

**Saqib Mohammad**  
*digital applications engineer*

**Punya Prakash**  
*business manager*  
*Texas Instruments*

---

# Low-latency industrial RS-485 communication

---

## Introduction

Building Automation Systems (BAS) are centralized, interlinked networks that use hardware and software to monitor and control environmental conditions in commercial, industrial, institutional and home building settings. These automation systems manage various control functions of building systems and ensure consistent operation and performance while maintaining enhanced comfort and safety of building occupants. BAS can be found in nearly all points of the wide spectrum of commercial buildings, ranging in size from large to small. Given that growing concern and effort towards green building and energy conservation, and the fact that commercial buildings account for 40 percent of energy consumption, it is no surprise that system upgrades and enhancements continue to evolve.

Historically control systems were pneumatic or air-based and focused mainly on controlling the HVAC system. It was not until the 1980s that analog

electronic control devices became popular, with the advantage that they provided faster and more precise responses than the pneumatics-based predecessors.<sup>1</sup>

Subsequently with the advent of digital control devices in the 1990s true building automation became a reality. It was not until the late 1990s and early 2000s that standards were developed for the digital communication and manufacturers began shifting from using their own proprietary communication-to-communication protocols such as BACnet and PROFIBUS®. For more details on this refer to this [white paper](#) on BACnet.

The physical connections between the nodes in most BAS are typically optical fiber, Ethernet, ARCNET, RS-232, RS-485, or a specialized wireless network. Many of the connections developed and installed in older BAS still use the same physical layer that they originally did, so many of the above examples can be found in automation applications. This white paper will focus on a low latency RS-485 communication that is widely used in the industrial segment, especially in realizing building automation solutions.

## Topology of a standard Building Automation System

BAS are architected as a communication network infrastructure that allows for control over various building services, and are deployed in all levels of building types. The key to an effective BAS is having a ubiquitous system that can be integrated with new and old building technology seamlessly. Typically, the complex building automation network includes a primary and secondary bus that is connected to a range of nodes in the system:

- Building management service
- Building control systems
- Zone controllers
- End nodes

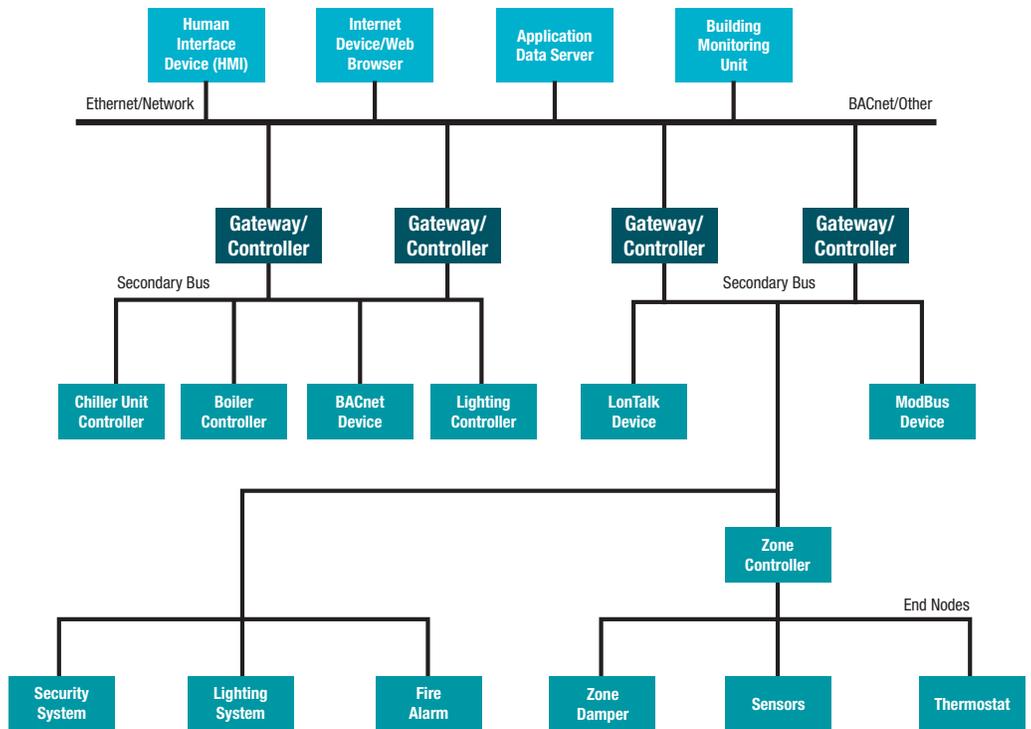


Figure 1. Typical building automation system topology

**RS-485 facilitating industrial serial communication**

For more details on a standard building automation system please refer to the **BAS white paper**.

Modern BAS leverage both wired and wireless Ethernet-based communication systems. However, there are a wide range of existing automation control systems and end nodes that are still based on serial communication.

As such, RS-485, an electrical standard used in a wide range of computer and automation systems, is a viable candidate for BAS.<sup>2</sup> The RS-485 standard defines the characteristics of drivers and receivers for use in a half-duplex digital multipoint system. It is most often used for industrial applications which require long range multi-drop configurations consisting of a single master and multiple slave nodes.<sup>3</sup> Since RS-485 is half-duplex it only uses two output signals, A and B, which act inversely together to transmit or receive a single signal, this means that the RS-485 transceiver must be able to toggle between transmit and receive as defined in the control signals in Table 1.

$\overline{RE}$	DE	Description	State
0 – GND	0 – GND	Receiver enabled, driver disabled	Receive (0,0)
0 – GND	1 – VCC	Receiver enabled, driver enabled	Loopback (0,1)
1 – VCC	0 – GND	Receiver disabled, driver disabled	Standby (1,0)
1 – VCC	1 – VCC	Receiver disabled, driver enabled	Transmit (1,1)

Table 1. State diagram for RS-485 transceiver

RS-485 is typically used for low-speed data communications requiring longer range and minimal wiring. In automation applications the simple bus wiring and long range of the cable are ideal for connecting two or more remote devices. It can be used to connect security control panels, or video surveillance systems, and access control card readers. The protocol sent over the line is not determined by the RS-485 standard which makes it desirable as a flexible infrastructure for a variety of protocols used in a particular system.<sup>4</sup>

### Low-latency RS-485 TX/RX

Wireless-based communication in modern systems such as Wi-Fi®, ZigBee®, Sub-1GHz is starting to replace RS-485-based links. But many industrial applications have safety critical requirements for both instrumentation and process control that can be compromised with interference when using wireless communications. RS-485 offers a light weight, long-ranged wired alternative.<sup>5</sup>

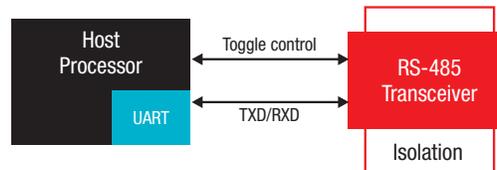


Figure 2. Interface between processor and RS-485 transceiver

There is a potential issue inherent to all half-duplex communication systems and one that exists in RS-485. The problem arises when transition time between states is greater than the time it takes for a slave node to respond to the master, if the delay is too great the transceiver may miss the message if the receiver is still disabled\*; to alleviate this issue, automated techniques are implemented which manage timely toggling once the transmission of the signal is complete. This automation can be achieved through hardware enablement of software solutions. Hardware solutions require additional, external modifications to the transceiver whereas software solutions offer a scalable solution while meeting the system timing requirements.

### Discrete TX/RX control

The Texas Instruments (TI) low-latency RS-485 implementation proposes a discrete TX/RX control that can be realized using the programmable co-processor. A software-based auto toggling for RS-485 can be established by utilizing the Programmable Real-Time Unit and Industrial Communications Sub System (PRU-ICSS) on TI processors.

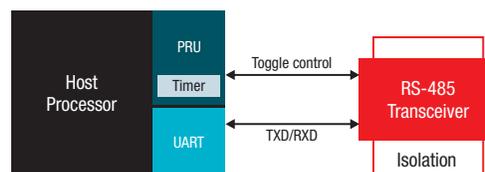


Figure 3. Interface between processor, RS-485 transceiver and auto toggling PRU co-processor

\*Ideal RS-485 turn-around delay is roughly 1 bit time, which is a factor of the baud rate (e.g., turn-around of 1 ms is ideal for a baud rate of 9600).

When the RS-485 transceiver is not transmitting any data, the auto-toggle configures the system to a receive state. When a transmit signal is detected in the auto-toggling mechanism, it modifies the state of the RS-485 transceiver to a transmit state. The turnaround time occurs quickly within a fraction of a bit time. Figure 4 exhibits the data signal that is being sent from the host processor to the RS-485 transceiver. To prevent loss of data, the toggling must occur very early during the 'Start Bit'. If too much time passes before toggling, then the RS-485 transceiver will not transmit the 'Start Bit' and the receiver will not know to receive the following data bits.

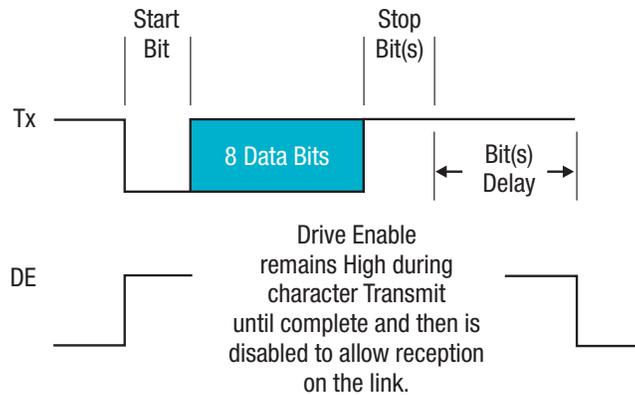


Figure 4. Signal levels showing operation of RS-485 transmit enable (DE) and UART\_TXD (Tx) signal

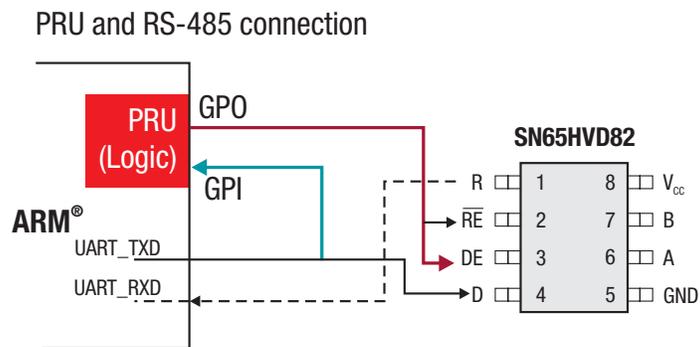


Figure 5. Block diagram of PRU and RS-485 transceiver connections. This is a detailed view of what is represented in Figure 3 on page 3

**Low-latency RS-485 software architecture**

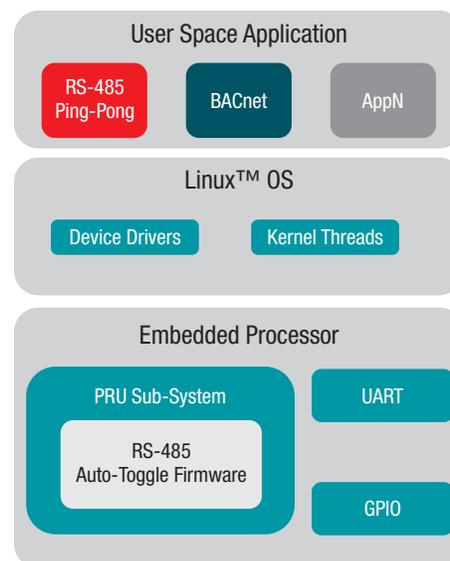
The toggling software on the PRU offers two key benefits:

- The co-processor is capable of monitoring and hence can automate all serial ports on the processor providing a scalable solution.
- The software stack is autonomous to the host operating system hence providing a OS-agnostic system solution.

The ability of the co-processor to cycle through and monitor all serial ports on the hardware, which was a maximum of six in our example use case, allows for an easily scalable solution. The limitation of the scalability comes when board configuration does not expose GPIO pins to connect to the desired number of RS-485 transceivers. With a proper hardware configuration it is possible from both a hardware and software point of view to have the full six serial connections with RS-485 transceivers connected to the PRU and for the UART to transmit and receive pins.

Since the auto toggling is done by the co-processor PRU, with no communication between it and the host processor, it is agnostic to the operating system on the host. The host processor is still responsible for loading and initiating the software onto the PRU.

### **System automation**    **Software set-up and integration:**



**Figure 6. High level operating system (HLOS) software stack for the AM335x processor**

The RS-485 auto toggle firmware enabled on the PRU is loaded through the PRU-loader through the host operating system. Figure 6 illustrates a HLOS such as Linux™. Considering the PRU firmware is operating system agnostic, it can be loaded using any host software system.

The first step for integration and set-up is to configure the host hardware. The pin definitions for each of the RS-485 transceiver's being connected to the PRU are typically defined by the host. In Figure 5 we highlight the connection between PRU, GPO and GPI with  $\overline{RE}$  and  $DE$  on the RS-485 transceiver. The pins used on the PRU must be defined for each  $\overline{RE}$  and  $DE$  pairing; the figure demonstrates a single transceiver connected to the PRU, but the software is capable of up to six. Once the configuration in the header file is complete, the software needs to be recompiled and the resulting firmware is loaded and executed on the PRU.

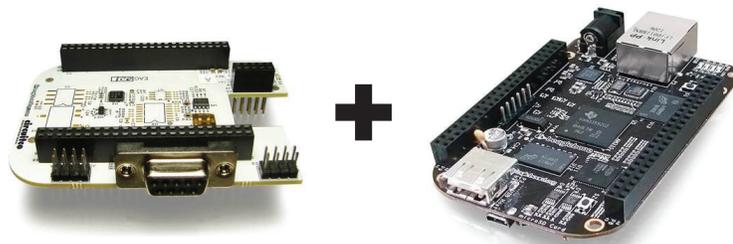


Figure 7. Image depicting the RS-485 cape (left) and the BeagleBone Black (right)

### Hardware set-up and integration:

At a high level the hardware set up uses at least two BeagleBone Blacks, and at least one RS-485 cape on each, see Figure 7. BeagleBone Black is capable of handling up to three capes stacked and the description below applies to each cape. The RS-485 capes are connected to one another via a straight through DB9 cable.

A BeagleBone Black and the RS-485 cape are used as the hardware platform for validation of the TI low-latency RS-485 auto toggle solution. The PRU general-purpose input and general-purpose output (GPI/GPO) are used to govern the RS-485 transceiver control pins. The UART transmit enable, UART\_TXD, is connected to one of the PRU input GPIs which is highlighted in teal in Figure 5. The second GPI is connected to both  $\overline{RE}$  and  $DE$  pins of the RS-485 transceiver highlighted in dark red in Figure 5. By connecting  $\overline{RE}$  and  $DE$  to a single GPO we toggle between the two states: receive (0,0) and transmit (1,1), where the receiver is enabled and driver disabled in the receive state, and the receiver disabled and driver enabled in the transmit state.

### Validation and testing

Performance and validation test data was collected on a BeagleBone White with three RS-485 capes stacked on one another. The capes had to be modified as described above so that the PRU was connected directly to the  $\overline{RE}$  and  $DE$  signals described in Figure 5. Figure 8 on the following page depicts a sample set up and pin muxing which allows for three RS-485 capes to be stacked.

## Conclusions

Continuously evolving smart building technology challenges the building owners and vendors to develop and provide solutions according to the latest industry technology. While the latest technology continues to introduce revolutionary benefits, it is necessary to support the legacy system solutions to aid a smooth transition. These systems with a critical response time requirement need a solution that not only supports existing solutions but also scales across platforms.

TI's low-latency RS-485 solution provides a strong foundation to enable the different entities of an automated building solution and the industrial market at large. This convergence facilitates the control technology to provision management of energy-efficient systems optimizing the operating conditions of the building devices.

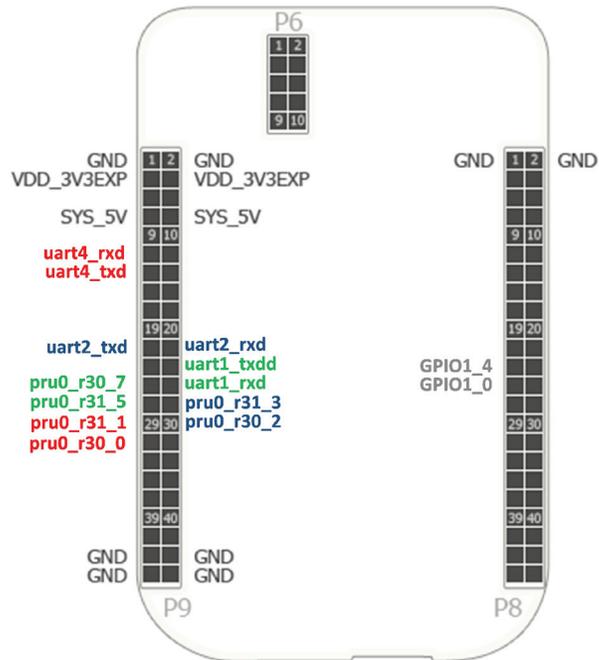


Figure 8. The RS-485 cape top view signal pin-muxing example for three stacked RS-485 capes, using UART1, UART2 and UART4

The building automation solutions utilizing TI processors provide a highly flexible solution for the building management service provider and occupants alike. The solution offers easy integration and a validated system solution, which enables the availability of smart building technology applications to a much broader market.

## References

- <sup>1</sup>[http://www.kmcccontrols.com/products/Understanding\\_Building\\_Automation\\_and\\_Control\\_Systems.aspx](http://www.kmcccontrols.com/products/Understanding_Building_Automation_and_Control_Systems.aspx)
- <sup>2</sup><http://anp.tu-sofia.bg/djiev/PDF%20files/Industrial%20Networks.pdf>
- <sup>3</sup><http://www.lammertbies.nl/comm/info/RS-485.html>
- <sup>4</sup><http://en.wikipedia.org/wiki/RS-485>
- <sup>5</sup><http://www.ti.com/lit/an/slla070d/slla070d.pdf>

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

All trademarks are the property of their respective owners.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)