How long can I have our image sensor cables/flexes (and can we connect multiple flex cables back-to-back)?

We get that question asked a lot of times, and the answer is not simple or direct. Like most technical concepts, the answer is “it depends”.

First, we will say that no customer should be connecting multiple flex cables back-to-back to increase length beyond what ModalAI has shipped as a valid and supported configuration. The risk here includes:

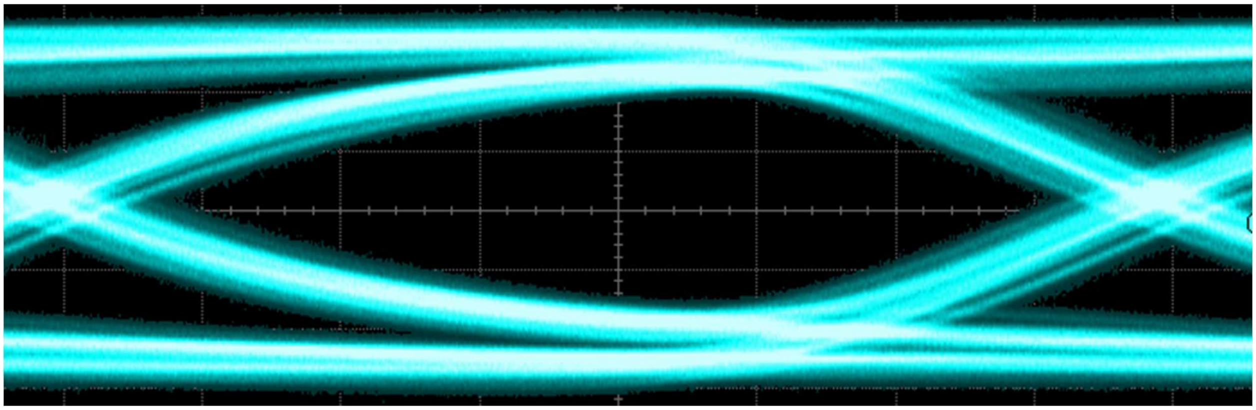
- Incorrect connector orientation risk resulting in sensor or Voxl failures (including power to ground shorts)
- Adding mating cycles to connectors that have limited life span
- Reducing reliability due to increased interconnect points
- Increasing the length or creating a configuration beyond the data link limits ModalAI has already proven and supports

If your application needs an extended length for your image sensor, please contact ModalAI and we can explore a custom flex/cable hardware and software solution that will work for you.

So why can a longer cable make these image sensors fail? These image sensors use a special interface called MIPI CSI (Mobile Industry Processor Interface, Camera Serial Interface) which run at very high speeds (800Mbps and upwards of 2.5Gbps) and require very special attention to design properly. Our team of experienced engineers are experts at high-speed design and every sensor flex (along with our Voxl PCB) has many attributes including controlled impedance, matched length, noise isolation, high-speed connectors, and special EMI protection.

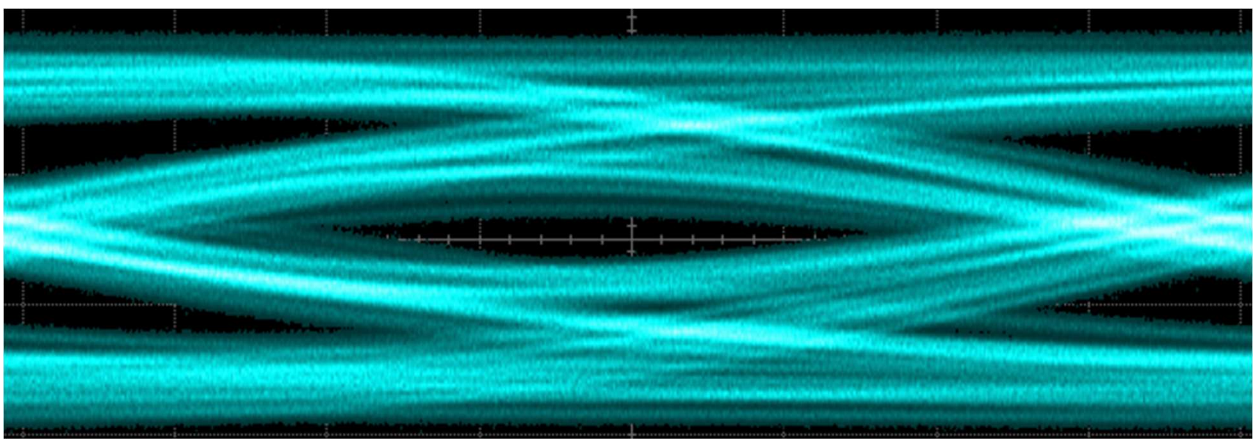
The CSI interface due to the high-speed nature is length limited due to an electrical phenomenon known as high-frequency losses. In all conductors (cables, wires, circuit boards, flex cables, etc.) a signal is degraded more the further it travels and the faster it changes (faster signals have more high-frequency content). The MIPI CSI signals are transmitted by the image sensor and travel through the conductors/flex cables to the Voxl PCB where the signal is received and must be decoded properly. The CSI signals travel as a “differential pair” where a logic HIGH or logic LOW is established by the difference of two signals, not just one signal relative to a ground like on UARTs or SPI busses. At the receiver where this differential pair is detected, the signal and its transitions (from high to low, or low to high) appear to an observer as an “eye” when thousands of bits are overlayed on each other (a very common technique to assess the signal quality of high-speed differential pairs).

The figure below shows an example of a high-speed “eye diagram” where the top signals and bottom signals do not meet in the center of the eye, thus allowing for a valid differential signal to be decoded (there are many other nuances here, but we are simplifying this for a broader audience).

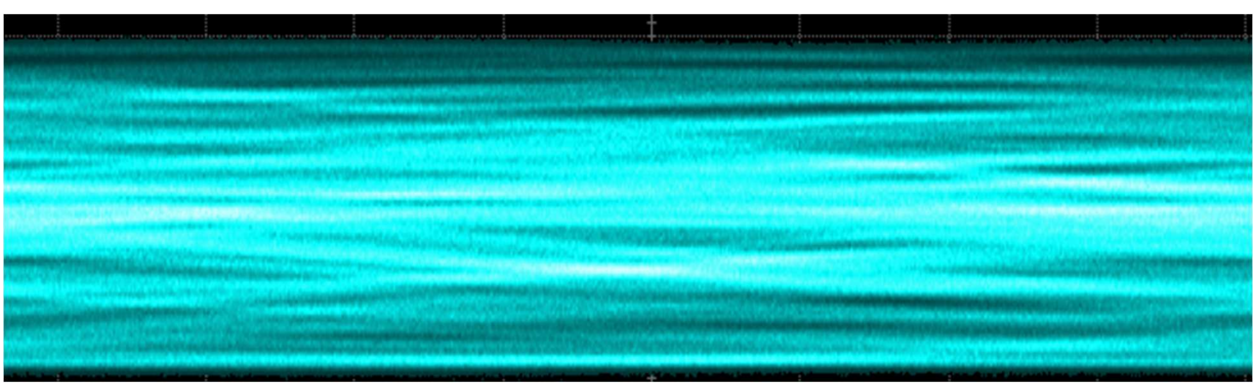


When a signal travels too far (or is increased in speed), the high frequency loses start to impact the edges of the signal and they take longer to reach the HIGH and LOW levels needed by the receiver.

An example of this phenomena can be seen in the figure below where this the exact signal above was made faster (from 2.5Gbps to 5Gbps) and the conductors degrade the signal more as evidenced by the sloped edges and lower amplitudes (the time scale has been adjusted accordingly to showcase a similar eye pattern)



As can be seen in the second image, the clean "difference between high or low" has decreased dramatically, making the receiver introduce more errors in the data link. If the signal speed is increased too much, or the length is increased even more, the eye can completely close resulting in near 100% error rate. The figure below shows an example of this "closed eye" concept.



The net result of this example is to introduce the two main factors for image sensor connection constraints of a system:

- the bit rate, and
- overall length of conductors.

As can be guessed, if an application needs an increased cable length, the bit rates must eventually be reduced. Or, if a very high bit rate is needed, then consequentially, the lengths must be kept very short. However, there are hard limits on either end. The image sensors we sell do have some flexibility on the bit rate, but it is not an unlimited range. For example, the OV7251 sensor nominally operates at 800Mbps, but it can be adjusted down to 200Mbps. Furthermore, Voxl must be aware of and capable of operating at the same exact bit rates as the sensor. Therefore, it is imperative that customers only rely on known tested configurations provided by ModalAI. For example, even though the OV7251 can operate down to 200Mbps, not all image sensor processors can support that rate, and the rate may also be too low for some applications. Note that Voxl can operate at a maximum rate of 2Gbps on the MIPI CSI receivers.

Our experiences with these types of sensors and varying customer needs have helped us to produce a rough table of capabilities, correlating length with maximum bit rates. However, we must caution that not all configurations are supported by ModalAI and the solution must be tested for confirming proper operation. And of course, not all sensors operate at these speeds. This table is only provided as a guide for anticipated capabilities. Additional connectors, conductors/traces on custom PCBs, and any design not following all high-speed constraints will only reduce the capabilities more.

Flex Cable Length	Maximum Image Sensor Bit Rates Expected
1-4”	1.5-2Gbps
5-8”	1.0-1.5Gbps
9-12”	800Mbps-1.0Gbps
13-18”	<=600Mbps
>18”	Not advised. Active circuits needed to amplify or “re-drive” the CSI signals.

From the table it’s easy to see why if you need to change our default provided configuration, it is imperative to work with us to understand your system limits and the changes that may be required. In some cases, the design will require more than passive conductors. We at ModalAI have the experience and capabilities to make your system work the way you need.