# ClimateTalk 2.0
# CT-485 Physical Specification

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## Abstract

ClimateTalk is a universal language for innovative, cost-effective solutions that optimize performance, efficiency and home comfort. The ClimateTalk Open Standards define a set of messages and commands to enable interoperability, enhanced user interface, and machine to machine control independent of the physical layer connecting the devices.

This document defines the Serial Hardware requirements for CT-485. Corresponding to OSI Layer 1, the Physical specification defines the electrical transmission requirements for implementing ClimateTalk over CT-485.

# Updates

This specification may be updated at any time and may be superseded by a more recent version or amended to from time to time. Users should be certain they are using the correct document version.

Contact the ClimateTalk Alliance for released versions of all specifications at http://www.ClimateTalk.org

# Version History

| ClimateTalk Version | Document Revision | Release Date | Comments |
|---|---|---|---|
| V 0.9 | | 2008-11-07 | Pre-Release |
| V 1.0 | | 2009-08-24 | Initial Release |
| V 1.1 | | 2011-06-23 | Errata Package |
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# Contributors

The following is a list of ClimateTalk Alliance member companies that were actively engaged in the development of this standard:

A.O. Smith Water Products Company

ecobee inc.

EDC

Emerson Electric, Co.

EWC Controls, Inc.

Microchip Technologies, Inc.

Nogginhaus, LLC.

Research Products Corp.

Rheem Manufacturing Company

Zonefirst

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# 1.0 Overview

## 1.1 ClimateTalk Model

ClimateTalk is a universal language for innovative, cost-effective solutions that optimize performance, efficiency and home comfort. The ClimateTalk Open Standards define a set of messages and commands to enable interoperability, enhanced user interface, and machine to machine control independent of the physical layer connecting the devices.

The messages and commands defined by ClimateTalk Information Model are the presentation and application layers as defined by the OSI Model[1]. ClimateTalk Applications are fully defined at Layer 7 of the OSI model by a combination of a Device Specific Application Profile, an Application Specification, and the Command Reference.

Below the application layer, ClimateTalk messages can be carried over any physical medium following the OSI model. CT-485 and CT-LWP are wired serial physical and network layers designed to support the formation of ClimateTalk networks and transport ClimateTalk messages, but other OSI based protocols –including wireless transports - can be used as well.

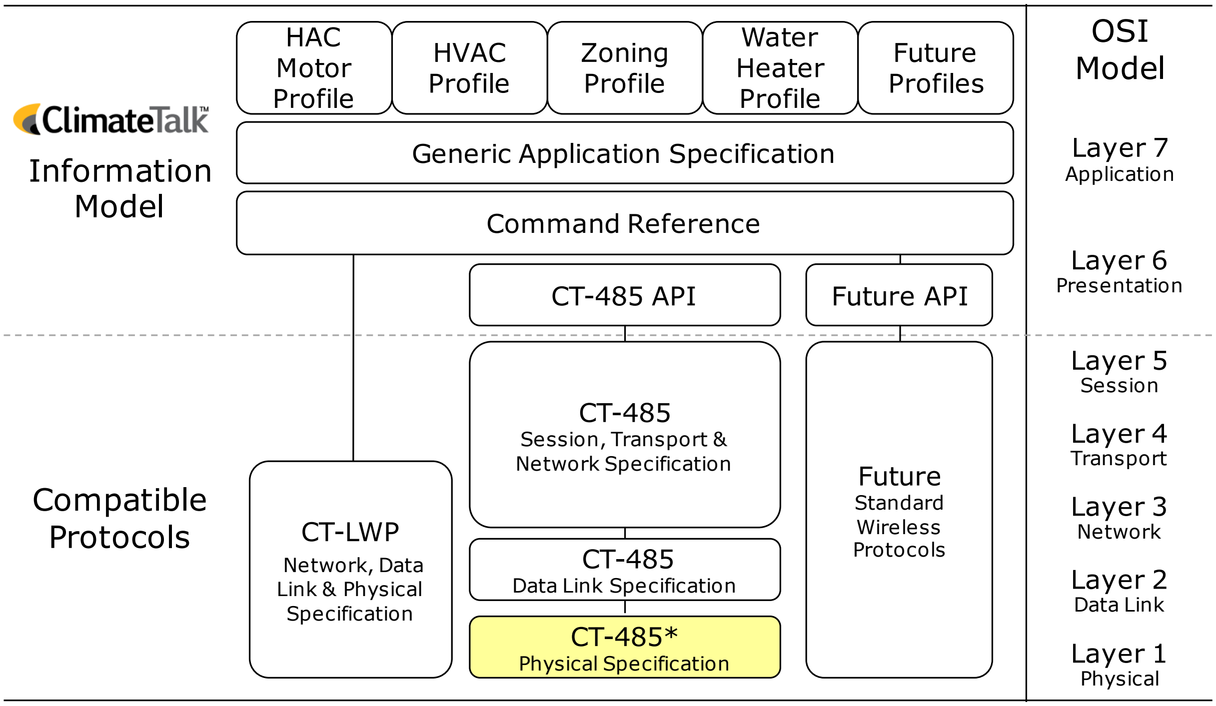
## 1.2 Scope

CT-485 is a Physical, Data Link, and Networking set of specifications that define one of the physical media over which ClimateTalk messages are sent. CT-485 is a variant of EIA/TIA-485[2] standards with provisions against incorrect wiring and grounding requirements that meet the needs of residential systems.

This document defines the Serial Hardware requirements for CT-485, which corresponds to OSI Layer 1. The Physical Specification defines the electrical transmission requirements for implementing ClimateTalk over CT-485. All hardware is defined in this specification and all devices must meet the requirements in this document to be certified as CT-485 devices. See Figure 1 - OSI Layers for a CT-485 Implementation for a diagram of relevant standards.

**Figure 1 - OSI Layers for a CT-485 Implementation**

1 http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=20269
2 http://standardsdocuments.tiaonline.org/tia-tsb-89-a.htm




**This Document*

The ClimateTalk Open Standards package shown in Figure 1 - OSI Layers for a CT-485 Implementation prescribes the requirements to ensure proper network formation of interoperable devices. Membership in the ClimateTalk Alliance as well as successful completion of conformance testing is required for listing a product as a ClimateTalk Certified Device.

Each device must comply with the mandatory requirements defined in this document as well as all other ClimateTalk standards applicable to the device functionality.

# 2.0 Normative References

A good understanding of the following document is required to apply the contents of this specification correctly.

TIA-485 (Revision A), Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems.[3]

[3] Telecommunications Industry Association (TIA) publications are available from IHS, http://global.ihs.com. This standard was known previously as RS-485 and EIA-485 and is sometimes referred to by all three sets of initials as TIA/EIA -485.

# 3.0 Terminology

## 3.1 Definitions

**2-Wire Configuration**
A CT-485 communication wiring mode that uses two wires of the same length and size to connect the indoor with the outdoor unit. This configuration requires one transformer in the Indoor Unit and one transformer in the Outdoor Unit to operate and can tolerate total wire resistances of up to 5.1 ohms per conductor. The trade-off for 2-Wire mode versus 3–Wire mode is distance between the Indoor and Outdoor Units. The wire length for 2-Wire mode is limited to thirty three percent of the operating length of 3-Wire configuration.

**3-Wire Configuration**
A CT-485 communication wiring mode that uses three wires of the same length and size to connect the Indoor Unit with the Outdoor Unit. This configuration requires one transformer in the Indoor Unit and one transformer in the Outdoor Unit to operate. It tolerates total wire resistances of up to 15 ohms per conductor and can provide the maximum operational distances (*A specification reference here).

**4-Wire Configuration**
A CT-485 communication wiring mode that uses four wires of the same length and size to connect "1," "2," "C," and "R" between multiple subsystems. This configuration tolerates total wire resistances of up to 0.8 ohms per conductor and adds the benefit of requiring only one transformer to power both the Indoor and Outdoor Subsystems. It is limited to 5.2 percent of the operating wire length as compared to the 3-Wire configuration.

**C**
Power and serial common, one of the 4 wires on the 2-wire bus

**CT-485 Serial Bus**
A differential communication standard that provides communication over a 2-Wire, 3-Wire, or 4-Wire bus. The communication signals on two of the wires (CT1, CT2) follow the signal standards and voltage levels equivalent to the TIA/EIA-485 serial communication standard. Several enhancements and requirements beyond the basics of TIA-485 are incorporated into the *CT-485 Serial Hardware Specification*.

**CT1**
Data communications positive for CT-485, one of the four wires on the CT-485 4-Wire bus

**CT2**
Data communications negative for CT-485, one of the four wires on the CT-485 4-Wire bus

| | |
|---|---|
| **HVAC Subsystem Nodes** | Any subsystem involved in the control of HVAC operation is considered an HVAC Subsystem Node. E.g. a Thermostat, Furnace, Air Handler, Air Conditioner, and Heat Pump. |
| **Master Controller** | This is the Indoor Subsystem that provides a proper pull-up and pull-down bias voltage and ground |
| **Profile** | Set of rules governing the implementation of certain aspects of the protocol, which includes timings and communication rules to function properly |
| **R** | 24 VAC power for CT-485, one of the four wires on the CT-485 4-Wire bus |

## 3.2 Acronyms

| | |
|---|---|
| **API** | Application Programming Interface |
| **AWG** | American Wire Gauge |
| **BOM** | Bill of Materials |
| **bps** | bits per second |
| **CT** | ClimateTalk |
| **EIA** | Electronic Industries Alliance |
| **F1** | Fuse one |
| **F2** | Fuse two |
| **HVAC** | Heating, Ventilation, Air Conditioning |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **LED** | Light Emitting Diode |
| **LSB** | Least Significant Bit |
| **MDI** | Message Data Interface |
| **MSB** | Most Significant Bit |
| **MTU** | Maximum Transmission Unit |
| **OSI** | Open Systems Interconnection |
| **PC** | Personal Computer |
| **PCB** | Printed Circuit Board |
| **PTC** | Positive Temperature Coefficient over-current protection device |
| **R3** | Resistor three |
| **R4** | Resistor four |
| **RMS** | Root Mean Squared, used in conjunction with voltage |
| **RX** | Receive, usually used in conjunction with data |
| **TIA** | Telecommunications Industry Association |

| | |
|---|---|
| **TVS** | Transient Voltage Suppressor |
| **TX** | Transmit, usually used in conjunction with data |
| **UART** | Universal Asynchronous Receiver Transmitter |
| **UTP** | Unshielded Twisted Pair |
| **VAC** | Volts Alternating Current |
| **VDC** | Volts Direct Current |

## 3.3 Word Usage

The conventions used in this document are modelled after the definitions of the *2009 IEEE Standards Style Manual*. The *IEEE Standards Style Manual* can be downloaded from https://development.standards.ieee.org/myproject/Public/mytools/draft/styleman.pdf.

**can** Equivalent to *is able to* or *is capable of*.

**may** Equivalent to *is permitted to* or *is allowed to*. The use of *may* means that something is optional and does not imply a requirement.

**must** Used to describe situations where no other course of action is possible.

**shall** Equivalent to *is required to*. Use of the word *shall* means that the specification shall be implemented exactly as described in order to ensure correct operation and interoperability with other devices.

**should** Equivalent to *is recommended that*. This is used in situations where there are several possible options, but one option is preferable to the others.

# 4.0 Data Transmission Specification

## 4.1 Data Rate

Each byte transmitted shall contain one (1) start bit, eight (8) data bits, and one (1) stop bit.

The default data rate is 9,600 bits per second (bps).

## 4.2 Network Transmission Wire

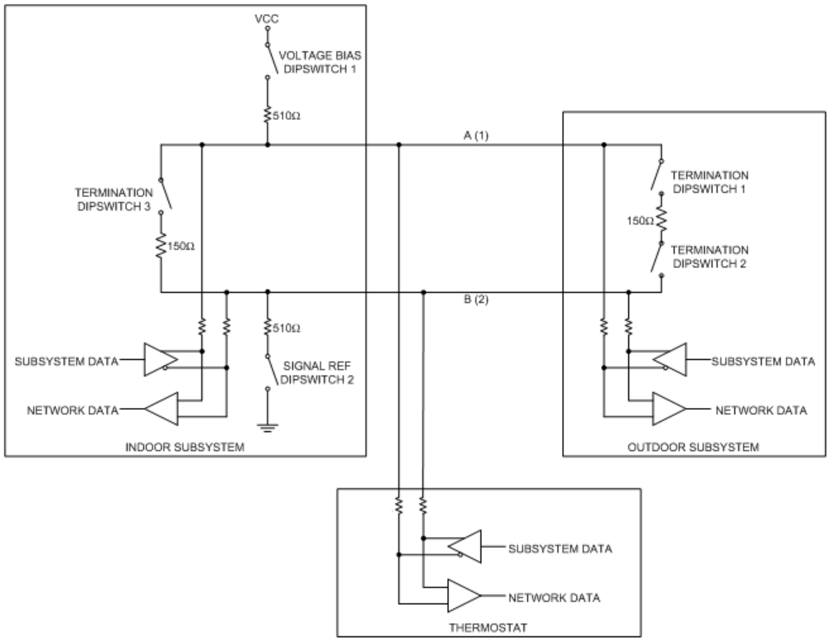
The indoor control shall bias the transmission line to add extra signal integrity to the system, which allows for higher reliable traffic on the network.

Figure 2 demonstrates the biasing of the network using the dipswitches required by the indoor and outdoor subsystems. Notice the thermostat or any other device added to the system would be a simple tap off the CT-485 Serial Network and will not require a bias and/or termination like these subsystems.

The voltage bias (dipswitch 1 of the indoor subsystem) holds the A (1) to the high voltage level to offer the highest signal integrity if there are noise and glitches on that line. The signal reference (dipswitch 2 of the indoor subsystem) will hold the B (2) to the complement level of the network, which is ground for CT-485's implementation of the CT-485 Serial Transmission Network.

The Master Controller shall be the indoor subsystem that provides a good bias w for proper signal pull-up and pull-down ensuring better quality communications.

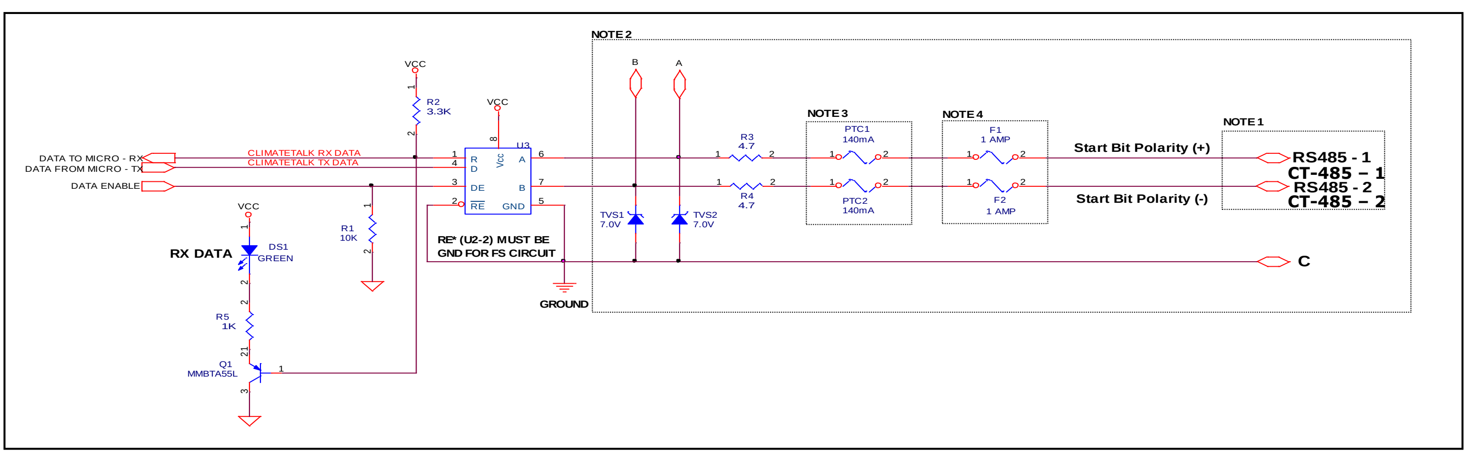
**Figure 2 - Single HVAC CT-485 Serial Network**




## 4.3 Data Transmission - CT-485 Serial Circuits

This section discusses the hardware requirements for each subsystem. Figure 3 - CT-485 Serial Transmission Network Example Schematic Circuit is the circuit to be utilized by all subsystems communicating on the CT-485 Serial Transmission Network.

**Figure 3 - CT-485 Serial Transmission Network Example Schematic Circuit**



NOTE 1 - CT1 = CT-485-1 (+) and CT2 = CT-485-2 (-) shall be routed as a pair having similar trace paths and distances. This is a differential bus.

NOTE 2 - F1, F2, PTC1, PTC2, R3, R4, TVS1, and TVS2 should be as physically close to each other as possible. They should also be close to the point where CT1, CT2, and C enter the board.

NOTE 3 - PTC1 and PTC2 should be masked from conformal coating. PTC devices need space for expansion to operate properly.

NOTE 4 - F1 and F2 are optional components that may not be present for all applications. PTC1, PTC2, R3, R4, TVS1, and TVS are mandatory on all CT-485 Serial devices

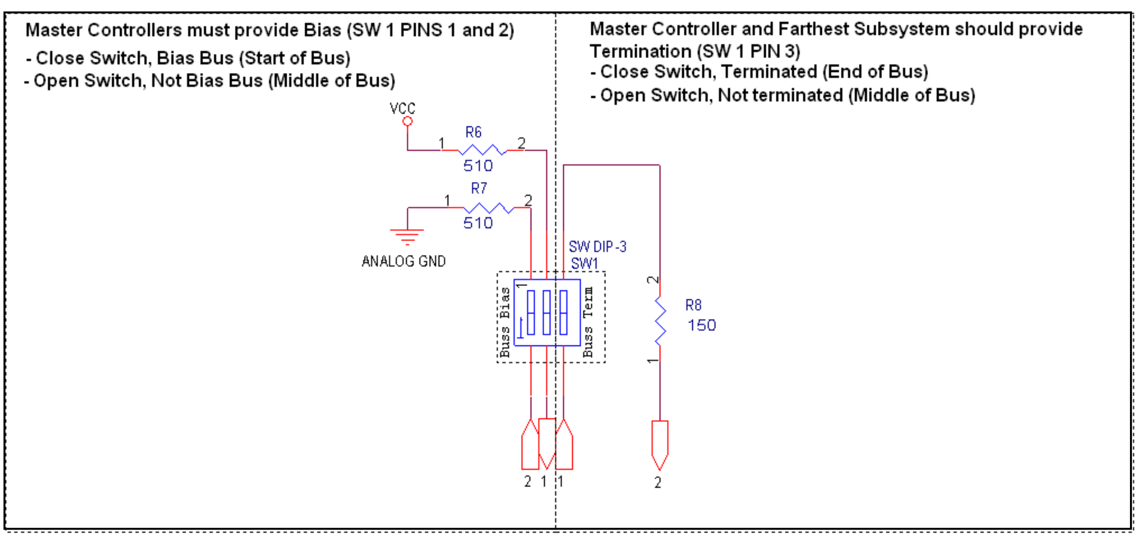
### 4.3.1 Transceiver Protection Circuit

Due to the presence of 24 VAC in the 4-Wire CT-485 bus, each control shall have adequate protection for the transceiver. The recommended protection circuit (*reference) is designed to protect against a direct short of the "R" line to either the "1" or "2" line. The overall goal of this protection circuit is to make any incorrectly wired configurations correctable without replacing the control.

### 4.3.2 Biasing and Termination Circuits

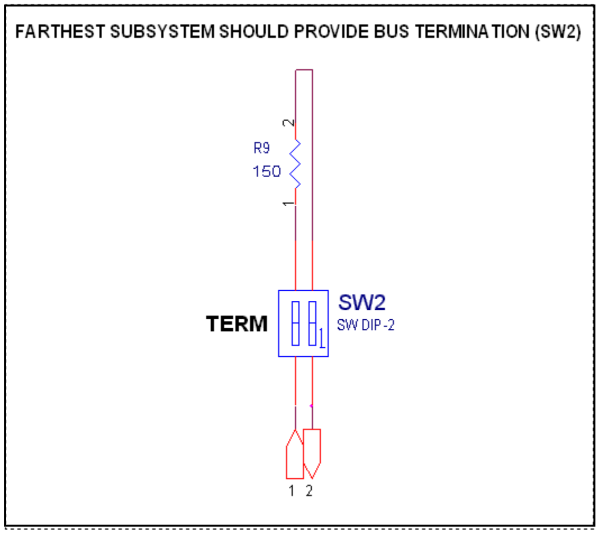
For one subnet, the indoor unit shall have a single termination and bias function of the CT-485 Serial communications bus as shown in Figure 4 - Indoor Termination/Bias Circuit.

**Figure 4 - Indoor Termination/Bias Circuit**




The outdoor unit shall have the final termination circuit of the bus as seen in Figure 5 - Outdoor Termination Circuit.

**Figure 5 - Outdoor Termination Circuit**




This circuit shall be capable of being turned off via a dipswitch if multiple HVAC subnets are active. At this time, the two farthest subsystems shall be switched to provide both a bias and termination.

## 4.4 Bill of Materials

The following table is a required bill of materials for the CT-485 Serial Transmission Network circuitry. The parts listed in the table specify the minimum electrical requirements. The part number and manufacturer are given as examples of parts that meet these requirements. If a replacement part is similar in electrical characteristics to the example in the table, then that part may be substituted in its place.

**Table 1 - CT-485 Bill-of-Materials (BOM)**

| Ref Des | Description | Package | Mfg. Part Number | Manufacturer | Qty |
|---|---|---|---|---|---|
| U1 | TIA-485 Transceiver, w/256 Nodes, Slew-Rate Limited, 5 Volt Operation | SMT | SN65HVD3082EDR<br>MAX13085ESA | TI<br>Maxim | 1 |
| Q1 | MMBTA55L - PNP Transistor | SOT-23 | MMBTA55LT1 | On Semiconductor | 1 |
| TVS1, TVS2 | Unidirectional 7.0 V 600 W SMB TVS | SMA | SMBJ7.0A | Diodes, Inc. | 2 |
| DS1 | Green LED, SMT | SMT | LT19209-240A | LEDTECH | 1 |
| DS2 | Red LED, SMT | SMT | LT19209-242A | LEDTECH | 1 |

| Ref Des | Description | Package | Mfg. Part Number | Manufacturer | Qty |
|---|---|---|---|---|---|
| PTC1, PTC2 | 140 mA "Polyfuse" Resettable Fuse | SMT | miniSMDC014F | Tyco | 2 |
| F1, F2 | 3 Amp Fast Acting Automotive Type Fuse | ATC/ATO | BK/ATC-3 | Bussmann | 2 |
| R1 | 10 K ohm 5% 1/8 W Resistor | 1206 | RMC1/8W 10K | SEI ELECTRONICS | 1 |
| R2 | 3.3 K ohm 5% 1/8 W Resistor | 1206 | RMC 1/8W 3.3K 5% | SEI ELECTRONICS | 1 |
| R3, R4 | 4.7 ohm 10% 3/4 W SMD Anti-Surge Resistor | 2010 | SG732HTTE4R7K | KOA | 2 |
| | 4.7 Ohm 5% 1/2W SMD Anti-Surge Resistor | 1210 | ERJ-P14J4R7U | Panasonic | |
| R5 | 1K ohm 5% 1/8 W Resistor | 1206 | RMC 1/8W 1K 5% | SEI ELECTRONICS | 1 |
| R6, R7 | 510 ohm 5% 1/4 W Resistor | 1206 | RMC 1/4W 510 5% | SEI ELECTRONICS | 2 |
| R8, R9 | 150 ohm 10% 3/4W 2010 SMD Anti-Surge Resistor | 2010 | SG732HTTE151K | KOA | 2 |
| | 150 ohm 5% 1/2 W 1210 SMD Anti-Surge Resistor | 1210 | ERJ-P14J151U | Panasonic | |
| SW1 | DIPSWITCH - 3 POS | THRU-HOLE | CTS 210-3S | CTS CORPORATION | 1 |
| SW2 | DIPSWITCH - 2 POS | THRU-HOLE | CTS 210-2MS | CTS CORPORATION | 1 |
| SW3 | SPST - Tactile switch | THRU-HOLE | B3F-1000 | Omron | 1 |

# 5.0 Additional Hardware Application Requirements

## 5.1 LED Indicators

There are two LEDs that a communications subsystem is required to have if there is no display module to inform installers of the system parameters.

### 5.1.1 System Status Indicator

A red status LED (DS3) is provided to inform the installer of any networking troubleshooting that needs to be performed. It also is used in the commissioning of subsystems in a multiple HVAC installation.

The status LED will indicate the specific fault codes as follows:

**Table 2 - Diagnostic LED Codes**

| Flash Code | Fault Description |
| --- | --- |
| Off | Normal Operation |
| Two Slow[4] Blinks | Power-Up/Reset |

At power-up or after a reset, the subsystem no longer has an address on the ClimateTalk network and must be re-addressed by the coordinator before it can communicate on the network.

### 5.1.2 Network Traffic Indicator

A green LED is provided to sense any data received from the network. This is helpful for troubleshooting installation wiring.

## 5.2 Buttons

### 5.2.1 Learn Button/Switch

The Learn Button is used to manually reset the subsystem’s connection to the network. Pressing and releasing the button causes the subsystem to reset its assigned address and subnet to 0x00 and then attempt to re-enter the network. If the button is pressed and held, the device resets its assigned address to 0x00, but will remain hidden from the network until the button is released.

This button may be implemented as a switch.

[4] Slow = ¼ second ON, ¾ second OFF

## 5.3 Non-Volatile Requirement

CT-485 has a requirement for storing other subsystems' shared data.

A CT-485 subsystem shall support a minimum of 200 bytes of storage for each of the following subsystems:

- Thermostat
- Indoor Unit
- Outdoor Unit

## 5.4 Diagnostic Port

An optional RJ-11 connection to the controller may be installed on communicating controls for easy access to power and the CT-485 Serial Transmission Network data lines. This section discusses the format necessary to provide a consistency of controls.

### 5.4.1 Diagnostics Connector

The recommended connector is a four-pin RJ-11 compatible with FCC 68 plugs. An example is Part Number 95003-2641 from Molex. This connector should be compatible with the requirements for the plug given in section 5.4.3.

**Figure 6 - Four-Pin RJ-11 Molex Connector - Part Number 95003-2641**

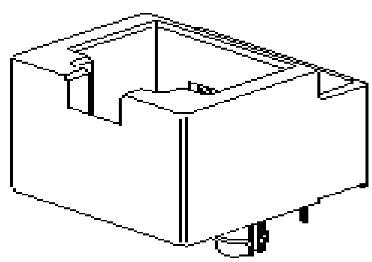
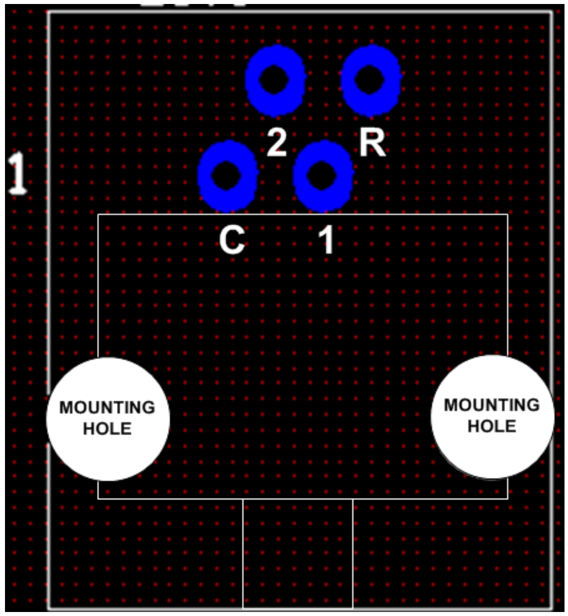


Figure 7 is the PCB footprint of the RJ-11 on controls implementing a diagnostics port.

**Figure 7 - Four-Pin RJ-11 PCB Footprint (Top View)**




### 5.4.2 Diagnostic Cables

It is important to note that not all consumer stock telephone cables are built as simple pass through cables and could be dependent on many independent factors. It is important that the proper validation of the cable is performed to ensure it meets the necessary requirements prior to connecting a subsystem.

### 5.4.3 Diagnostic Mating Plug

A four pin RJ-11 plug is recommended for use on diagnostic cables used to connect to the diagnostic port on the subsystem. An example is part number 90075-0027 from Molex. This plug should be compatible with the requirements for the port given in the previous section.

RJ-11 cables are built to handle up to 3 pairs of wires for each plug. The diagnostic cable requires a 2 pair cable with a 2 pair plug to provide power and data as seen in Figure 8 - Four-Pin RJ-11 Molex Plug - Part Number 90075-0027

**Figure 8 - Four-Pin RJ-11 Molex Plug - Part Number 90075-0027**

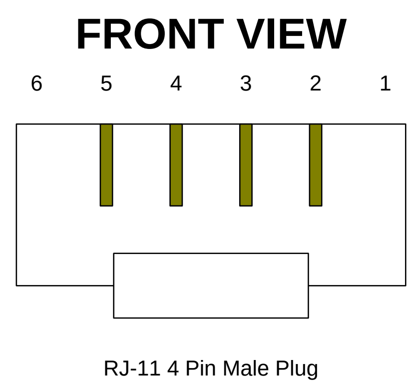
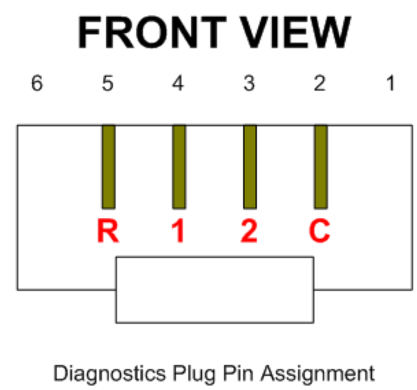



Figure 9 - Four-Pin RJ-11 Pin Assignment shows the pin layout for the data and power pin assignments.

**Figure 9 - Four-Pin RJ-11 Pin Assignment**



# 6.0 CT-485 4-Wire Configuration

CT-485 4-Wire configuration provides a way to run the entire system with a single control transformer at the Indoor Unit while offering wire lengths in excess of 100 feet (30.48 meters) at 18 AWG between the Indoor and Outdoor Units. The wire length restriction of 4-Wire mode is due to the current flow on the "C" line. Providing the "R" 24 VAC wire between the Indoor and Outdoor Unit requires only one 24 VAC transformer at the Indoor Unit, saving the cost of an additional transformer for the outdoor unit. The CT-485 4-Wire configuration is ideal for systems that require medium distance communications between the Indoor Unit and Outdoor Unit and have at least four pre-existing wires in place.

## 6.1 System Control Voltage Tolerance

The Outdoor Unit receives its 24 VAC (nominal) power from the Indoor Unit's control transformer. Additionally, the "C" line servers as both as a power current return path and a non-isolated ground reference for the transmission bus. The multipurpose usage of the "C" line requires down rating the wire lengths to achieve a reasonable operating range of the overall system while providing high noise immunity to the communications system. The operating range for the control transformer is 20 to 30 VAC. This is due to the voltage drop of up to 2 Volts between the Indoor and Outdoor Units at maximum wire lengths.

In all CT-485 wiring modes, it is important that the "C" terminal of the Indoor Unit be the only subsystem with its “C” wire tied directly to earth ground. The goal is to provide a “single-point-grounding” for maximum noise-immunity in the system. The Outdoor Unit shall not be tied directly to earth ground and shall not exceed 2.0 VAC RMS between "C" and earth ground. Furthermore, the voltage from "C" to "C" of any two subsystems shall not exceed 2.0 VAC RMS.

## 6.2 Transmission Bus Stability

To tolerate the presence of a 24 VAC contact (in any combination of wires) to the CT-485 Bus, the CT-485 specification and implementation includes a protection circuit that restricts the common mode range of minus 3.0 VDC to plus 12.0 VDC. This can cause communication limitations if the ground differentials become too great between the Indoor and Outdoor subsystems. This is one reason it is not recommended to connect the Outdoor Unit's "C" line directly to earth ground since this can cause ground loops. The goal of the overall system is to maintain the common mode range within plus or minus 2.0 VDC with respect to the maximum excursion of the "C" line throughout the entire system. This means that the maximum common mode noise shall fall within this tolerance range after taking into consideration all ground differentials of the system.

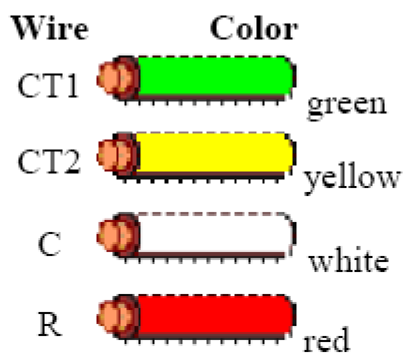
## 6.3 Transmission Bus Specifications

The overall goal of the CT-485 4-Wire mode is to maintain a resistance of less than 0.8 ohms per conductor, or 1.6 ohms loopback of any two conductors. Exceeding this maximum resistance is not recommended and may reduce bus stability. All wires should be the same type, size, and length.

Because the "C" and "R" wires are used to supply power from the Indoor Unit to the Outdoor Unit in the 4-Wire configuration, a maximum peak current of 1.0 amperes shall not be exceeded. The wires shall be 22 AWG or greater in size. 24 AWG or smaller wire shall not be used in CT 4-Wire configuration.

The recommended wiring color codes for CT-485 4-Wire are as follows:

**Figure 10 - 4-Wire Color Code**




## 6.4 Maximum Operating Lengths in 4-Wire CT Mode

**Table 3 - 4-Wire Configuration Maximum Operating Lengths**

| Wire Gauge AWG | Operation Length in Ft. | (Indoor) System VAC RMS | Comments |
|---|---|---|---|
| 22 | 40 | 20-30 | Using 22/4 Thermostat Wire |
| 20 | 75 | 20-30 | Using 20/4 Thermostat Wire |
| 18 | 125 | 20-30 | Using 18/4 Thermostat Wire |
| 16 | 150 | 20-30 | Using 16/4 Thermostat Wire |
| 14 | 300 | 20-30 | Using 14/4 Thermostat Wire |
| 12 | 500 | 20-30 | Using 12/4 Thermostat Wire |

# 7.0 CT-485 3-Wire Configuration

CT-485 3-Wire configuration provides the maximum operating length (wire length from the Indoor Unit to Outdoor Unit in CT-485) and bus stability with only three wires: "1," "2," and "C." Eliminating the "R" 24 VAC wire from the CT-485 4-wire configuration, CT 3-Wire requires each unit to have its own power source. The benefit of removing the "R" wire is that the common "C" wire can provide the best communication bus reference for the system because the "C" wire is no longer required to provide power for the outdoor unit. CT-485 3-Wire configuration is ideal for systems that require long distance communications between the Indoor Unit and Outdoor Unit, are susceptible to noise, or already have three pre-existing wires in place.

## 7.1 System Control Voltage Tolerance

One advantage of 3-Wire mode is the ability to leverage the system operating range of 18 to 30 VAC.

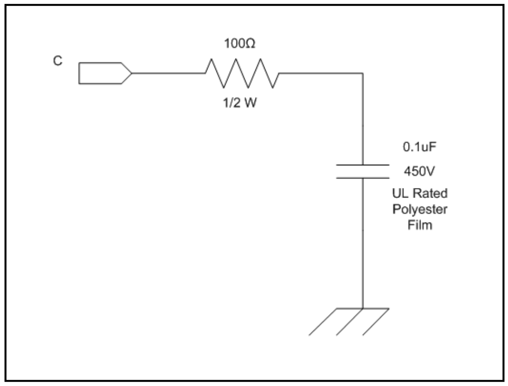
## 7.2 Transmission Bus Stability

To tolerate the presence of a 24 VAC contact (in any combination of wires) to the CT-485 Bus, the CT-485 specification and implementation includes a protection circuit that restricts the common mode range to between minus 3.0 VDC and plus 12.0 VDC. This can be a problem if the ground differentials become too great between the Indoor and Outdoor Units. This is one reason it is not recommend connecting the Outdoor Unit's "C" line directly to earth ground. The goal of the overall system is to maintain the common mode range within plus or minus 2.0 VDC with respect to the maximum excursion of the "C" line throughout the entire system. This means that the maximum common mode noise shall fall within this tolerance range after taking into consideration all ground differentials in the system.

One major benefit of 3-Wire mode is that the "C" line connection between the Indoor and Outdoor Units provides a non-current carrying reference between the "C" lines of the Indoor and Outdoor Unit. This means that the "1" and "2" lines can operate solely as a transmission bus and not a power distribution bus. This dramatically improves the noise immunity of the CT-485's communication bus and allows for the longest wire lengths.

In 3-Wire mode, it is most beneficial NOT to have any connection between the Outdoor Unit's "C" line and earth ground. However, an optional configuration is to use a permanently mounted 100 ohm 10 W resistor between "C" and the chassis of the Outdoor Unit. Additionally, there is an improved mode where the "C" line also could have a 100 ohm ½ W (or 100 ohm in series with a capacitor [0.1 uF]) between "C" and earth ground. This technique improves the transmission bus' ability to maintain a ground reference while avoiding ground loop current paths.

**Figure 11 - R-C Network between "C" and Earth Ground**

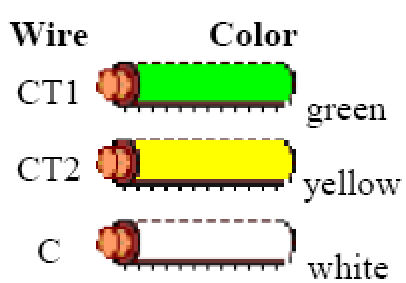



## 7.3 Transmission Bus Specifications

The overall goal of CT-485 3-Wire mode is to maintain a resistance of less than 15 ohms per conductor (a 30-ohm loopback of any two conductors). This allows for wire lengths three times that of 2-Wire and eighteen times that of a 4-Wire configuration. Exceeding the maximum wire resistance is not recommended and may reduce bus stability. All wires should be the same type, size, and length.

The recommended wiring color codes for CT-485 3-Wire are as follows:

**Figure 12 - 3-Wire Color Code**



## 7.4 Maximum Operating Lengths in 3-Wire CT Mode

**Table 4 - 3-Wire Configuration Maximum Operating Lengths**

| Wire Gauge AWG | Operation Length in Ft. | (Indoor) System VAC RMS | Comments |
|---|---|---|---|
| 22 | 1,000 | 18-30 | Using 22/3 Thermostat Wire |
| 24 | 150 | 18-30 | Using 24 AWG 2 Twisted-Pair CAT-5 cable |
| 20 | 1,600 | 18-30 | Using 20/3 Thermostat Wire |
| 18 | 2,400 | 18-30 | Using 18/3 Thermostat Wire |
| 16 | 4,000 | 18-30 | Using 16/3 Thermostat Wire |
| 14 | 4,000 | 18-30 | Using 14/3 Thermostat Wire |
| 12 | 4,000 | 18-30 | Using 12/3 Thermostat Wire |

# 8.0 CT-485 2-Wire Configuration

CT-485 2-Wire configuration provides mid-range operating length (wire length from the Indoor Unit to the Outdoor Unit) and bus stability with only two wires: "1" and "2." Eliminating the "R" 24 VAC wire and "C" Common from the CT-485 4-Wire configuration, CT 2-Wire requires each unit to have its own power source. The benefit is that only two wires are required to maintain mid-range operating distances and bus stability. A CT-485 2-Wire configuration is ideal for systems that require longer distance communication between the Indoor Unit and Outdoor Unit than is allowed by 4-Wire or have only two pre-existing wires in place.

## 8.1 System Control Voltage Tolerance

One advantage of the 2-Wire mode is the ability to leverage the system operating range of 18 to 30 VAC.

## 8.2 Transmission Bus Stability

To tolerate the presence of a 24 VAC contact (in any combination of wires) with the CT-485 bus, the CT-485 specification and implementation includes a protection circuit that restricts the common mode range to between minus 3.0 VDC and plus 12.0 VDC. This can be a problem if the ground differentials become too great between the Indoor and Outdoor Units. This is one reason that it is not recommend to connect the Outdoor Unit's "C" line directly to earth ground. The goal of the overall system is to maintain the common mode range to within plus or minus 2.0 VDC with respect to the maximum excursion of the "C" line throughout the entire system. This means that the maximum common mode noise shall fall within this tolerance range after taking into consideration all the ground differentials of the overall system.

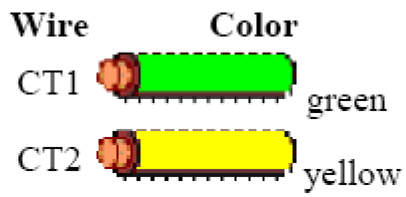
There is an improved mode where the "C" line could also have a 100 ohm 10 W resistor (or 100 ohm resistor in series with a capacitor [0.1 uF to 1.0 uF]) between "C" and earth ground. This technique improves the transmission bus' ability to maintain a ground reference while avoiding ground loop current paths. Refer to Figure 11 for this circuit.

## 8.3 Transmission Bus Specifications

The overall goal of CT-485 2-Wire mode is to maintain a resistance of less than 5.1 ohms per conductor, or 10.2 ohms loopback between any two conductors. This allows for wire lengths six times that of a 4-Wire configuration. Exceeding this maximum resistance is not recommended and may reduce bus stability. All wires should be the same type, size, and length.

The recommended wiring color codes for CT-485 2-Wire are as follows:

**Figure 13 - 2-Wire Color Code**




## 8.4 Maximum Operating Lengths for 2-Wire CT Mode

**Table 5 – 2-Wire Configuration Maximum Operating Lengths**

| Wire Gauge AWG | Operation Length in Ft. | (Indoor) System VAC RMS | Comments |
|---|---|---|---|
| 24 | 150 | 18-30 | Using 24 AWG 2 Twisted-Pair CAT-5 cable |
| 22 | 300 | 18-30 | Using 22/2 Thermostat Wire |
| 20 | 500 | 18-30 | Using 20/2 Thermostat Wire |
| 18 | 800 | 18-30 | Using 18/2 Thermostat Wire |
| 16 | 1,200 | 18-30 | Using 16/2 Thermostat Wire |
| 14 | 2,000 | 18-30 | Using 14/2 Thermostat Wire |
| 12 | 3,200 | 18-30 | Using 12/2 Thermostat Wire |

# 9.0 T-Taps and Local Devices

## 9.1 T-Taps

For CT-485, the only T-Tap allowed is a thermostat connected to the Indoor Unit using a 3-Wire or 4-Wire connection of less than 100 feet (30.48 meters) in length. The thermostat shall have no termination and may have bias resistors of 4.7 K ohms or greater. The thermostat connection may be 4-Wire even when the connection between the Indoor and Outdoor Units is a 3-Wire or 2-Wire configuration. In 4-Wire mode, the thermostat may not draw more than 100 mA from the 24 VAC source.

In all configurations, local devices with a maximum wire length of 6 feet can be connected to a terminated device using a 3-wire or 4-wire connection only. When using 4-Wire mode, the current pull of all local devices at one terminated device cannot exceed 25 mA from the 24 VAC source. These local devices shall have no termination and may have bias resistors of 4.7 K ohms or greater. Local devices shall have their own power source. The number of local devices allowed in a CT-485 system is limited by the parameters outlined in the CT-485 Network Specification (*reference).

## 9.2 Wire Color Codes

The color codes below are the recommended standard for CT-485 Serial Transmission Network wiring. Follow these color codes whenever possible.

**Figure 14 - CT-485 Wire Color Codes**

**HVAC Thermostat Wire [Note: C = Common, R = Control 24VAC]**

**18/2** Red/Black (Red = CT2, Black = CT1)

**18/2** Red/White (Red = CT2, White = CT1)

**18/3** Red/White/Green (Red = CT2, White = Common, Green=CT1)

**18/4** Red/White/Green/Yellow
(Red = R, White = C, Green = CT1, Yellow = CT2)

**18/4** Alternate Colors as Red/White/Green/Black
(Red = R, White = C, Green = CT1, Black = CT2)

**18/5** Red/White/Green/Yellow/Blue
(Red=R, White = C, Green = CT1, Yellow=CT2, Blue=C*)

**Telephone Wire**

**24/2** Green/Red (Pair1) (Green = CT1, Red = CT2)
(Green=CT1, Red=CT2)

**24/4** Green/Red(Pair1), Yellow/Black(Pair2)
(Yellow=R, Green=CT1, Red=CT2, Black=C)

**24/6** Red/Green(Pair1),Yellow/Black(Pair2),Blue/White(Pair3)
(Blue=R*, Yellow=R, Green=CT1, Red=CT2, Black=C, White=C*)

**CAT5e 24/8 (4 Pair) Network Cable - Wire**

| Wire | Color |
|---|---|
| R | orange |
| R | white/orange |
| CT1 | blue |
| CT2 | white/blue |
| C | green |
| C | white/green |
| C* | brown |
| C* | white/brown |

**Signal Levels**

**R = 24VAC Control Voltage**
**CT1 = CT-485(+)**
**CT2 = CT-485(-)**
**C = Ground (Common)**

*= Optional when connecting between Indoor and Tstat.

# 10.0 Serial Baud Rate and Byte Timing Calculations

## 10.1 Byte Timing

Networking over any serial communications bus requires that the time to transmit data be taken into account when developing a timing spec for that network. To make intelligent decisions about timing specifications in the system it is necessary to determine the time it will take to transmit a packet at its maximum length. The following section will outline a simple way to do this calculation.

Baud Rate is defined as the number of bits per second that can be transmitted onto a bus. The Bit Time (the time to transmit one bit of data). The following formula mathematically defines Bit Time:

Bit Time = 1 / Baud Rate (in seconds)

Knowing the time it takes to transmit 1 bit of data, it is simple to determine the time it takes to transmit one Byte of information. The Byte Time (the time to transmit one byte) is the cumulative time it takes to transmit all of the bits that make up one Byte of data. The number of bits required to transmit one Byte of data is found by adding the number of Data Bits, Start Bits, and Stop Bits. Below is the formula for calculating Byte Frame Time.

Byte Frame Time = (1 / Baud Rate) x Number of bits per Byte frame

An example calculation uses the default settings for CT-485 of 9600 Kbps, 8 Data Bits, 1 Start Bit, and 1 Stop Bit.

Byte Frame Time = (1 / 9600) x (8 + 1 + 1)
Byte Frame Time = (1 / 9600) x 10
Byte Frame Time = 1.04 milliseconds

## 10.2 Maximum MTU Size

Information is sent as blocks of data generically referred to as a Network Data Frame. A Network Data Frame (i.e. a packet) includes the checksum, source address, destination address, and payload data. The largest packet that can be sent through the Data Link Layer is defined as the Maximum Transmission Unit (MTU). The absolute largest MTU is 256 Bytes, although the currently supported MTU is 252 Bytes (based on a 240-Byte maximum data payload).

## 10.3 CT-485 Serial Pre-Drive Hold Time

The Serial Pre-Drive Hold Time is the time it takes for the CT-485 Serial Driver to stabilize the bus in an IDLE condition and overcome any capacitance from the cables in preparation for the Start Bit to be driven. The required amount of time is between 200 µsec and 500 µsec.

## 10.4 CT-485 Serial Post-Drive Hold Time

The microcontroller drives the CT-485 Serial Bus for 200 µsec beyond the Stop Bit completion time. The DI (UART-TX) pin shall be maintained high until the DE pin is completely low (*references).

## 10.5 CT-485 Serial Inter-Packet Delay (Transmission Method)

When a CT device transmits onto the bus, the TX packets shall be "Delimit Guaranteed" by providing a minimum inter-packet TX timing. Inter-Packet Delays shall be at least 100 msec. The simplest method of guaranteeing the inter-packet delay is to add a fixed delay immediately before each packet transmitted onto the bus.

The Inter-Character delay during a single packet transmission should strive to maintain a contiguous bit stream transmission without any idle time between the characters contained within a single packet. A CT-485 packet transmission shall not have any Inter-Character Delay(s) of more than 1.5 msec between the characters during a single packet transmission. The Inter-Character Delay is defined as the time from the end of a specific Stop Bit to the beginning of the next Start Bit within a single packet transmission. This delay often is referred to as "Jitter" and can vary between 0.0 msec and 1.5 msec during the transmission of a CT-485 packet. Any Inter-Character Delay greater than 1.5 msec during a single packet transmission is considered illegal under the CT-485 specification.

**Figure 15 - Minimum Transmit Inter-Packet Timing Example**

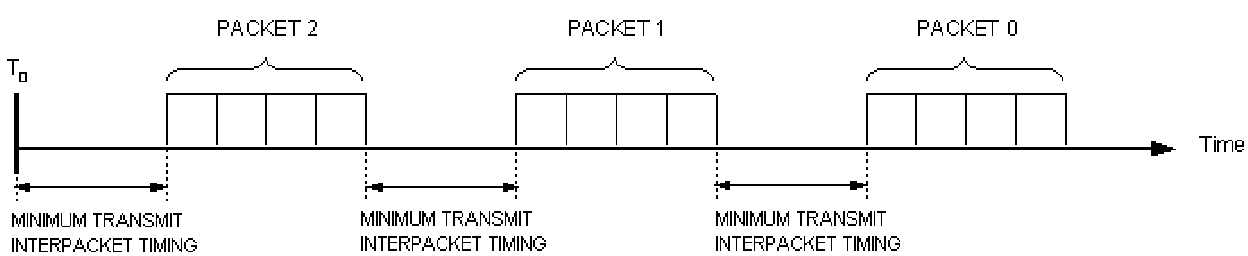



Figure 15 above demonstrates the time between transmission packets and when the 100 msec Inter-Packet Delay should occur.

**Figure 16 - Invalid Minimum Transmit Inter-Packet Timing at Packet 1**

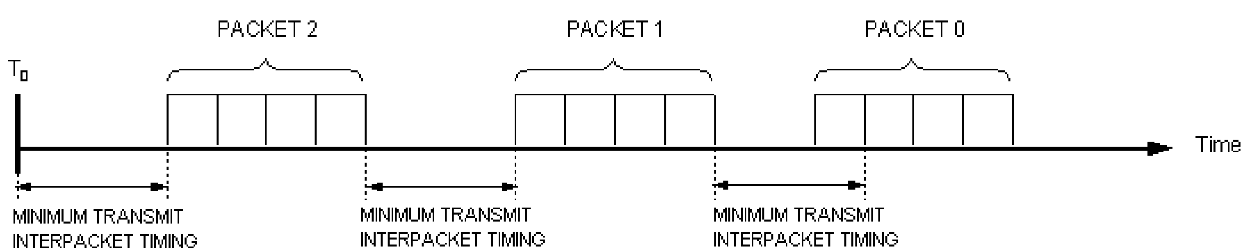


Figure 16 above is an example of transmitting too soon and violating the 100 msec Inter-Packet Delay time.

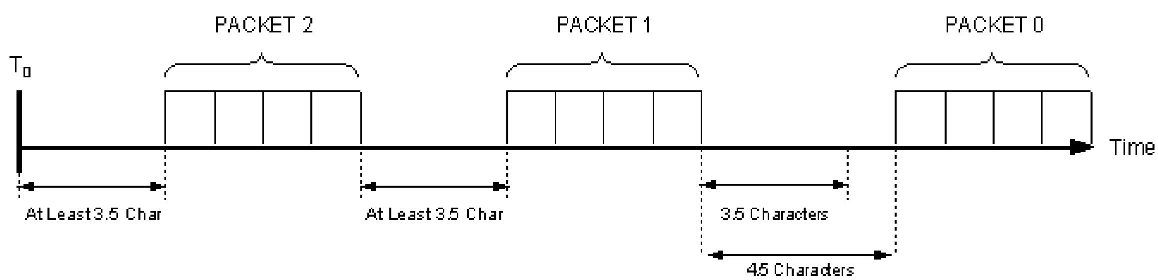
## 10.6 CT-485 Serial Inter-Character Delimiting (Receive Method)

When a CT device receives a packet, the RX packets shall be "Delimit Measured" by monitoring the Inter-Character Delay. The CT inter-character delay shall be at least 3.5 msec from the time that the previously received character was received until the most recent character is received.

This is typically accomplished by zeroing a timer whenever a character is received. Set up the timer to expire and generate an interrupt (or a flag) that occurs at 3.5 msec. This flag is called the Receive Delimit Flag. As long as you are receiving contiguous characters, the Receive Delimit Flag will never be set. Once the Bus goes idle for 3.5 msec, declare that a valid "Time Delimited Packet" has been received and disable the timer.

This is typically the time that you would start processing (or finish processing) the pending received packet data and validate the checksum, etc. If you do not adhere to "Inter-packet Time Delimiting," then partial packets or bus glitches can cause undesired results in network traffic. In addition, this mechanism allows routers and bridges to manage network traffic over multiple mediums.

**Figure 17 - Inter-packet Delimiting Receive Method Example**




When receiving a packet, monitor the time since receiving the last character. If the time since the last character is less than 3.5 msec, then it potentially is considered to be a valid part of a contiguous packet, pending checksum and other packet validation. If 3.5 msec or more time has passed since the last character, then this character is either part a new packet or garbage data.

## 10.7 CT-485 Serial Maximum Transmission Unit (MTU) Timing

For determining appropriate packet timeouts, it is important to know the time it takes to send a Maximum Transmission Unit (MTU). As discussed previously, a MTU is the largest data frame (i.e. packet) allowed by the Data Link Layer.

The previous sections showed how to determine the time required to send a byte of data on a serial communications bus.

- Each packet is delimited by a certain amount of 'idle' time on the bus (a period with no communication data present on the bus)

- The CT-485 packet structure supports 252 total bytes (240 bytes of data + 10 Byte Header + 2 Byte checksum)
- The amount of time it takes to send a MTU on the CT-485 Serial bus can determined mathematically

Using the CT-485 default baud rate of 9600 Kbps, 8 Data Bits, 1 Start Bit, and 1 Stop Bit, the time for a maximum length packet is below.

MTU Time = (Byte Time x Number of Bytes) + Inter-packet + (Delimit) Time Delay
MTU Time = (((1 / 9600) x 10) x Number of Bytes) + Inter-packet + (Delimit) Time Delay
MTU Time = (((1 / 9600) x 10) x 252) + 100 msec
MTU Time = 262.5 msec + 100 msec
MTU Time = 362.5 msec

# 11.0 Annex A

## 11.1 CT-485 Serial Converter

CT-485 conformant serial converters may be used for traffic logging and debugging communicating subsystems with PC diagnostic applications. These converters shall conform to the CT-485 specification for local devices. Specifically, these converters shall have a transmission line that is six feet or shorter, no terminating resistor, bias resistors greater than or equal to 4.7 K ohms, and include the CT-485 recommended protection circuit.

## 11.2 Troubleshooting Techniques

This section defines some techniques to be used by installers in the field to ensure proper wiring of the network to allow for good communications.

### 11.2.1 Nominal Voltage Readings

Table 6 below shows the nominal voltages that should be present when read with a voltmeter set to DC.

**Table 6 - Nominal CT-485 Serial Network Voltage Readings**

| Measurement Locations | Nominal Voltage Readings |
|---|---|
| 1 – 2 | > 200 millivolts |

Measuring the system voltages is the primary and first key step in debugging a CT-485 Serial communicating system.

**Table 7 - Nominal Electrical Connection Voltage Readings**

| Measurement Locations | Nominal Voltage Readings | Corrective Action |
|---|---|---|
| C – Chassis | < 1.0 Volts RMS | Verify that “C” is connected to Chassis Ground |
| L1 – Chassis | 120 Volts RMS | Verify the Center-tap of the L1-L2 transformers are connected to Chassis Ground |
| L2 – Chassis | | |

If at any time there is a voltage reading that is different, then the installation wiring must be checked for continuity and incorrect wiring.

#### 11.2.1.1 Nominal Resistance Readings

The following resistance measurements may be made to assist in troubleshooting. These measurements shall be made with the bus connected but with the bus subsystems not powered.

**Table 8 – Nominal Resistance Readings**

| Measurement Locations | Nominal Resistance Range | Corrective Action |
|---|---|---|
| CT1 – CT2 | 50 – 100 ohms | Verify that termination dipswitches are set to ON at the endpoints of the CT bus |
| CT2 – C | 300 – 600 ohms | Verify that one and only one bias dipswitch is set to ON (at the Indoor Unit). |

#### 11.2.1.2 Bus wiring verification

To check that a subsystem is properly wired to the bus and seeing traffic from other subsystems, the Learn Button can be used. Hold down the Learn Button for up to three minutes and verify that the RX LED blinks indicating that another node is transmitting and that the subsystem being diagnosed is seeing the traffic.

## 11.3 Silkscreen Naming Convention

This section defines the silkscreen to be used on all CT-485 PCBs or plastic housing to comply with all instruction sheets created for the system.

**Table 9 - Silkscreen PCB Convention**

| | Long Form | Short Form | Pin Number |
|---|---|---|---|
| Pushbutton Switch | LEARN | LRN | N/A |
| Green LED | RX DATA | RX | N/A |
| Red LED | STATUS | STAT | N/A |
| 3-Pin Dipswitch | BUS BIAS PULL-DOWN | BIAS DWN | 1 |
| | BUS BIAS PULL-UP | BIAS UP | 2 |
| | BUS TERM | TERM | 3 |
| 2-Pin Dipswitch | BUS TERM | TERM | ALL |

## 11.4 HVAC Failure Modes

The following subsections discuss the ability to overcome potential HVAC failures in a communicating system and a potential method for recovering.

#### 11.4.1.1 Freeze-Protection (Future)

A communications failure by the thermostat controller may result in the freezing of the zone for which the thermostat is in control. This section discusses how additional hardware on both the thermostat and the indoor heating device can provide emergency heat even if communications have failed.

#### 11.4.1.2 Fail-Safe Mode of Operation

If the thermostat is in this failure mode, a mechanical peptide switch may be used to create an analog signal on the communication bus to tell all subsystems that are responsible for heat to turn on due to the house temperature falling to freezing temperatures.

#### 11.4.1.3 Indoor Subsystem Fail-Safe Modes

If communications to any thermostat have been lost, the failed thermostat shall be equipped with a mechanical device to send an analog signal to the network. Once detected, a Heat (W1) and Fan (G) demand is evaluated and processed by each subsystem on the network. Once the demand has been met, the mechanical analog switch shall disengage returning the network to its previous communicating state.

# 12.0 Annex A – Bibliography

"TIA-485 (Revision A), Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems" *Telecommunications Industry Association*, 1998.

Zimmermann, Hubert (April 1980). "OSI Reference Model — The ISO Model of Architecture for Open Systems Interconnection". *IEEE Transactions on Communications*