

# Designing Physical Network Layouts for the CPI Bus

*Cameron Madsen, Engineering Assistant, Campbell Scientific, Inc.*

*Scott Cornelsen, Senior Design Engineer, Campbell Scientific, Inc.*

## Introduction and Background

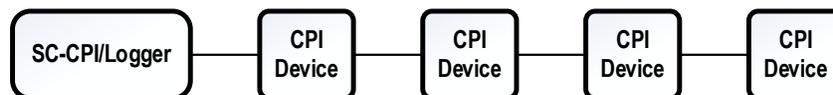
The CAN Peripheral Interface (CPI) is a proprietary measurement bus that provides communication between Campbell Scientific dataloggers and various peripheral modules and sensors. A major advantage of Campbell Scientific's CPI protocol is the ability to communicate between devices over long distances at high rates with various physical network topologies. To use the CPI bus, the CR3000 and CR1000 dataloggers must use a SC-CPI Datalogger-to-CPI Interface because these datalogger designs predate the CPI bus design. In newer dataloggers, the CPI bus will be supported directly by the datalogger. A growing number of Campbell Scientific smart sensors and measurement devices use the CPI bus, including devices that conform to the Campbell Distributed Module (CDM) form factor. CDMs and most other CPI-enabled devices have two available CPI connections on the device, which are internally wired together to allow the passing of signals through the device and on to another device in the network. Standard Cat5e Ethernet cables are used to make connections between the devices on the CPI bus.

The factors that limit distance and baud rate in a CPI network are easily understood conceptually. However, analytically predicting the precise physical limits of a system is a very complex problem, and deriving a sufficiently accurate model of the network can be challenging. Factors that influence the model include the topology of the installation (number and placement of nodes on the line), the cable quality and construction consistency, transceiver electrical tolerances, connector selection and layout, the use of termination resistors, and the presence of external noise. These factors are highly specific to each individual network, so the general rules provided herein for the speed-versus-distance capabilities of the CPI bus are based on estimates, simplifications, and most importantly, experimentation on sample networks.

Several common network topologies were tested and will be discussed. The resulting recommendations are meant to be very conservative so that they can be used with confidence for most systems. The numbers presented can be used as a starting point when designing a CPI network. The user should keep in mind that all the values presented were measured under favorable conditions in the lab without the presence of significant external noise. If a system requires operation near the limits suggested here, then site-specific testing is recommended to guarantee desired performance.

## Daisy-Chain Topologies

A daisy chain is a network topology in which devices are connected one after another with no branches in the sequence of devices. An illustration of this is shown in Figure 1.



*Figure 1: Daisy-Chain Topology*

For the CPI device nearest the datalogger, one CPI port is connected to the datalogger/SC-CPI, and the other CPI port connects to a neighboring CPI device. For CPI devices in the middle of the chain, both ports are connected to neighboring CPI devices. For the CPI device at the end of the chain, one port is connected to the neighboring CPI device, and the other port can either be left open or can contain a special RJ-45 termination resistor plug (pn 28558). In a general daisy-chain topology, termination resistors are usually installed at both ends of the network, but a half-terminated bus is also allowed by using only the resistors at the datalogger end of the network. For simplicity, the datalogger/SC-CPI already contains one set of the necessary termination resistors internally, so all CPI networks are automatically half-terminated. Termination at the other bus end by using the RJ45 termination resistor plug is necessary to eke the absolute maximum performance from the system.

The function of termination is to absorb signal reflections along the wire. When a high-speed signal is sent down a transmission line, a portion of that signal is reflected backward on the line anytime the signal encounters a discontinuity in the impedance of the conductor. Discontinuities most commonly occur at connectors or at the ends of the wire. Conceptually, this is similar to a wave in a still pool of water. When those waves reach the wall of the pool, they reflect and begin to propagate back toward the source of the wave. The wave reflections can continue for some time until all the energy of the wave is dissipated. Electrical signals behave similarly, and the reflections can combine constructively or destructively with the original signal on the wire. This may cause errors when determining the value of each bit in the transmission. The function of a termination resistor is to make the end of the cable look the same electrically as the rest of the conductor so that there is no discontinuity and thus no reflection produced. In the CPI bus, multiple differential signals are transmitted inside the CAT5e cable. These signals are based upon the CAN and RS-485 electrical standards. To achieve termination at the end of a cable, a 100 Ω resistor is connected between the two wires of each signal pair.

A conservative baseline of maximum system performance of a daisy-chained network is given in Table 1. This table was generated based upon extensive empirical testing in laboratory conditions. The experiments conducted for each bit rate covered a variety of daisy-chain topologies over various cable lengths. These topologies ranged from one to four CDM devices attached to a CR3000/SC-CPI, with different combinations of cable spacing between each device. The total lengths specified in the table were verified to work for all tested combinations. The column labeled “half termination” only used the internal termination resistors at the datalogger. The “full termination” case included termination resistors at the far end of the bus as well. Notice that the maximum cable lengths in the table are only slightly longer for the full termination compared to the half termination for most of the slower baud rates. Termination becomes more important as the baud rates of a transmission increase, and as the slew rates on signal transition edges become faster. At slower rates, the maximum usable cable length is dominated by errors caused by propagation delays and signal attenuation. The CPI bus will function very well in the half-terminated state for most systems. These suggested lengths are generally supported by documents published by manufacturers of CAN and RS-485 equipment and ICs. Note that the maximum lengths specified represent the aggregate length of the cable run, including all nodes in the system.

Bit Rate (kbps)	Max Total Cable Length (feet)	
	Full Termination	Half Termination
1000	50	1
500	200	200
250	500	400
125	1200	1000
50	2800	2400

Table 1: Daisy-Chain Network Maximum Cable Length

## Star Topologies

CDM devices can also be linked together in a star topology by using a passive RJ-45 hub to connect all the devices at a single point. This is illustrated in Figure 2. Each CPI device and the datalogger/SC-CPI have a single connection in the hub. In this configuration, only half termination is allowed. Full termination would call for termination at each individual node of the network, which would overload the transceivers and the system would not function. Three different star topologies were tested extensively: the balanced star, the remote star, and the local star (shown in Figures 2, 3, and 4, respectively). In the balanced-star topology, all cables in the network have a similar length. In the remote star topology, the length of cable between the hub and the datalogger/SC-CPI is maximized, while the lengths of cable from the hub to each individual CPI device are relatively short. In the local-star topology, the length of cable between the hub and datalogger/SC-CPI is short (considered to be in the same enclosure), allowing the lengths of cable from the hub to each individual CDM device to be maximized.

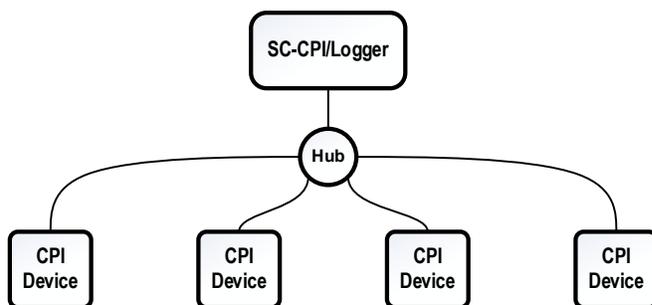


Figure 2: Balanced Star Topology

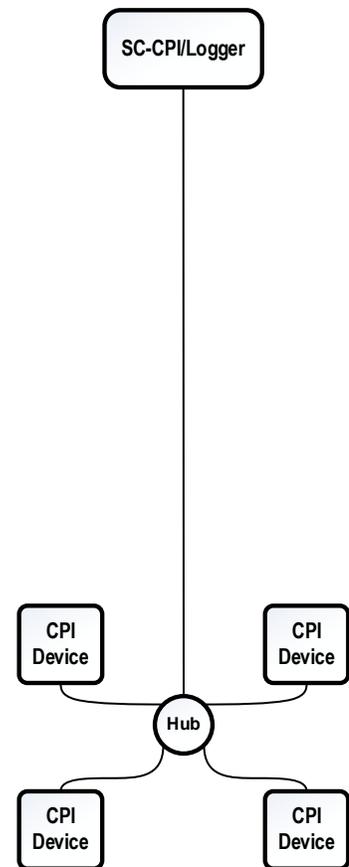


Figure 3: Remote Star Topology

A conservative baseline of maximum system performance of star-topology networks is given in Table 2. Just as was done with the daisy-chain topologies, this table was generated based upon extensive empirical testing under laboratory conditions with many variations of each star network. Five CDM devices interfacing to a CR3000/SC-CPI with different combinations of cable spacing were used in the experiments. The total lengths specified in the table were verified to work for all tested combinations. The testing of the different star configurations gave similar results for total allowed cable length, so the results are summarized into a single table. Notice the maximum cable lengths for the slower baud rates in Table 2 are very close to the half-termination lengths for daisy-chain topologies shown in Table 1. Since the star topology precludes the use of full termination, the

1000 kbps bit rate was shown to not work reliably in a star network. The cable lengths for the 500 kbps rate were also rather limited. These observations are further evidence that the causes of bit errors for baud rates of 250 kbps and below are dominated by propagation delay and signal attenuation, which are a function of cable length in the system and are mostly independent of termination. Meanwhile, for rates of 500 kbps and higher, signal reflections are the greater source of bit errors, which can be improved through the use of full termination. In general, the star experiments showed that having the lengths of cable evenly distributed between each of the five nodes gave better results. Again, note that the maximum lengths specified represent the aggregate length of the cable run, including all nodes in the system.

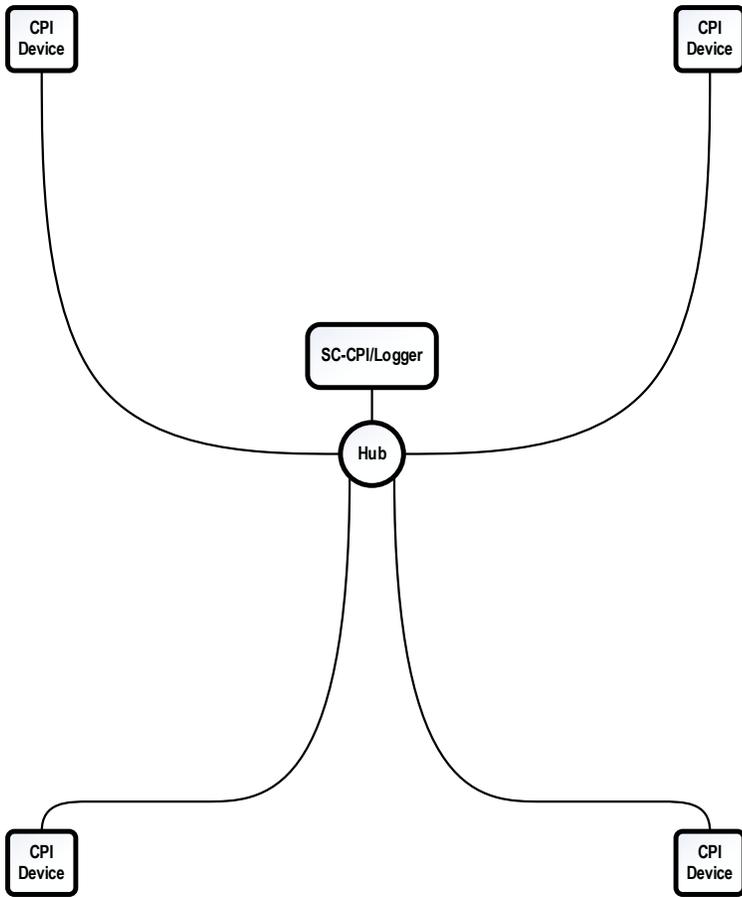


Figure 4: Local Star Topology

Bit Rate (kbps)	Max Total Cable Length (feet)
	Star Networks
1000	not viable
500	100
250	400
125	1000
50	2400

Table 2: Star Network Maximum Cable Length

## Conclusion

Campbell Scientific's CPI protocol is an effective, flexible communication bus with the ability to carry signals over long distances at high rates. These experiments explored the most commonly used network topologies supported by the CPI, but the conceivable combinations of network layouts are limitless. To further explore those cases, randomly selected hybrid configurations with elements of both star topologies and daisy-chain topologies were also tested. The results were generally equivalent to the results of the star topology testing. Therefore, by following these guidelines with regard to topologies, cable lengths, and the use of termination, the user can confidently design a unique network tailored to their specific application and installation.