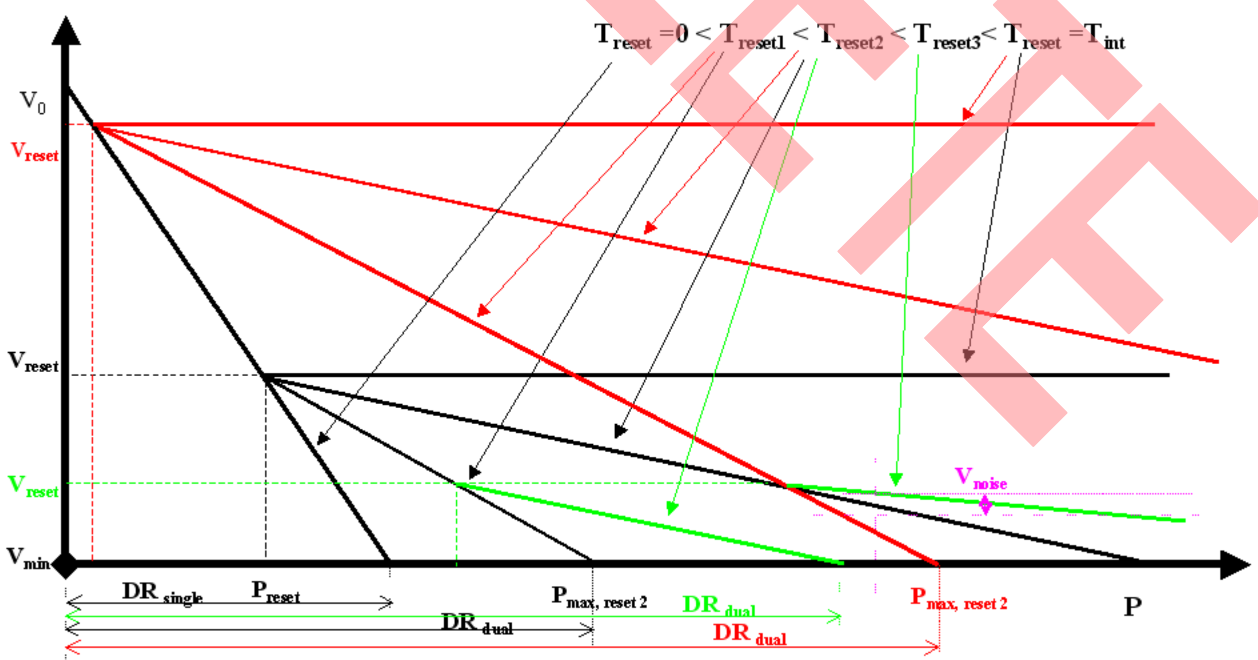
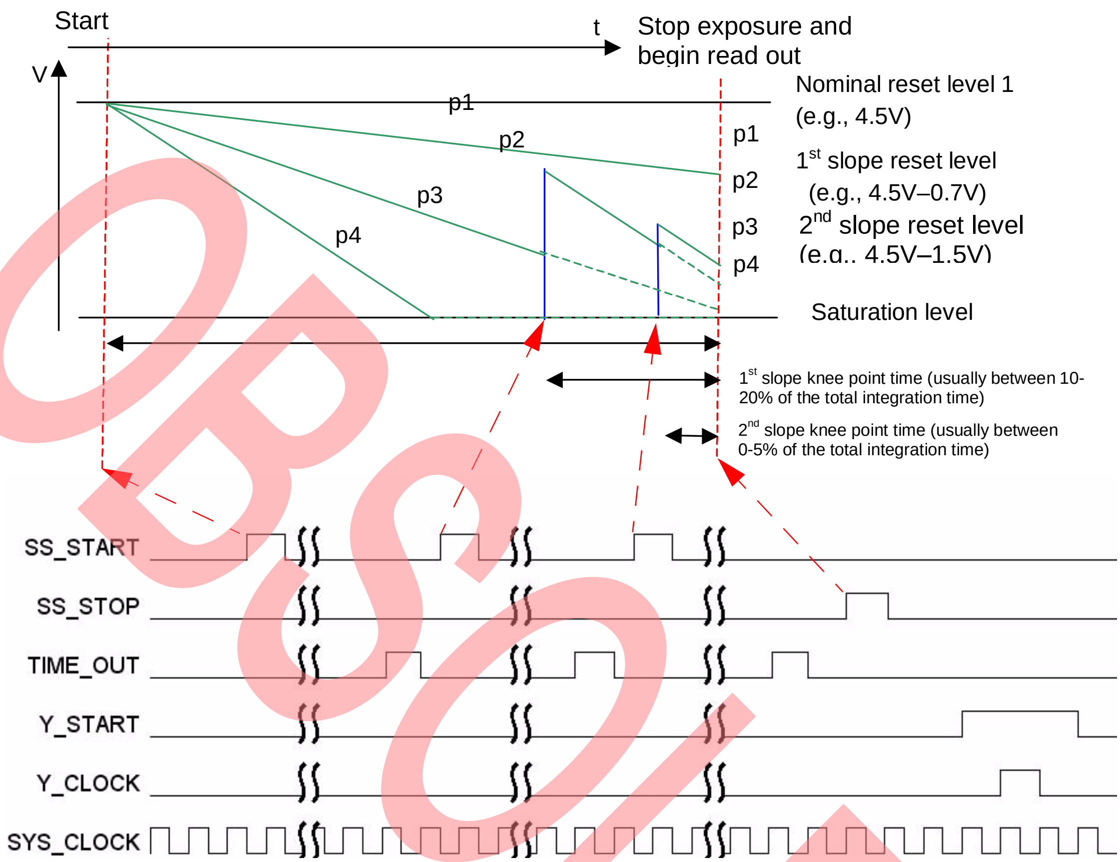


Figure 4. Multiple Slope Operation with Synchronous Shutter

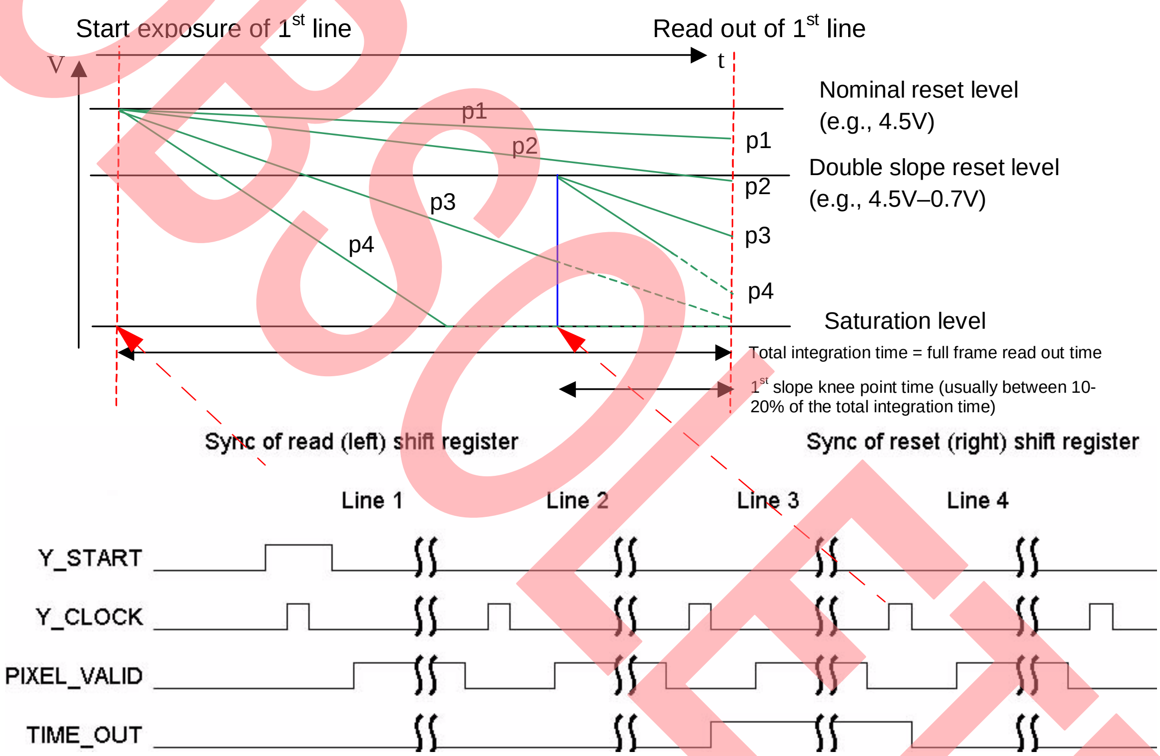


Multiple Slope Operation with Rolling Shutter

The working of double slope in rolling shutter is identical to synchronous shutter, although the timing is a little different. In rolling shutter, the timing of single slope operation is equal to the timing of the double slope operation. The only difference is that in double slope mode, the reset pointer resets the line to the double slope reset voltage instead of the normal reset voltage. The complete integration time in double slope mode is always equal to the full-frame read-out time. THis is because the pixels are only reset to the nominal reset level during read-out (due to the double sampling FPN correction). The position of the reset pointer (changeable with the INT_TIME register) changes the position of the actual double slope knee point.

Because there are only two pointers available in rolling shutter only double slope and no multiple slope (>2) can be achieved. Figure 5 shows the timing involved in double slope operation in rolling shutter.

Figure 5. Double Slope Operation with Rolling Shutter



Example Images

Figure 6. Image with Short Exposure Time (left) and Long Integration Time (right)

Figure 7. Double Slope Image Combining Long and Short Exposure Time in One Image Capture

Figure 8. Single Slope Response

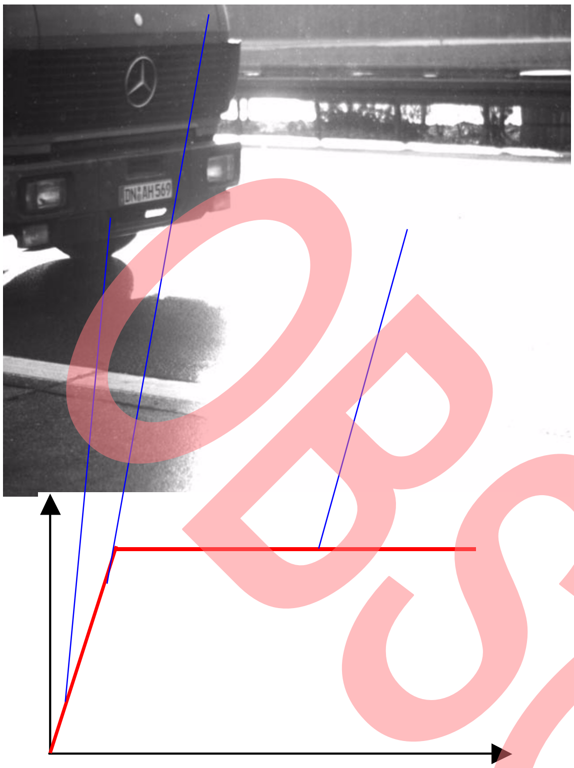
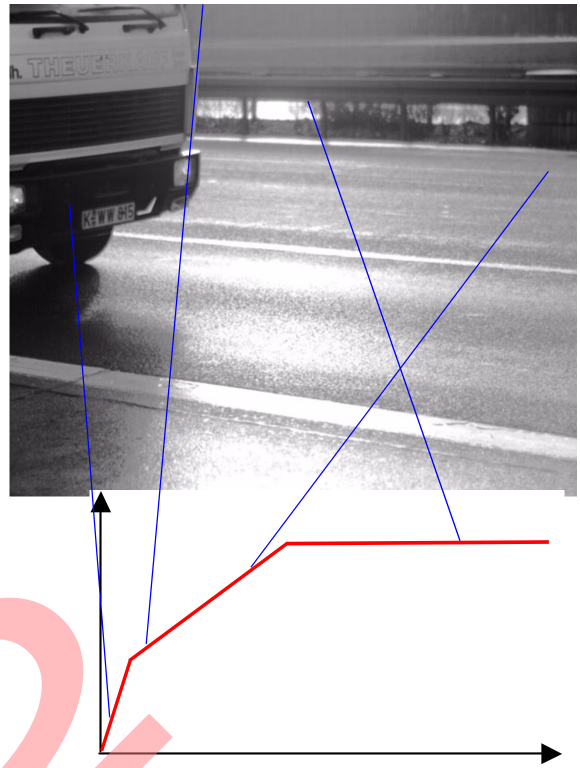


Figure 9. Double Slope Response



Document History

Document Title: Multiple Slope Integration with IBIS5B-1300 - AN4081
Document Number: 001-16627

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	1200303	YIS	See ECN	New application note
*A	3147367	NPA	01/19/11	Changed IBIS5A-1300 to IBIS5B-1300. Added Application Note Abstract section and Document History table.
*B	4112285	MTA	09/04/13	Obsolete specs.

In March of 2007, Cypress recataloged all of its Application Notes using a new documentation number and revision code. This new documentation number and revision code (001-xxxxx, beginning with rev. **), located in the footer of the document, will be used in all subsequent revisions

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