FRAMOS Industrial Depth Camera D400e Series - External Event Camera Synchronization

APPLICATION NOTE

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List of Abbreviations

Abbreviation	Explanation
SDK	Software Development Kit

NIC	Network Interface Card
I/O	Input/output
DC	Direct Current
GND	Ground
VDC	Volts Direct Current
HW	Hardware
IN	Input
OUT	Output

1. Overview

The *FRAMOS Industrial Depth Camera D400e Series - External Event Camera Synchronization* application note provides general recommendations on how to synchronize FRAMOS D400e camera series to an external event.

Stream synchronous to an external event can be achieved by:

- Hardware: utilizing the camera's external synchronization interface
- Software: sending the software trigger command

Additionally, the cameras need to be configured via the software interface to work in such environment.

Information: All the information given in this application note is valid for FRAMOS D400e camera series firmware version v1.11.0.0 (or higher) for D435e, and v1.6.0.0 (or higher) for D415e. Required D400e software package version is v2.1.0 (or higher).

2. Functional Description

By default, FRAMOS D400e camera series is in "Default Mode", streaming at the requested frame rate. When operating in "Master Mode" (refer to *FRAMOS Industrial Depth Camera D400e Series - Multi-Camera Synchronization* [Ref-2] for operating modes explanation), the camera outputs synchronization signal on the Opto-isolated OUT (VSYNC) as shown in Figure 1. VSYNC signal is related only to stereo sensor. RGB sensor does not output signal on the Opto-isolated OUT.

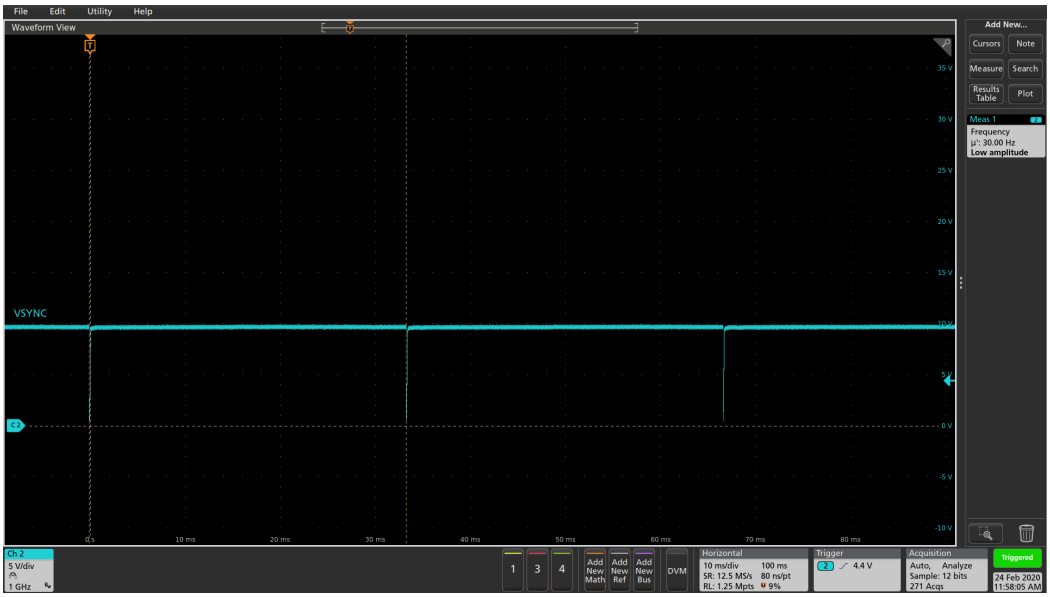

Figure 1 – Opto-isolated OUT in "Master Mode", VSYNC, 30Hz

2.1 External Event Operation

In "External Event" operating mode, camera works in continuous mode at the requested frame rate, but no frames are sent to the host. When external pulse is applied on the synchronization interface or software trigger command is sent, camera sends the next frame generated to the host as shown in Figure 2.

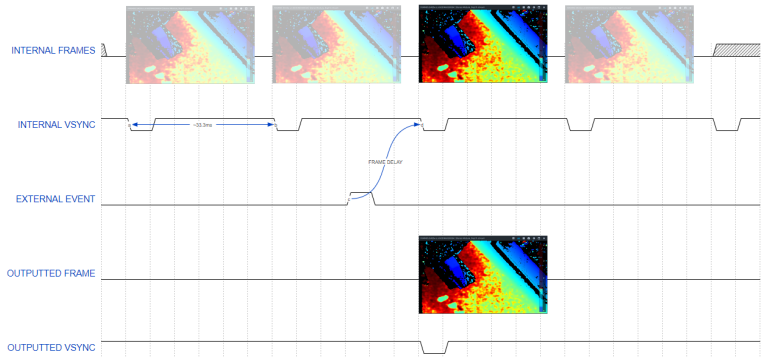

Figure 2 – External Event Operation

As the external event is asynchronous to the internal camera sensor timing, there will be a variable delay between the input pulse (hardware or software) and the generated frame, as shown on Figure 3, where SYNC PULSE is the external pulse applied to the camera, while VSYNC represents the start of the generated stereo frame that is sent to host.

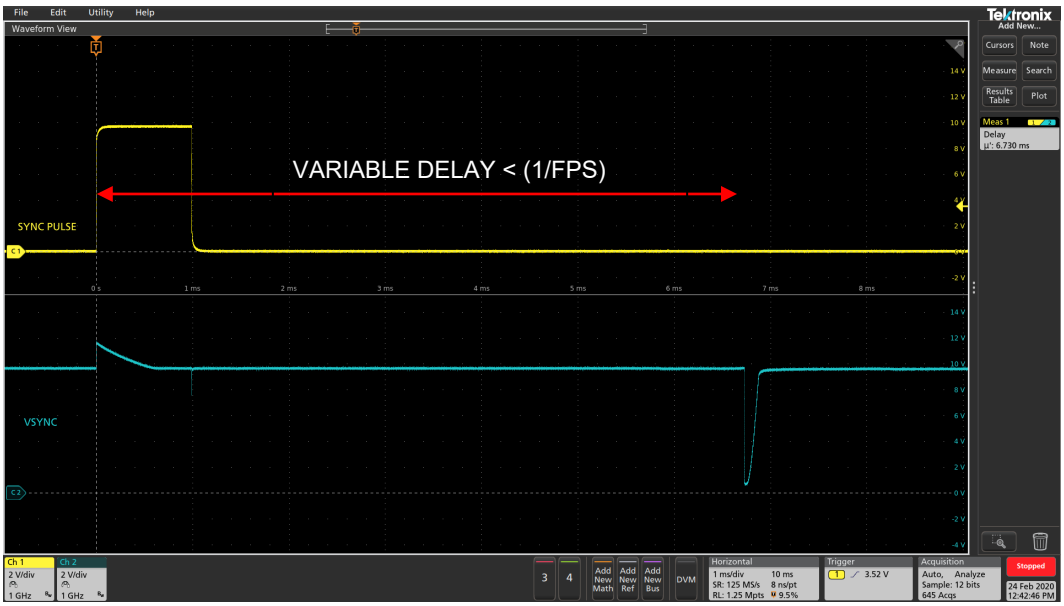

Figure 3 – SYNC PULSE, VSYNC

This variable delay (frame jitter) will never exceed the 1 frame readout time. Maximum delays (T_{MAX}) for various frame rates are given in Table 1.

FPS	T_{MAX} < 1/FPS
60 Hz	16.66 ms
30 Hz	33.33 ms
15 Hz	66.66 ms

Table 1 – Maximum frame jitter for various frame rates

Information: In multi-camera system, where cameras are triggered by external event, each camera will have different frame jitter. The reason for this is that each camera works with its own internal camera sensor timing.

2.1.1 Software Trigger

In "External Event" software trigger operating mode, stereo and RGB sensors work in continuous mode at the requested frame rate, with no frames sent to the host. When software trigger command is sent to either stereo or RGB, camera sends the next frame generated to the host as shown in Figure 2.

Stereo sensor has additional option "RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS" that specifies whether the trigger signal is forwarded to all sensors or is sent to stereo sensor only.

When "RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS" is set to 1, trigger signal is sent to all sensors and camera sends the next frames generated to the host as shown in Figure 4.

If "RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS" is set to 0, software trigger signal is sent to stereo sensor only and camera sends the next stereo frame generated to the host as shown in Figure 4.

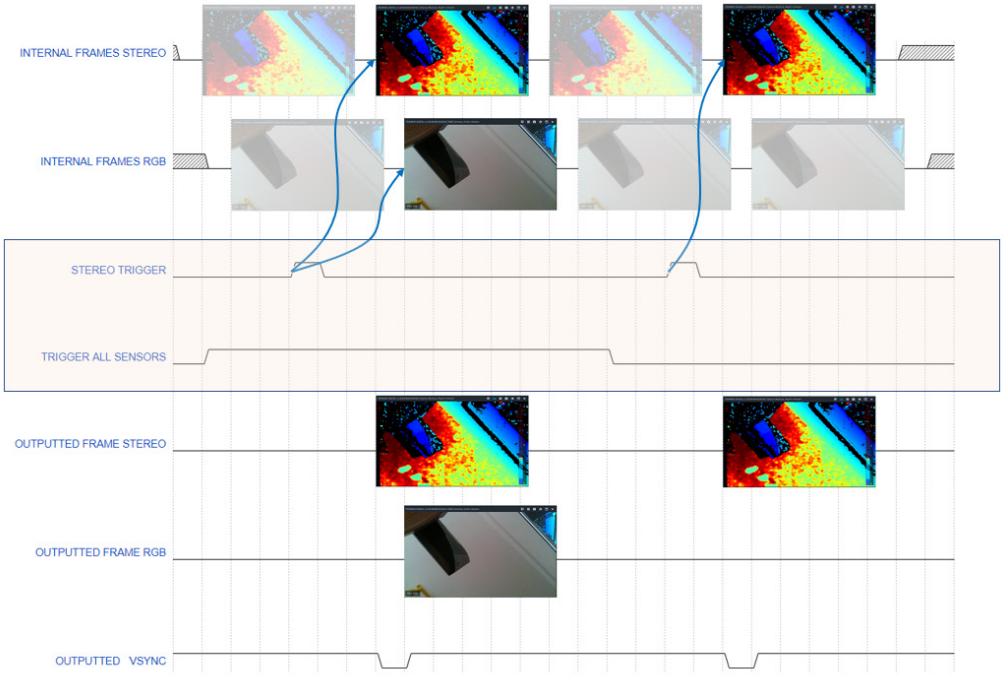

Figure 4 – Software trigger, RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS

Information: Camera outputs **VSYNC** signal only for stereo sensor.

2.2 Genlock Operation

Genlock functionality, introduced in the latest Intel D4 firmware, is available on depth cameras that are based on Global Shutter imagers. From FRAMOS D400e series, this feature is supported on D435e camera.

With the Genlock feature, depth frames can be triggered at arbitrary times or frequencies. Basically, Genlock feature can be related to a slave mode operation for machine vision cameras where input trigger signal starts the exposure window on the image sensor.

More details on the feature are given in *External Synchronization of Intel® RealSense™ Depth cameras* white paper [Ref-4].

As described in Chapter 2.1, for the external event operation there will be a variable delay between the input pulse (hardware or software) and the generated frame, as shown on Figure 3.

For the Genlock operation, delay between the input pulse and the generated frame is fixed and depends on the exposure time set, as shown on Figure 5.

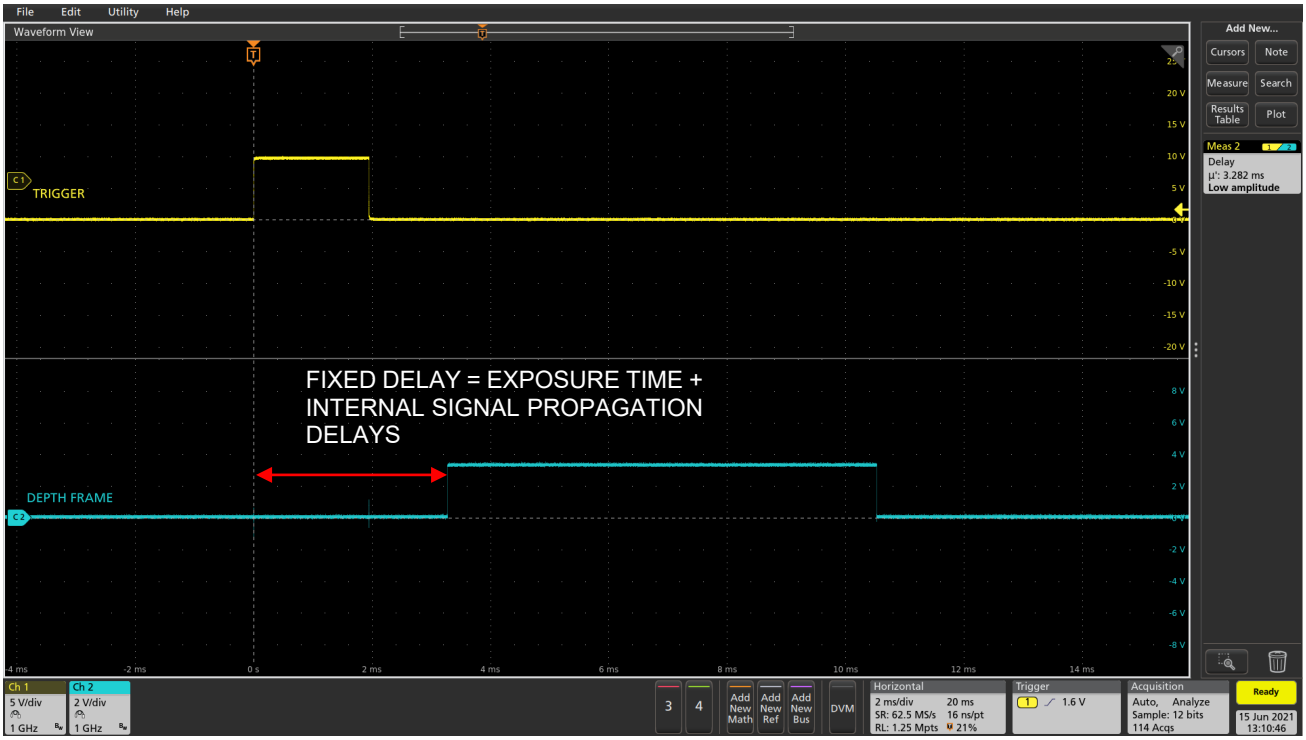

Figure 5 – SYNC PULSE, VSYNC for Genlock

The internal signal propagation delay is an additional delay between the input pulse and start of the exposure, as shown on the Figure 6. This delay vary for different stream profiles, as shown in Table 2.

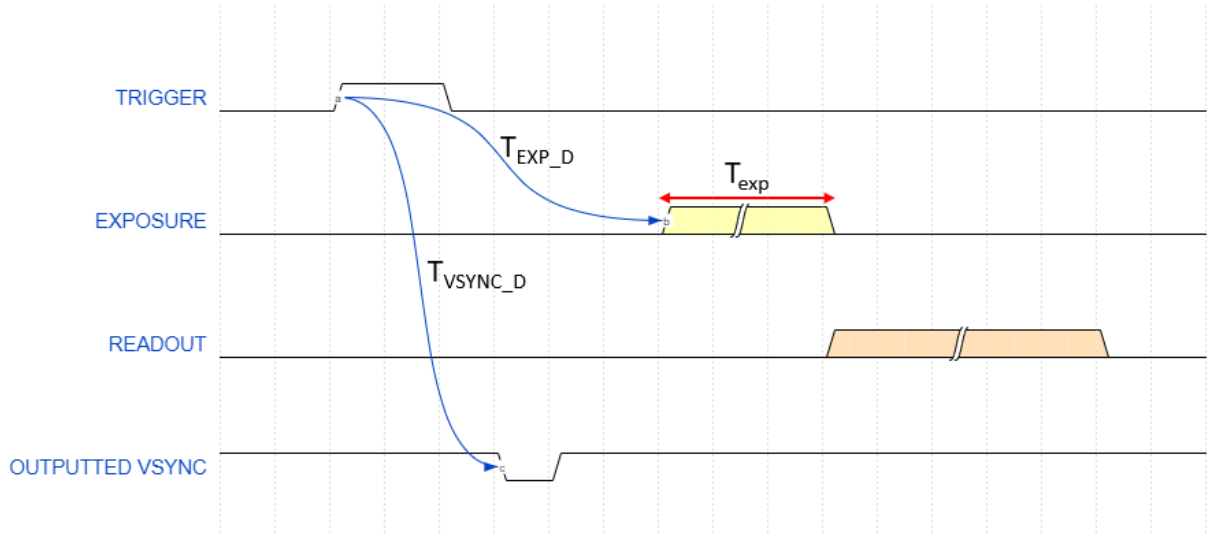

Figure 6 – Delay From Input Pulse to Start Of The Exposure

Stream Profile	T_{EXP_D} [µs]	T_{VSYNC_D} [µs]
1280x720	~880	~2.3
Others	~790	~2.3

Table 2 – Delay from trigger to start of exposure for various stream profiles

Information: When operating in Genlock mode, VSYNC represents the start of the frame generation sequence (not start of exposure or start of readout, as shown on the Figure 6).

For the other operating modes VSYNC represents the start of readout.

In addition, when using Genlock feature, burst of frames can be sent to host using one trigger. Number of frames within one burst is limited to 255 frames.

2.3 External Event Burst Mode

The "External Event Burst" operating mode is similar to "External Event" operating mode, with the difference that the burst of frames is sent instead of single frame for each external event pulse.

The number of frames sent to host within one burst can be specified using sensors option "RS2_OPTION_EXTERNAL_EVENT_BURST_COUNT".

This option is an extension for the Rolling Shutter based cameras (D415e) to simulate the Genlock burst functionality, but it is implemented for all D400e series cameras.

3. Hardware Configuration

The FRAMOS Industrial Depth Camera D400e series is equipped with an industrial grade M8 connector used for power supply and external synchronization through the I/O interface as shown in Figure 7 and described in Table 3.

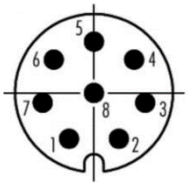

Figure 7 – Power M8 Connector, A-Coded, Male

M8 Pin	Description
1	DC Power supply, 12-24V DC (+/- 10%)
2	Opto-isolated IN
3	Opto-isolated OUT
4	GND for opto-isolated I/O
5	Not connected
6	Not connected
7	Not connected
8	GND

Table 3 – M8 Connector Pin Description

The physical input line **Opto-isolated IN** (Pin 2) is designated as opto-isolated input. The operational limits of the opto-isolated input are given in Table 4.

Description	Limits
Recommended operating voltage	+0 to +24 VDC
Voltage level representing logical 0	+0 to +1.4 VDC
Voltage level representing logical 1	> +2.2 VDC
Absolute maximum voltage	+30.0 VDC
The current draw for each input line	5 to 15 mA

Table 4 – Electrical Specification for Opto-Isolated Input

Physical output line **Opto-isolated OUT** (Pin 3) is designated as opto-isolated output. The operational limits of the opto-isolated output are given in Table 5.

Description	Limits
Recommended operating voltage	+3.3 to +24.0 VDC
Absolute maximum voltage	+30.0 VDC
Maximum output current	90 mA

Table 5 – Electrical Specification for Opto-Isolated Output

Caution: Exceeding the operational limits given in Table 4 and Table 5 can cause permanent damage to the device.

3.1 Schemes

3.1.1 Opto-Isolated OUT/IN Schemes

Electrical scheme of **Opto-isolated OUT** is shown in Figure 8.

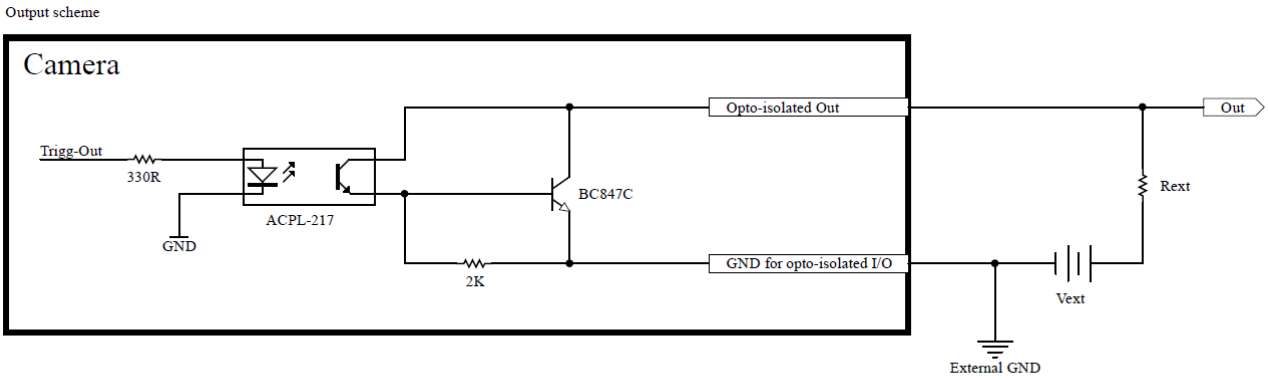

Figure 8 – Opto-Isolated OUT Scheme

Electrical scheme of **Opto-isolated IN** is shown in Figure 9.

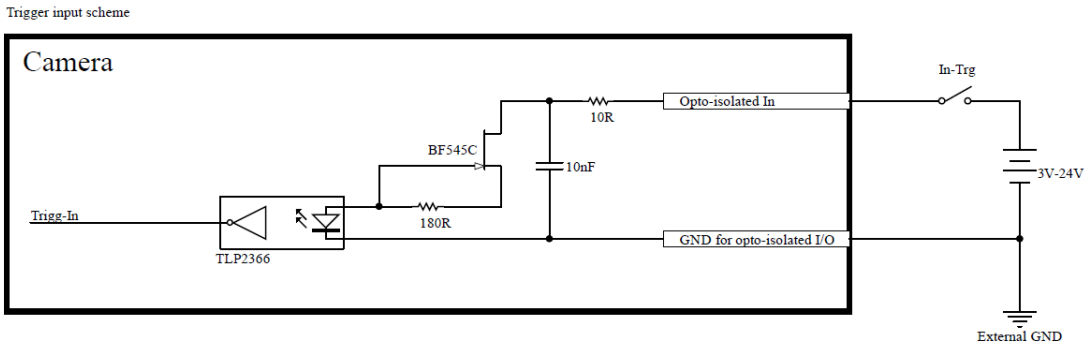

Figure 9 – Opto-Isolated IN Scheme

3.1.2 Synchronization Scheme

The electrical scheme of synchronization of multiple cameras to the external event is shown in Figure 10.

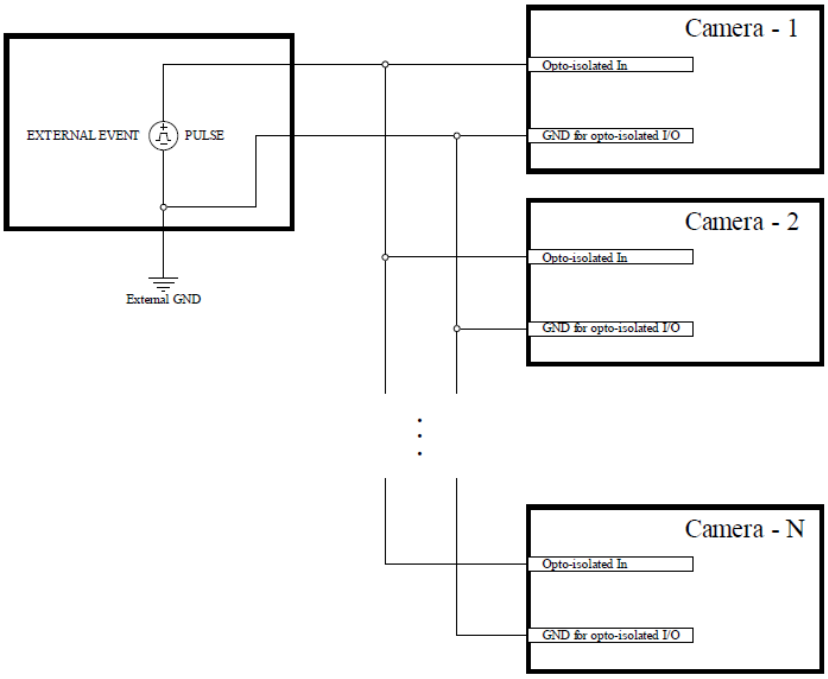

Figure 10 – External Event Synchronization Scheme

For HW synchronization to the external event, External Event Pulse Generator output is connected to Opto-isolated IN of multiple cameras as shown in Figure 10. Additionally, GND for opto-isolated I/O of all cameras is common.

3.2 Recommendations

3.2.1 External Synchronization Pulse

When applying an external synchronization pulse, it is recommended to generate pulse as shown in Figure 11.

For the signal amplitude, follow the electrical specification for opto-isolated input given in the Table 4.

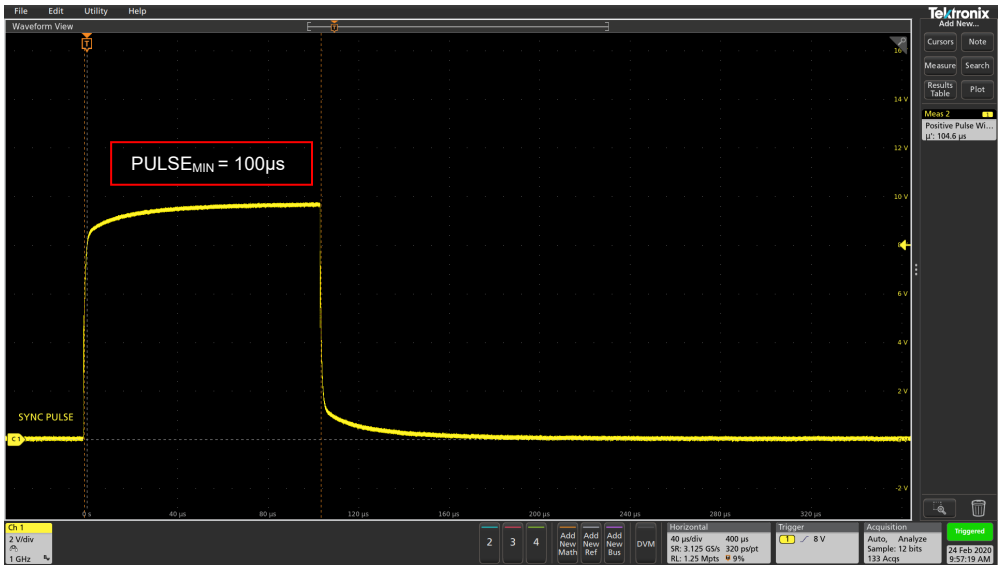

Figure 11 – External Synchronization Pulse

3.2.2 VSYNC Output

When operating in external event mode (single or burst mode), camera outputs VSYNC signal on Opto-isolated OUT. The generated VSYNC pulse corresponds to the frame sent to the host. This signal can be used to verify frame jitter (the delay between the applied input trigger pulse and the frame generated).

4. Software Configuration

4.1 Camera Settings

FRAMOS D400e camera series can operate in following modes:

- Default Mode
- Master Mode
- Slave Mode
- Genlock Mode (only FRAMOS D400e Global Shutter based cameras)
- External Event Mode
- External Event Burst Mode

If it is required to synchronize camera to an external event, camera must be set to "External Event Mode" or "External Event Burst Mode".
For additional information on other operating modes, please refer to *FRAMOS Industrial Depth Camera D400e Series - Multi-Camera Synchronization* [Ref-2] application note.

4.1.1 Setting Operating Mode

External event operating mode can be set for both Stereo Module and RGB camera. Option "RS2_OPTION_INTER_CAM_SYNC_MODE" is used for setting the camera operating mode.

```
// Stereo Module
enum cs_inter_cam_sync_mode
{
    CS_INTERCAM_SYNC_DEFAULT = 0,
    CS_INTERCAM_SYNC_MASTER = 1,
    CS_INTERCAM_SYNC_SLAVE = 2,
    CS_INTERCAM_SYNC_EXTERNAL = 3,
    CS_INTERCAM_SYNC_EXTERNAL_BURST = 4,
    CS_INTERCAM_SYNC_MAX = 5 //enumeration purpose only
};
// RGB Camera
enum cs_inter_cam_sync_mode_color
{
    CS_INTERCAM_SYNC_DEFAULT_COLOR = 0,
    CS_INTERCAM_SYNC_EXTERNAL_COLOR = 1,
    CS_INTERCAM_SYNC_EXTERNAL_BURST_COLOR = 2,
    CS_INTERCAM_SYNC_MAX_COLOR = 3 //enumeration purpose only
};
// Stereo Module Global Shutters
enum cs_inter_cam_sync_mode_gs
{
    CS_INTERCAM_SYNC_DEFAULT_GS = 0,
    CS_INTERCAM_SYNC_MASTER_GS = 1,
    CS_INTERCAM_SYNC_SLAVE_GS = 2,
    CS_INTERCAM_SYNC_FULL_SLAVE_GS = 3,
    CS_INTERCAM_SYNC_EXTERNAL_GS = 259,
    CS_INTERCAM_SYNC_EXTERNAL_BURST_GS = 260,
    CS_INTERCAM_SYNC_MAX = 261 //enumeration purpose only
};
```

4.1.1.1 Setting Operating Mode for the Global Shutter based camera

Example of configuring camera “External Event Mode” through Intel RealSense Viewer is shown in Figure 12.

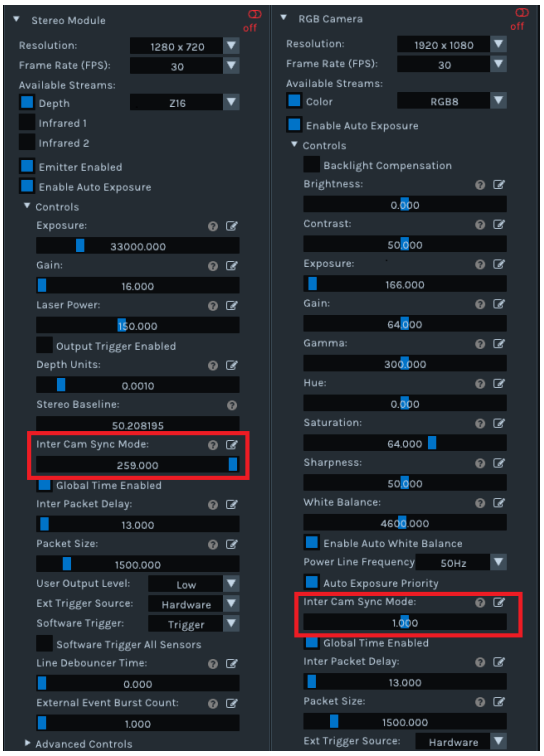

Figure 12 – Setting camera operating mode to external event mode for Global Shutter cameras

To set the “External Event” operating mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_GS);
color_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_COLOR);
```

To set the “Genlock” operating mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
int genlock = 4; //can be set between 4 and 258 with 1-255 frames within burst respectively
depth_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, genlock);
```

Example of configuring “External Event Burst” mode through Intel RealSense Viewer is shown in Figure 13.

Figure 13 – Setting camera operating mode to external event burst mode for Global Shutter cameras

To set the “External Event Burst” operating mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_BURST_GS);

int depth_burst_count = 100;
depth_sensor.set_option(RS2_OPTION_EXTERNAL_EVENT_BURST_COUNT, depth_burst_count);



color_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_BURST_COLOR);

int color_burst_count = 200;
color_sensor.set_option(RS2_OPTION_EXTERNAL_EVENT_BURST_COUNT, color_burst_count);
```

4.1.1.2 Setting Operating Mode for Rolling Shutter based camera

Example of configuring camera “External Event” operation mode through Intel RealSense Viewer is shown in Figure 14.

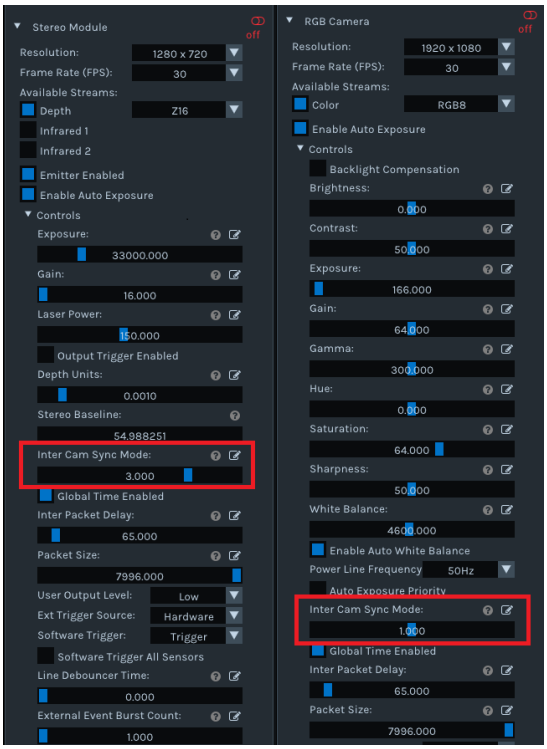

Figure 14 – Setting camera operating mode to external event mode for Rolling Shutter cameras

To set the “External Event” operating mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL);
color_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_COLOR);
```

Example of configuring camera “External Event Burst” operation mode through Intel RealSense Viewer is shown in Figure 15.

Figure 15 – Setting camera operating mode to external event burst mode for Rolling Shutter cameras

To set the “External Event Burst” operating mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_BURST);

int depth_burst_count = 100;
depth_sensor.set_option(RS2_OPTION_EXTERNAL_EVENT_BURST_COUNT, depth_burst_count);

color_sensor.set_option(RS2_OPTION_INTER_CAM_SYNC_MODE, CS_INTERCAM_SYNC_EXTERNAL_BURST_COLOR);

int color_burst_count = 200;
color_sensor.set_option(RS2_OPTION_EXTERNAL_EVENT_BURST_COUNT, color_burst_count);
```

4.1.2 External Event Mode Sources

When FRAMOS D400e camera series is set to "Genlock Mode", "External Event Mode" or "External Event Burst Mode" and stream is started, following sources can be selected for generating the pulse applied to camera:

- Hardware
- Software

4.1.2.1 Hardware Source

Example of selecting hardware trigger source for external event mode through Intel RealSense Viewer is shown in Figure 16.

Figure 16 – Selecting external event source: Hardware

To select the hardware trigger source mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_EXT_TRIGGER_SOURCE, 1);
color_sensor.set_option(RS2_OPTION_EXT_TRIGGER_SOURCE, 1);
```

4.1.2.2 Software Source

Example of selecting software trigger source for external event mode through Intel RealSense Viewer is shown in Figure 17.

Figure 17 – Selecting external event source: Software

To select the software trigger source mode in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_EXT_TRIGGER_SOURCE, 2);
color_sensor.set_option(RS2_OPTION_EXT_TRIGGER_SOURCE, 2);
```

4.1.2.3 Setting RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS Option

Option "RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS" is available only when camera is set to "External Event Software Trigger" mode.

Example of setting "RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS" through Intel RealSense Viewer is shown in Figure 18.

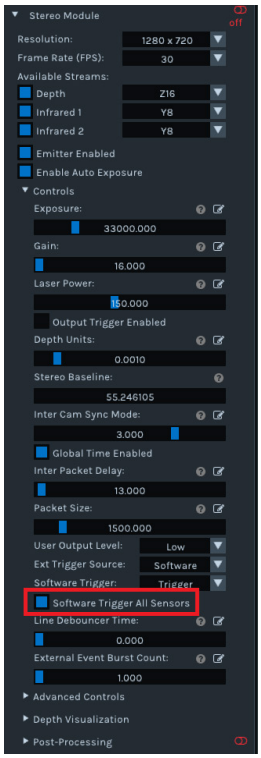

Figure 18 – Setting RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS

To set the "RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS" in code, call the "set_option" function with option name and requested value as shown below.

```
// To set an option to a different value, call set_option with a new value
depth_sensor.set_option(RS2_OPTION_SOFTWARE_TRIGGER_ALL_SENSORS, 1);
```

4.1.2.4 Executing Software Trigger

Example of executing software trigger through Intel RealSense Viewer is shown in Figure 19.

Figure 19 – Executing software trigger

To execute software trigger in code, call the "set_option" function with option name and value as shown below.

```
// Executing software trigger
depth_sensor.set_option(RS2_OPTION_SOFTWARE_TRIGGER, 1);
color_sensor.set_option(RS2_OPTION_SOFTWARE_TRIGGER, 1);
```

Information: All the given examples of configuring the camera to external event software trigger, genlock and external event burst software trigger operating mode can be found in "rs-software-trigger" example that is part of D400e software package v2.1.0 and above.

5. Hardware Validation

External Event Camera Synchronization validation is performed using FRAMOS D435e camera and Function Generator.

5.1 Frame Jitter

As mentioned in Chapter 2.1, frame jitter is less than 1/FPS when external event synchronization is used.

The following test scenario is used for validation:

- Resolution: 1280x720
- Streams: Depth, Infrared, Color
- Frame Rate: 30 FPS
- External Event Frequency: 14 Hz

Results for more than 10000 trigger pulses, that were applied to camera synchronization interface, are given in Table 6 and shown in Figure 20.

Measurement	Mean [ms]	Min [µs]	Max [ms]	Std Dev [ms]
Frame Jitter	16.70	2.628	33.32	9.624

Table 6 – Frame Jitter Result on 10000 Trigger Pulses

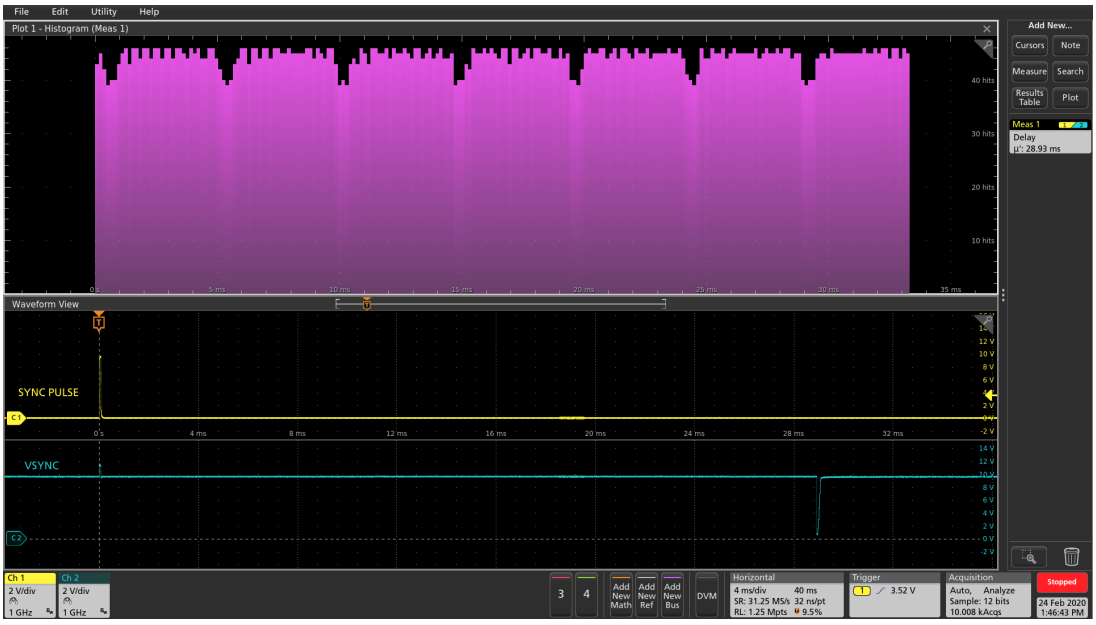

Figure 20 – Real Time Frame Jitter Histogram

SYNC PULSE in Figure 20 is trigger pulse applied to camera and VSYNC represents the start of the generated frame that is sent to host.

Histogram shows different frame jitter captured, varying from 2.63 µs to 33.32 ms.

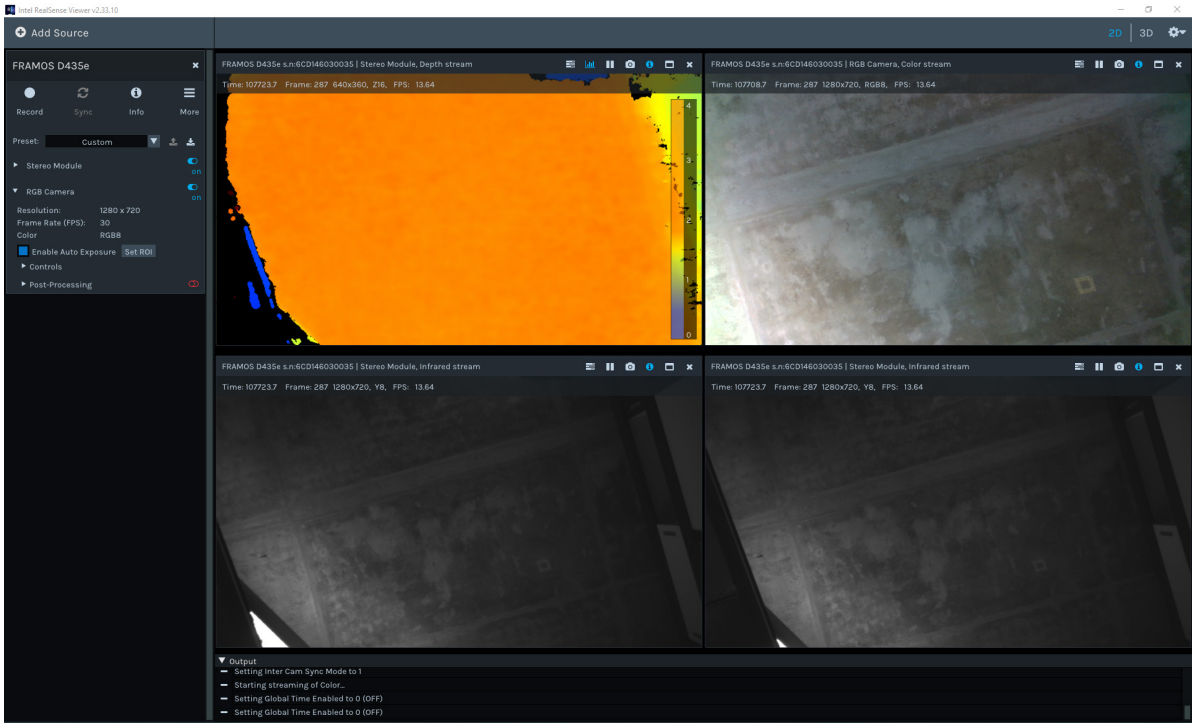

Figure 21 – FRAMOS D435e Camera Streaming in External Event Mode

FRAMOS D435e camera streaming in “External Event” mode is shown in Figure 21. It is visible from the figure that the acquired framerate corresponds to external event pulse frequency.

6. Troubleshooting

This chapter provides troubleshooting information for various issues related to synchronizing D400e cameras with external events.

6.1 Software Trigger Issues

6.1.1 Exceptions

Certain options related to software triggering are dependent on other options. For this reason, RealSense library may throw exceptions if using those features when camera is not in expected operating mode.

Recommended steps to enable software triggering mode and send software triggers to camera:

1. Set the operating mode to "External Event" operating mode (Refer to Chapter 4.1.1).
2. Set the external trigger source to "Software" (Refer to Chapter 4.1.2).
3. Execute "Software Trigger" (Refer to Chapter 4.1.2).

Following exception can be thrown when changing external trigger source, and camera operating mode is not set to "External Event" operating mode.

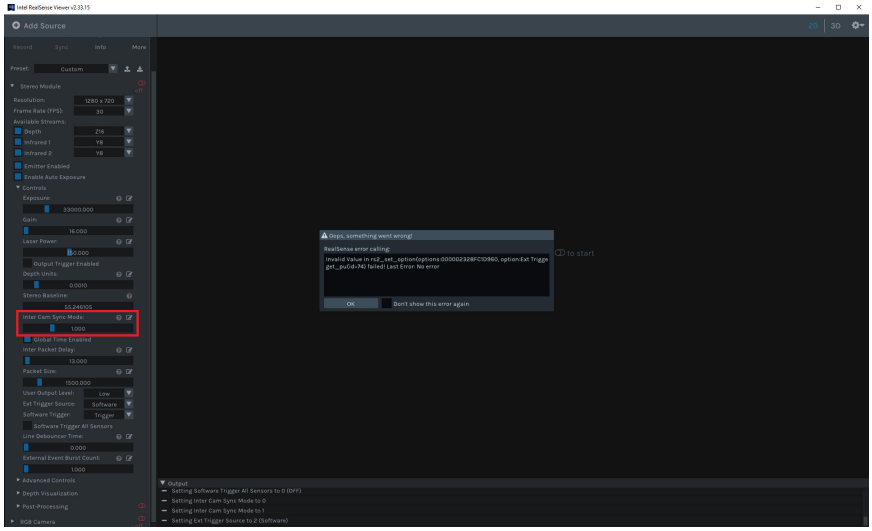

Figure 22 – Changing "Ext Trigger Source" in wrong "Inter Cam Sync Mode"

Exception can be thrown when trying to execute "Software Trigger" and external trigger source is not set to "Software" as shown in Figure 23.

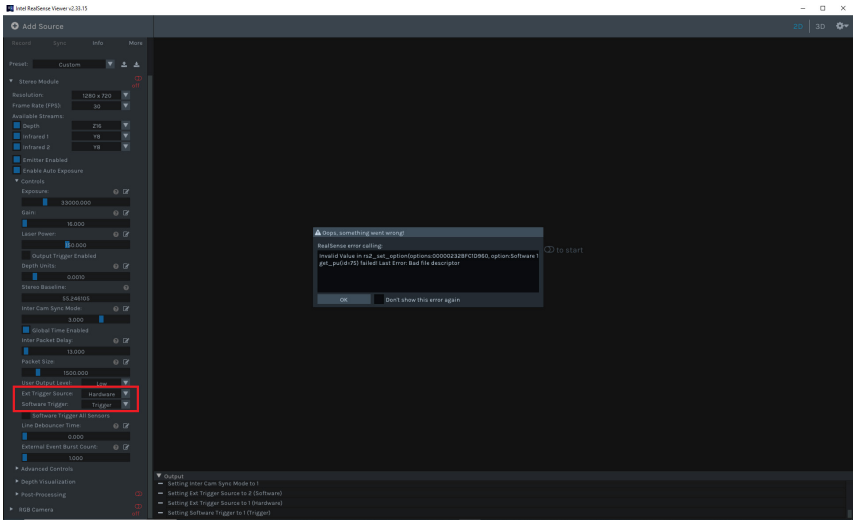

Figure 23 – Executing "Software Trigger" with wrong "Ext Trigger Source"

6.1.2 Rendering

When using software trigger, all frames may not be visualized in RealSense Viewer as it can be seen in Figure 24: one of the infrared sources shows different frame number. Frames are not dropped by the library but are just not shown in RealSense Viewer.

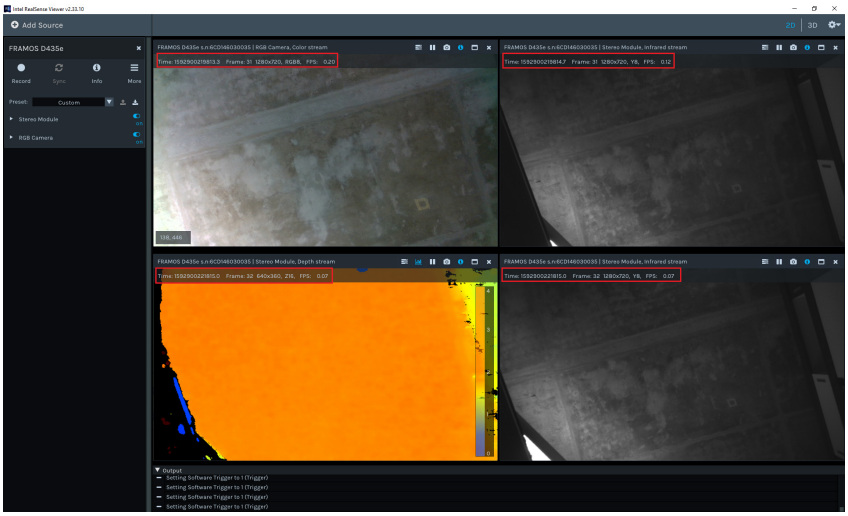

Figure 24 – Frame numbers vary when synchronization in RealSense Viewer is enabled

When using external trigger mode, disable synchronization between the pointcloud and the texture using padlock in upper right corner in the RealSense Viewer as shown in Figure 25.

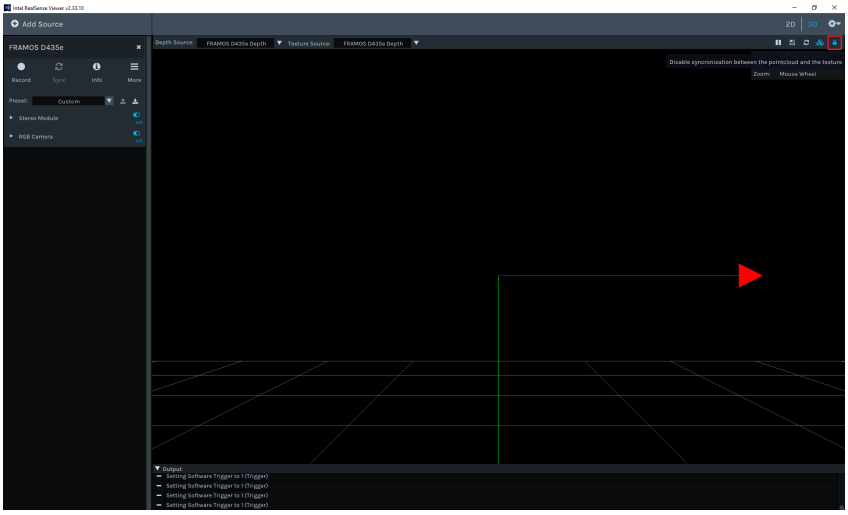

Figure 25 – Disable synchronization between the pointcloud and the texture

6.1.3 Post-processing

Some of the post-processing algorithms require multiple frames for calculations. If post-processing is active, depth information might not be updated correctly as shown in Figure 26.

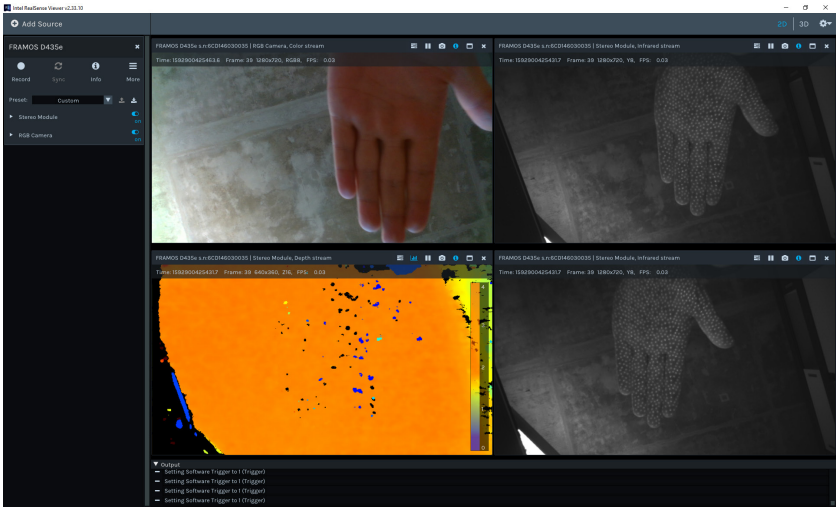

Figure 26 – Post-processing active

With post-processing disabled, depth information is properly updated as shown in Figure 27.

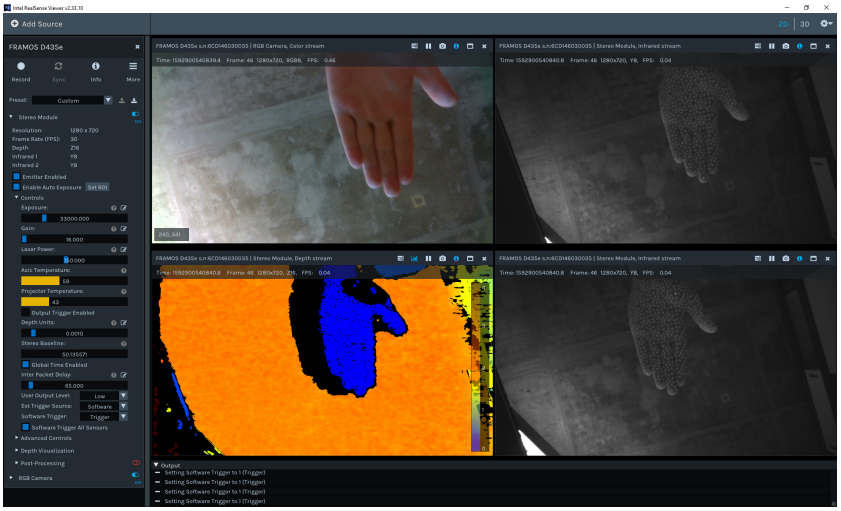

Figure 27 – Post-processing disabled

6.2 Genlock Known Issues

There is a known issue with the Intel D400 global shutter based cameras when using the genlock functionality (Issue 7628): when streaming is enabled, camera generates burst of frames without external trigger being applied on synchronization interface.

For D400e cameras, the extra frames described above are filtered out inside the camera when streaming is enabled, effectively masking out the issue as seen from host perspective. This can lead to different issue on D400e camera in case external trigger is applied immediately after the stream is started. As the camera internally still generates a burst of frames, because of the above mentioned issue, a newly applied trigger does not start new burst of frames (it is ignored), but will disable frame filtering consequently sending the remaining frames from initial burst.

The example below illustrates the problem:

1. Set Inter Cam Sync Mode value to 250, this will enable "Genlock" operating mode and camera should produce and send a burst of 247 frames (refer to Chapter 4.1.1).
2. Set the external trigger source to "Software" (refer to Chapter 4.1.2).
3. Enable stream for Stereo Module.
4. Execute "Software Trigger" (Refer to Chapter 4.1.2) immediately after enabling the stream.
5. Number of frames acquired on the host is less than expected 247 frames, as shown on Figure 28. In presented case only 206 frames were acquired by the host.

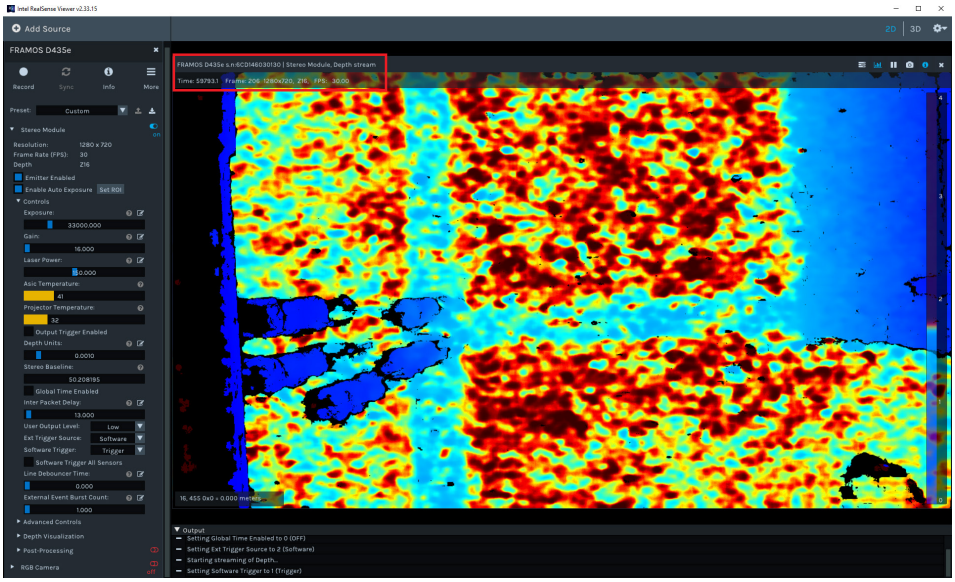

Figure 28 – Genlock issue for D400e series camera

Information: To avoid the described issue on D400e cameras, it is recommended to wait for certain time after stream is enabled before applying the external trigger. Time to wait is calculated by dividing number of frames in burst by frame rate.

7. References

1. FRAMOS Industrial Depth Camera D400e Series - Tuning System For Best Performance, FRAMOS GmbH.
2. FRAMOS Industrial Depth Camera D400e Series - Multi-Camera Synchronization, FRAMOS GmbH.
3. FRAMOS Industrial Depth Camera D400e Series - User Manual, FRAMOS GmbH.
4. External Synchronization of Intel® RealSense™ Depth cameras, v1.0, Intel.

8. Revision History

Date	Version	Changes
2020-06-30	1.0.0	Initial release
2021-01-15	1.1.0	Added chapter "Genlock Operation"; Added chapter "External Event Burst Mode"; Updated chapter "Functional Description"; Updated chapter "Software Configuration"
2021-07-15	1.2.0	Updated chapter “Hardware Configuration”; Updated “References”; Updated chapter “Genlock Operation”

Table 7 – Revision History

NOTE: *This document replaces and supersedes the application note "FRAMOS Industrial Depth Camera D435e - External Event Camera Synchronization" v1.1.0.*