W H I T E   P A P E R

Saqib Mohammad
digital applications engineer

Punya Prakash
business manager
Texas Instruments

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.[1]

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
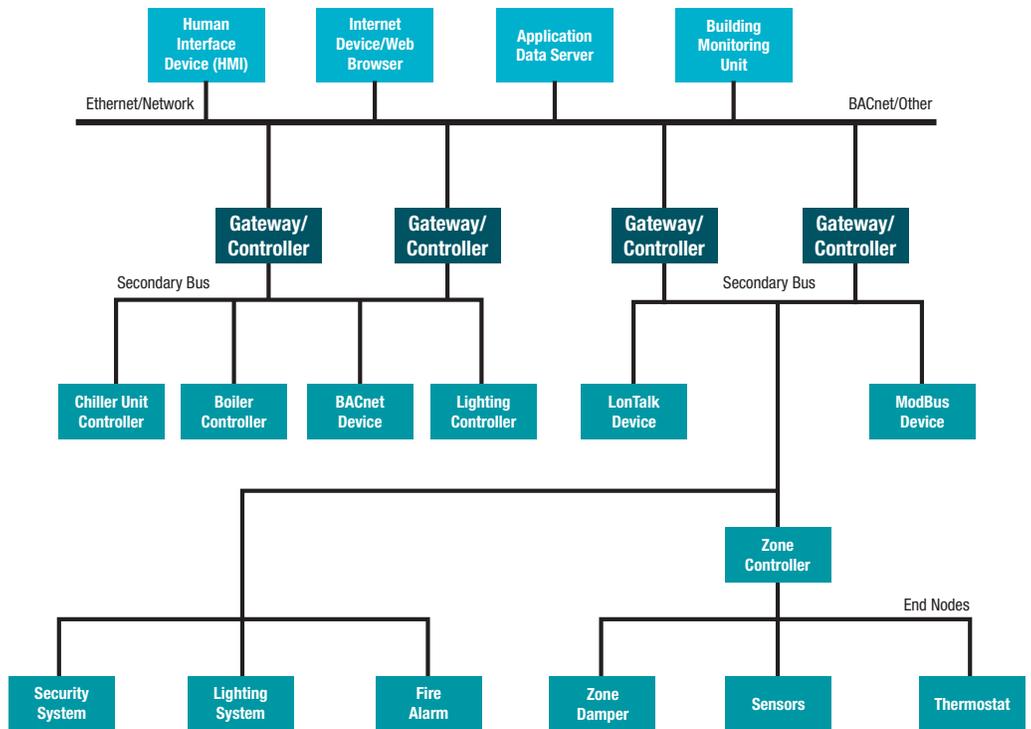- Building control systems
- Zone controllers
- End nodes

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.[2] 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.[3] 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.[4]

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.[5]
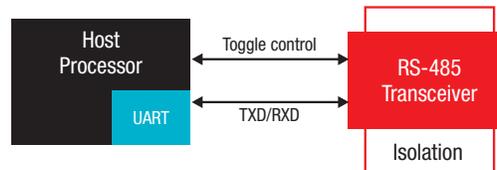
Figure 2. Interface between processor and RS-485 transceiver

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.
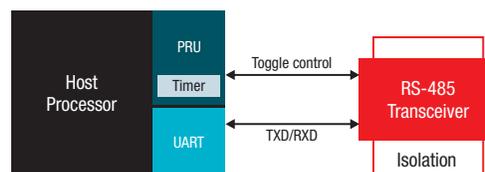

Figure 3. Interface between processor, RS-485 transceiver and auto toggling PRU co-processor

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.
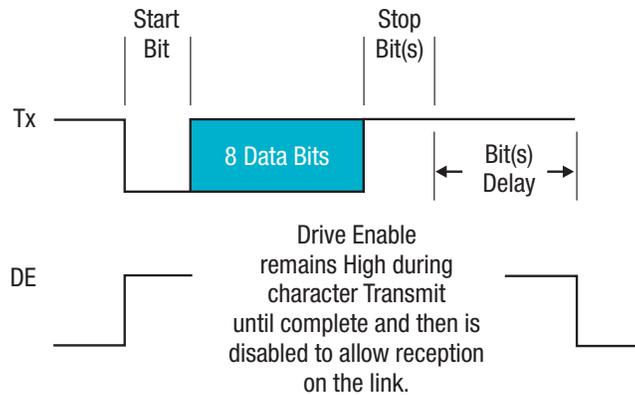
Figure 4. Signal levels showing operation of RS-485 transmit enable (DE) and UART_TXD (Tx) signal
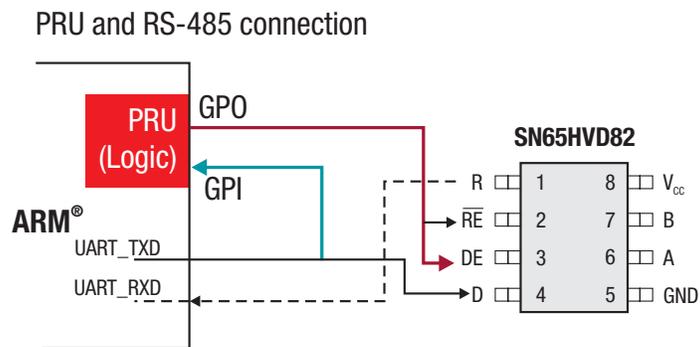
Figure 5. Block diagram of PRU and RS-485 transceiver connections. This is a detailed view of what is repre-sented in Figure 3 on page 3

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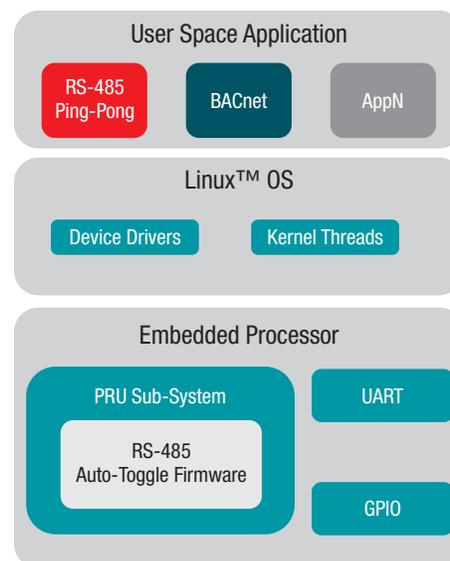
Figure 6. High level operating system (HLOS) software stack for the AM335x processor

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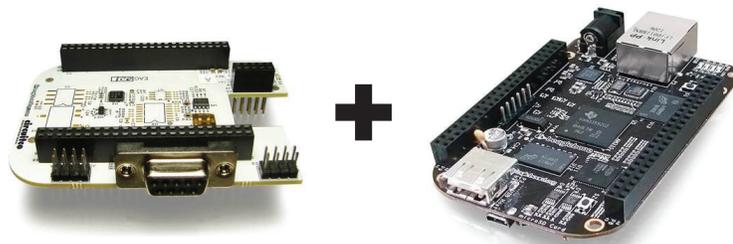
Figure 7. Image depicting the RS-485 cape (left) and the BeagleBone Black (right)

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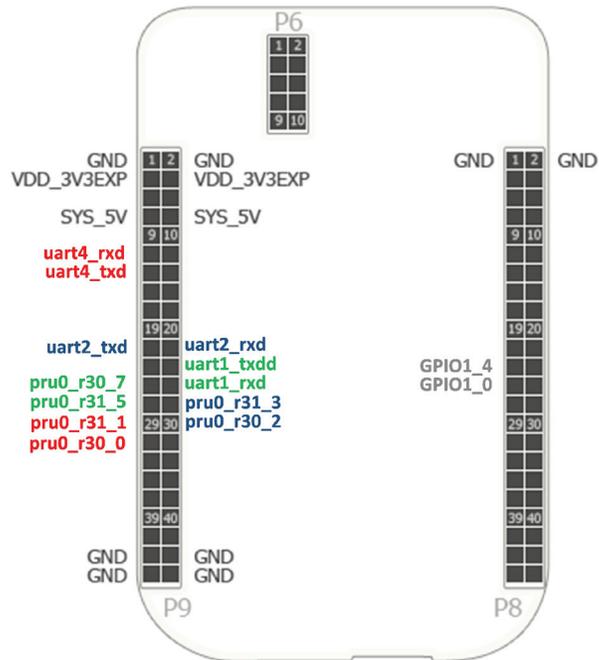
Figure 8. The RS-485 cape top view signal pin-muxing example for three stacked RS-485 capes, using UART1, UART2 and UART4

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

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[2] http://anp.tu-sofia.bg/djiev/PDF%20files/Industrial%20Networks.pdf

[3] http://www.lammertbies.nl/comm/info/RS-485.html

[4] http://en.wikipedia.org/wiki/RS-485

[5] http://www.ti.com/lit/an/slla070d/slla070d.pdf

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