CALIFORNIA
ENERGY
COMMISSION

Integrated Building Equipment Communications Systems (IBECS) Lighting Components

TECHNICAL REPORT

October 2003
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CALIFORNIA ENERGY COMMISSION

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Program's final report and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the High Performance Commercial Building Systems (HPCBS) Program. This Commercial Building Energy Benchmarking attachment provides supplemental information to the final report (Commission publication # 500-03-097-A2). The reports, and particularly the attachments, are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the fifth of 22 technical attachments to the final report, and consists of research reports:

- IBECS Network/Ballast Interface (E3P2.1T1d)
- Final Report on Internet Addressable Light Switch (E3P2.1T2d)
- Low-Cost Networking for Dynamic Window Systems Review (E3P2.2T2c)

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced this document as part of a multi-project programmatic contract (#400-99-012). The Buildings Program includes new and existing buildings in both the residential and the nonresidential sectors. The program seeks to decrease building energy use through research that will develop or improve energy-efficient technologies, strategies, tools, and building performance evaluation methods.

For the final report, other attachments or reports produced within this contract, or to obtain more information on the PIER Program, please visit http://www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. The reports and attachments are also available at the HPCBS website: http://buildings.lbl.gov/hpcbs/.

Abstracts

IBECS Network/Ballast Interface - Final Report

This report describes the work performed to design, develop, and demonstrate an IBECS network/ballast interface that is useful for economically dimming controllable ballasts in commercial buildings. The first section of the report provides the general background of the IBECS (Integrated Building Environmental Communications System) research and development work as well as the context for the development of the network/ballast interface. The research and development effort that went into producing the first proof-of-concept circuit and the physical prototype of that concept is detailed in the second section. In the third section of the report, we describe the lessons learned from the first demonstration of the network/ballast interface at an office at LBNL. The fourth section describes how electrical noise interference encountered with the first generation of interface led to design changes for a refined prototype that hardened the interface from electrical noise generated by the ballast. The final section of the report discusses the performance of refined prototype after we replaced the proof-of-concept prototype with the refined prototypes in the demonstration office at LBNL.

Title 24 Wall Switch

This report describes the work performed to develop and test a new switching system and communications network that is useful for economically switching lighting circuits in existing commercial buildings. The first section of the report provides the general background of the IBECS (Integrated Building Environmental Communications System) research and development work as well as the context for the development of the new switching system. The research and development effort that went into producing the first proof-of-concept (the IBECS Addressable Power Switch or APS) and the physical prototype of that concept is detailed in the second section. In the third section of the report, we detail the refined Powerline Carrier Based IBECS Title 24 Wall Switch system that evolved from the APS prototype. The refined system provided a path for installing IBECS switching technology in existing buildings that may not be already wired for light level switching control. The final section of the report describes the performance of the IBECS Title 24 Switch system as applied to a small demonstration in two offices at LBNL's Building 90. We learned that the new Powerline Carrier control systems (A-10 technology) that have evolved from the early X-10 systems have solved most of the noise problems that dogged the successful application of X-10 technologies in commercial buildings. We found that the new A-10 powerline carrier control technology can be reliable and effective for switching lighting circuits even in electrically noisy office environments like LBNL. Thus we successfully completed the task objectives by designing, building and demonstrating a new switching system that can provide multiple levels of light which can be triggered either from specially designed wall switches or from a digital communications network. By applying commercially available powerline carrier based technologies that communicate over the in-place lighting wiring system, this type of control can be economically installed even in existing buildings that were not wired for dual-level lighting.

Low-Cost Networking for Dynamic Window Systems

A low-cost building communications network is needed that would allow individual window and lighting loads to be controlled from an existing enterprise LAN network. This building communications network concept, which we term IBECS™ (Integrated Building Environmental Communications System), would enable both occupant-based and building-wide control of individual window, lighting, and sensor devices. IBECS can reduce the cost of systemic control because it allows a drastic cost reduction in per point networking costs. This kind of effort is needed to encourage the control industry to make the commitment to build this technology and to demonstrate to prospective customers that this breakthrough approach to more comprehensive systemic control will provide them with high-quality, convenient control while saving them money.

The development and demonstration of network interfaces to DC- and AC-motorized shades and to an electrochromic window are described. The network interfaces enable one to control and monitor the condition of these fenestration appliances from a variety of sources, including a user's personal computer. By creating a functional specification for an IBECS network interface and testing a prototype, the ability to construct such an interface was demonstrated and the cost-effective price per point better understood. The network interfaces were demonstrated to be reliable in a full-scale test of three DC-motorized Venetian blinds in an open-plan office over two years and in limited bench-scale tests of an electrochromic window.

California Energy Commission
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HPCBS

High Performance Commercial Building Systems

IBECS Network/Ballast Interface - Final Report

Element 3 - Lighting, Envelope and Daylighting
Project 2.1 - Lighting Controls
Task 2.1.1 - Ballast Interfaces

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Novemeber, 2001

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Lawrence Berkeley National Laboratory Final Report

IBECS Network/Ballast Interface Final Report

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Executive Summary

This report describes the work performed to design, develop and demonstrate an IBECS network/ballast interface that is useful for economically controlling dimmable fluorescent lamp ballasts in commercial buildings. The first section of the report provides the general background of the IBECS (Integrated Building Environmental Communications System) research and development work as well as the context for the development of the network/ballast interface. The research and development effort that went into producing the first proof-of-concept circuit and the physical prototype of that concept is detailed in the second section. In the third section of the report, we describe the lessons learned from the first demonstration of the network/ballast interface in an office at LBNL. Electrical noise interference from the ballast encountered with the first generation of interface led to design changes that hardened the refined prototype from any electrical noise generated by the ballast. The final section of the report discusses the performance of refined prototype after we replaced the proof-of-concept prototype with the refined prototypes in the demonstration office at LBNL.

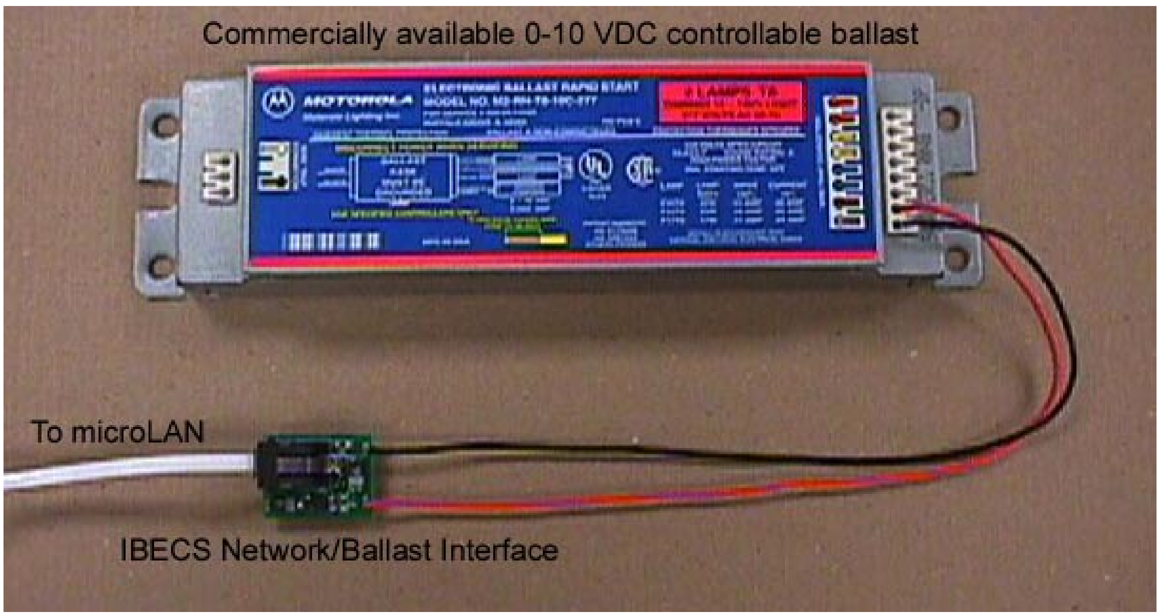

Figure i. Final IBECS network/ballast interface connected to a controllable ballast

We learned that newly available silicon microchips are a suitable platform for designing low-cost digital network/ballast interfaces that are useful for enabling network operation of commercially available 0-10 VDC dimming ballasts. We found that electrical noise generated by the ballast in the control loop can interfere with digital network operation unless the interface is hardened from this noise. We found that controllable ballasts from different companies generate different noise signatures. Using optical isolation, we produced a refined IBECS network/ballast interface that can provide universal control of most available 0-10 VDC controllable ballasts. In large quantities, we estimate that the cost of the universal interface would be about $1-2 to OEMs. This is 5 to 10 times cheaper per unit than any other proposed communications system.

Thus we successfully completed the task objectives by designing, developing, fabricating and demonstrating an IBECS network/ballast interface that is useful for economically dimming controllable ballasts.

IBECS Network/Ballast Interface
Final Report

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Introduction

This report describes the work performed to design, develop, and demonstrate an IBECS network/ballast interface that is useful for economically dimming controllable ballasts in commercial buildings. The first section of the report provides the general background of the IBECS (Integrated Building Environmental Communications System) research and development work as well as the context for the development of the network/ballast interface. The research and development effort that went into producing the first proof-of-concept circuit and the physical prototype of that concept is detailed in the second section. In the third section of the report, we describe the lessons learned from the first demonstration of the network/ballast interface at an office at LBNL. The fourth section describes how electrical noise interference encountered with the first generation of interface led to design changes for a refined prototype that hardened the interface from electrical noise generated by the ballast. The final section of the report discusses the performance of refined prototype after we replaced the proof-of-concept prototype with the refined prototypes in the demonstration office at LBNL.

Background

Lighting controls companies have developed controls products that can be specified as systems to achieve simple lighting control functions in buildings. Research conducted by LBNL in the late 1990s demonstrated that components from different manufacturers could be specified, assembled as systems, and installed in buildings to achieve simple lighting control functions and obtain significant energy savings. However, the fragmented nature of U.S. lighting controls market is such that manufacturers of lighting controls components (ballasts, switches and controls) produce products that often do not work well together as systems. Thus advanced lighting control equipment capable of implementing strategies such as daylighting proved difficult to commission in the field, leading to poor operation and user complaints. Failure to involve the occupants in the commissioning process also resulted in low occupant acceptance of more advanced lighting control strategies. The software that is necessary to coordinate the operation of lighting control sub-systems is also still immature and current systems lack appropriate networking software that would allow sub-systems from different manufacturers to communicate reliably.

To address the above market shortcomings, the overall technical goal IBECS Project is to develop an integrated building equipment communications (IBECS) network that will allow appropriate automation of lighting systems to increase energy efficiency, improve building performance, and enhance occupant experience in the space. This network will provide a low-cost means for occupants to control local lighting systems, thereby improving occupant comfort, satisfaction, and performance.

The goal of the IBECS project is to design, build, and test the IBECS interface and networking system between controllable lighting devices that will enable local and system-wide energy-efficient operations of various lighting systems and components.

IBECS Network/Ballast Interface Proof-of-Concept

The thrust of the IBECS work for FY2001 was to design, fabricate and demonstrate an IBECS network/ballast interface that is useful for economically dimming controllable ballasts from a digital network.

Any viable system for communicating with building lighting equipment should be able to accommodate the controllable ballasts currently available on the market. There are four dimming ballast types of interest for purposes of dimming lighting control in buildings:

- 0-10 VDC controllable ballasts (several companies manufacturing)
- Phase-cut (also called two-wire) ballasts (Advance Mark X is example)
- Three-wire ballasts (especially Lutron)
- Digital ballasts (only one company, Tridonic, currently producing in US)

The phase-cut ballasts, though less expensive than the other types of controllable ballasts, are not appropriate to widespread installation throughout a facility as the resulting harmonics introduced would negatively affect power quality. Three-wire ballasts, while of very high quality, cannot be dimmed using low-voltage circuits. Digital ballasts, though eventually the ideal vehicle for IBECS control, were thought to be a too limited market at this time. So for our initial interface development work, we elected to focus on the 0-10 VDC controllable ballasts.

How 0-10 VDC Controllable Ballasts Operate

At present, commercially available controllable (or dimming) ballasts for fluorescent lamps are equipped with two extra leads for controlling the intensity of the lamps. These extra leads form a two-wire low-voltage "bus," to which various control devices can be connected. For example, an appropriate photocell connected to the low-voltage "bus" can control the ballast light output by varying the voltage on the bus. It is common practice to connect several ballasts in parallel to the low-voltage bus so that multiple ballasts can be controlled in unison from a single controller or photocell (see **Figure 1**).

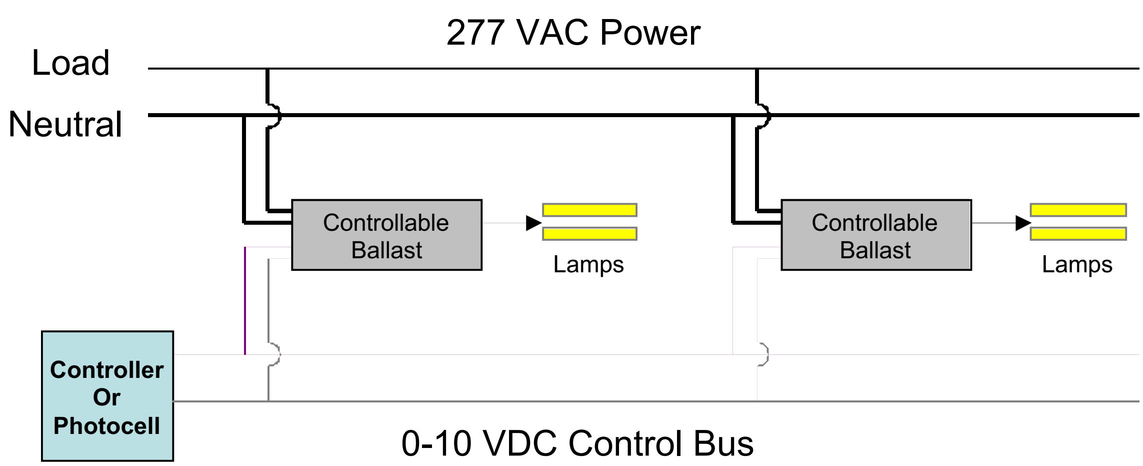

Figure 1. Wiring diagram for the low-voltage control circuit used in most commercially available 0-10 VDC controllable fluorescent lamp ballasts.

Designing the First Interface

Our initial task was to design a proof-of-concept interface that would allow control of the 0-10 VDC controllable ballast from a digital LAN. Pete Pettler researched the market in 1999 and identified Dallas Semiconductor as the manufacturer with the hardware (microchips) and the communications LAN (1-wire LAN) that was most appropriate to our purpose.

Pettler designed the ballast network interface around the microchip set from Dallas Semiconductor. The initial circuit design proof-of-concept was as shown in **Figure 2** below.

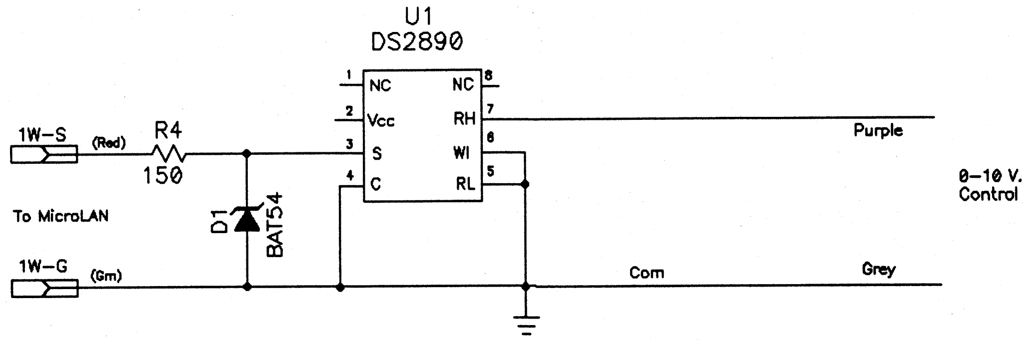

Figure 2. Circuit diagram for first proof-of-concept for the IBECS network/ballast interface.

The above circuit contains the Dallas Semiconductor DS 2890 digital potentiometer along with the other circuitry required to serve as the network interface for any 0-10 VDC controllable fluorescent ballast that can source current (most commercially available controllable ballasts are able to do this). Consequently, the network interface above requires no additional power. The power to drive the communications portion of the digital pot is borrowed from the MicroLan itself. The current to drive the dimming portion is provided by the current sourced by the low-voltage leads from the controllable ballast.

The technical specifications for the Dallas Semiconductor digital potentiometer can be found at http://pdfserv.maxim-ic.com/arpdf/DS2890.pdf and in Appendix A to this report. Note the selection of this company's hardware to construct the interface does not imply that there are not other companies that have similar products and capabilities.

We packaged the above circuit in plastic as shown below (**Figure 3**). The two solid copper leads connect to the purple and grey wires from the controllable ballast. The pigtail wires connect to the microLAN. Once the microLAN is installed (using CAT5 cable or equivalent) each ballast to be controlled would be wired to an interface and the interface wired to the microLAN.

Figure 3. Image of the first IBECS network/ballast interface for communicating digitally with controllable fluorescent ballasts. The blue and white wires coming out of the top of the interface are connected to the purple and grey leads on a controllable ballast. The blue and white pigtails go to the digital microLAN.

Demonstration of Proof-of-Concept Prototype at LBNL Office

To test the above network interface, we installed six of the interfaces to control the overheads lights in an office at LBNL's Building 46 (**Figure 4**). The office consisted of four three-lamp luminaires that were tandem wired so that the in-board and out-board lamps could be separably switched using two manual wall switches (**Figure 5**). (Tandem wiring is code for non-residential California buildings under Title 24).

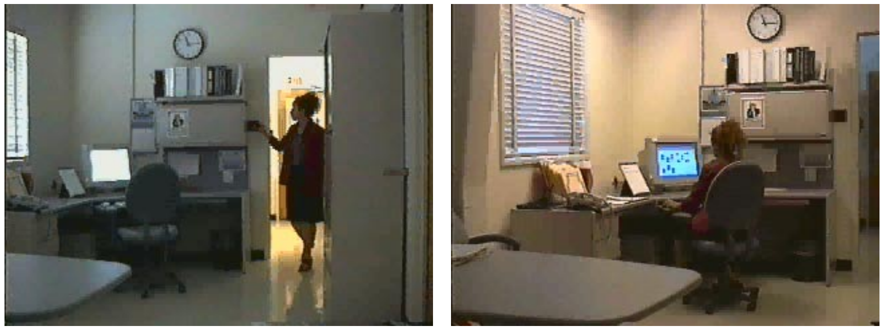

Figure 4. Images of office at LBNL Building 46 where the IBECS network interface was first tested. Left image shows a person entering the office and switching on the manual wall switches for the overhead lights. Right image shows the occupant working at the computer where the IBECS control software to control the overhead lights resides.

Figure 5. Images of the ceiling lights in office at LBNL Building 46 where the IBECS network interfaces were first tested. The upper left image shows the lights with both wall switches in the OFF position. The location of the installed low-voltage wire raceway is shown in the callout. The upper right image shows the lights with the in-board switch ON and the outboard switch OFF. The lower left image shows the lights with the outboard switch ON and the inboard switch OFF. The lower right image shows the lights with both switches in the ON position.

To test the IBECS network/ballast interfaces, the existing six, two-lamp, non-dimming, ballasts were replaced with 0-10 VDC two-lamp controllable ballasts from General Electric (GE B232SR120VS, product code 80355, 5-100% dimming). Each of the six installed dimming ballasts were equipped with a ballast network interface so they could be individually controlled. In addition, the electricians installed a low-voltage CAT-5 cable wire in a surface-mounted raceway connecting all the ballast interfaces (see **Figure 5**). We intended to run the IBECS microLAN on the CAT-5 cable. We terminated one end of the microLAN with an RS-232/microLAN bridge near the occupant's personal computer so that the occupant could dim the overhead lights to taste using IBECS. To complete the demonstration, we connected the bridge (HA3 adaptor from Point Six, http://www.pointsix.com) at the end of the run to the serial port on the PC where we installed the 1-wire control software from Advantech (GenieDAQ, http://www.advantech.com) and the DDE server (also from Point Six). [Note: the HA3 port adaptor has been superceded by subsequent port adaptor designs. Appendix A gives the port adaptor specifications for the Maxim DS9097E port adaptor, which is equivalent to the earlier HA3 adaptor]. We produced a simple control screen using the Advantech software that let us control 1-wire devices from the PC.

Our tests of the first interface were disappointing. Electronic noise generated by the ballast and injected back onto the low-voltage control circuit added a large noise signature onto the digital microLAN. Because each ballast is connected in parallel to the low-voltage circuit, the noise generated by each adds to the overall noise level. This noise swamped the signal level on the digital microLAN, this prevented the digital microLAN from communicating with the network interfaces. We did not detect this problem with our initial IBECS demonstration kit because that kit controlled only one interface and the wire runs were very short.

Once we identified the noise problem described above, we tested several other types of controllable ballasts and found that these ballasts also generated unacceptable electronic noise levels, although we found that the noise signature of different ballasts varied significantly. Our first solution was to add capacitors at the interface input terminals. However, this did not prove to be a reliable solution.

Development of the Refined Prototype

To solve the ballast noise interference problem identified above, Pettler made major modifications to the circuit shown in **Figure 1** in order to optically isolate the interface from noise interference generated by the controllable ballast. The circuit was entirely redesigned so that Dallas Semiconductor's digital potentiometer would control the ON-OFF ratio of a pulse width modulated (PWM) signal that is transmitted to the 0-10 volt input of the ballast(s) via an optical isolator as shown in **Figure 6** below.

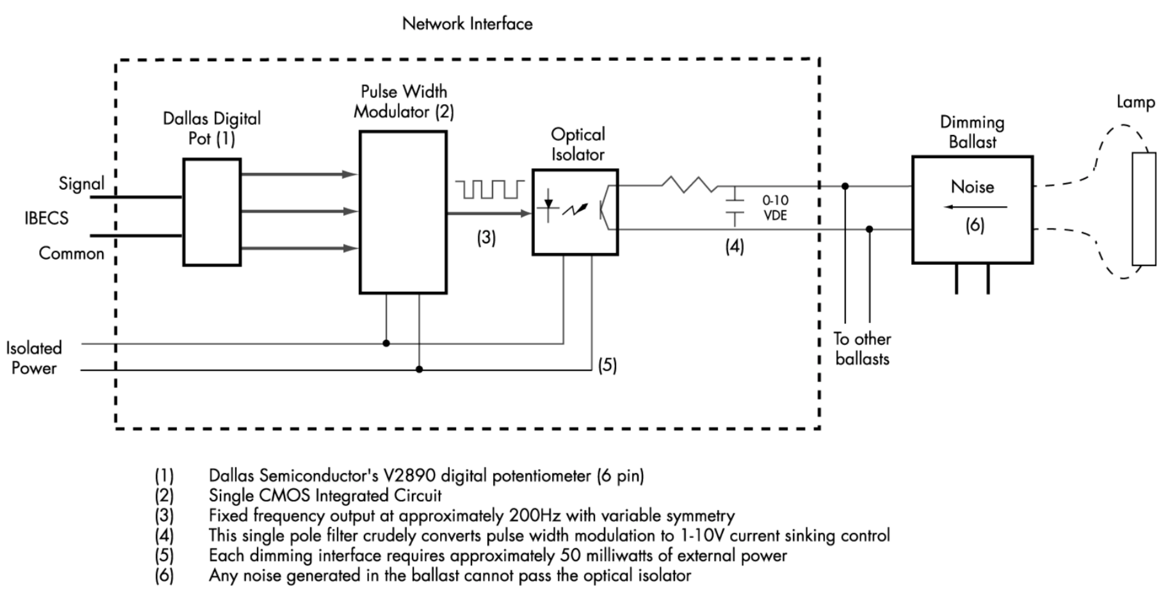

Figure 6. Block diagram of the revised IBECS network/ballast interface designed to eliminate noise from the electronic ballast.

Since both the pulse width modulator and the optical isolator require external power (the digital pot does not), the above network interface requires a powered, i.e., four-wire IBECS network. Note that this is a departure from the initial prototype, which did not require any external power. Since the two obvious candidates for IBECS network cable (CAT 5 or standard Telco wiring) already contain at least four conductors, the cost per linear foot of network cable is only marginally more expensive with four wires than with two. The added robustness of the 4-wire system would more than make up for any marginal increases in wiring costs.

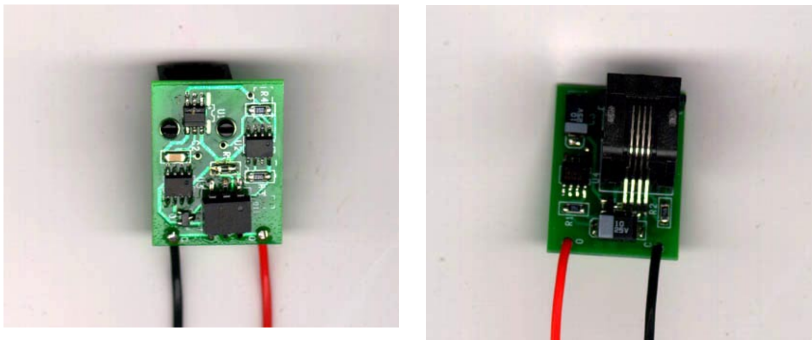

Figure 7. Bottom and top views of the final refined IBECS network/ballast interface. The red and black wires connect to the low-voltage "poke-thru" connector on the controllable ballast, while the IBECS microLAN plugs into the black RJ-11 connector on the top of the interface.

Network Considerations

Unlike the first prototype, the refined network interface cannot be self-powered. Several components on the circuit require external instrumentation power (clean 12 VDC) in order to operate correctly. This implies that the classic two-wire microLAN should be modified to consist of at least four wires (rather than just two) and that two of those wires must be dedicated to supplying low-voltage current to devices on the (modified) microLAN. These changes required that we re-think the network issues.

The refined ballast network prototypes use RJ-11 style modular jacks with telephone wire to form a "plug and play" control network. As shown in **Figure 8**, this allows additional ballast network interfaces to be "daisy-chained" together without the installer worrying about which of the inputs on the Y-splitter to use. This solution uses telephone cable that is wired in a particular way (called "network-wired" to distinguish it from the "telephone-style" wiring that is often used in homes.).

In **Figure 8** we have located the MicroLAN controller/bridge, which bridges between the microLAN and Ethernet, at one end of the microLAN run (although it can be located anywhere in the run). We have also shown a power supply at the other end of the microLAN run which will provide 12 VDC power to two wires of the telephone cable.

The above network wiring arrangement forms the basis of a reliable "plug-and-play" network that can be easily installed using existing telecommunications trade techniques.

Demonstrated Performance of the Refined Prototype

We modified the test office by replacing the old interfaces with the redesigned IBECS network/ballast interfaces to ascertain whether we had successfully treated the noise problem. We also added instrumentation voltage to the low-voltage cable using a simple DC power supply (called, curiously, a "wall wart").

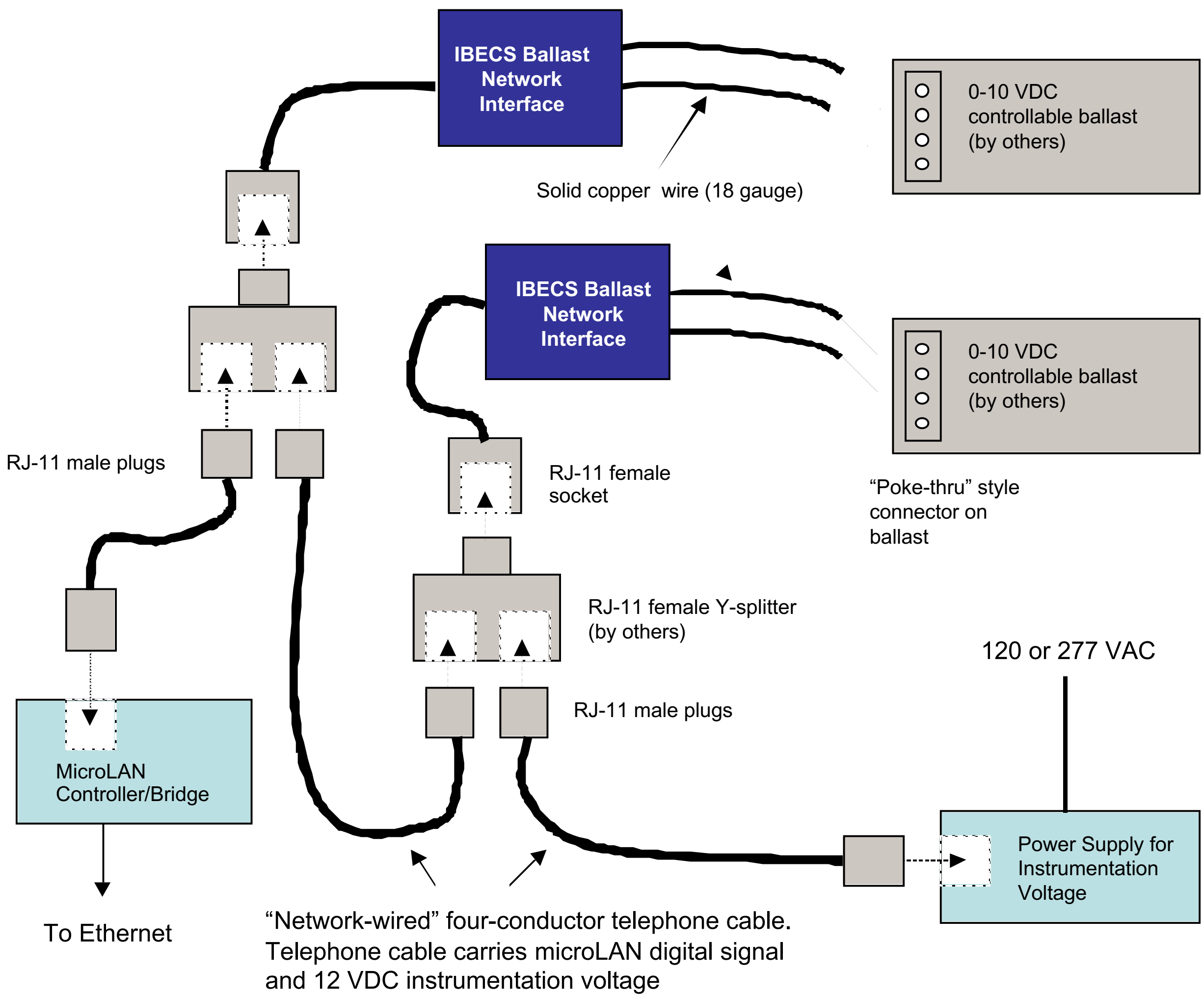

Figure 8. Diagram showing how the IBECS network/ballast interfaces would be daisy-chained together using a system of RJ-11 connectors and four-conductor telephone cable to form a robust "plug-and-play" network.

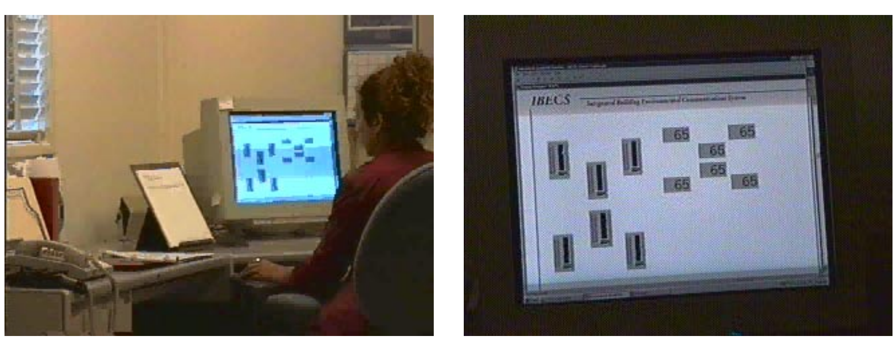

Figure 9. Left image shows occupant using IBECS to change the dim levels of the overhead lights using the computer. The right image is a closeup of the IBECS control screen. Note the six "sliders" on the left portion of the image each corresponding to a separately controlled ballast.

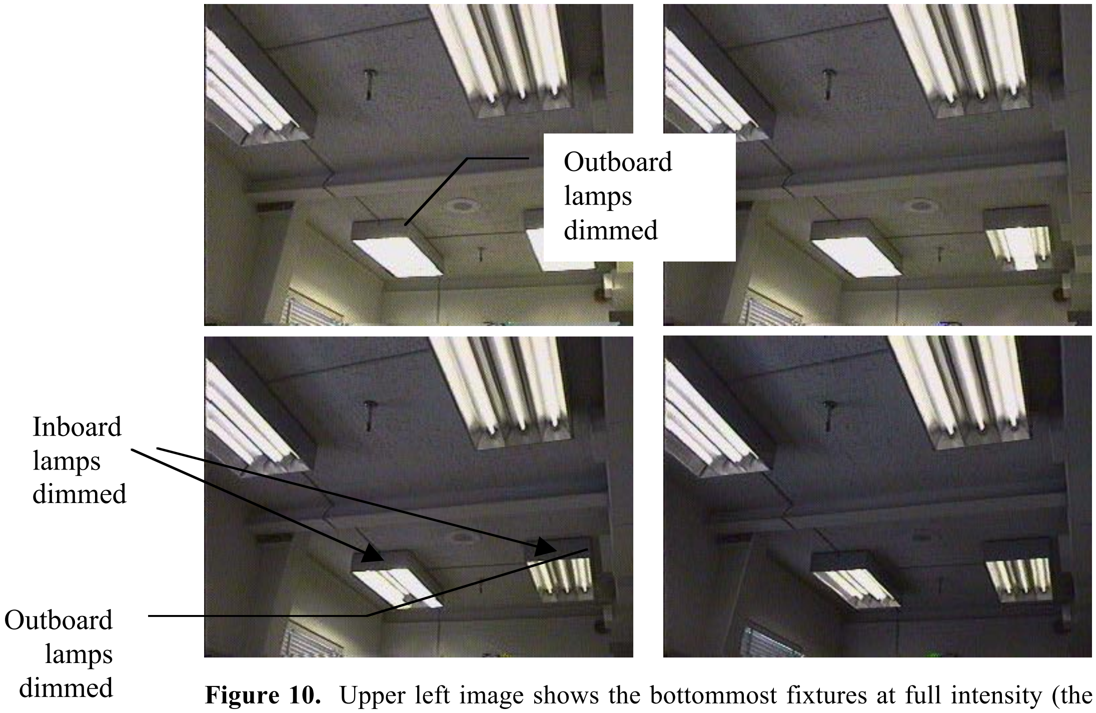

Figure 10. Upper left image shows the bottommost fixtures at full intensity (the topmost fixtures were set to low intensity in all images). Callouts indicate the dim state of the lights in the other two images. The lower right image shows all ballasts operating in fully dimmed state.

We found that the refined IBECS network/ballast interfaces worked very reliably in our test office. Not only could we control each ballast exactly as desired, but the lights dimmed very quickly without any discernable delay. All of the noise problems encountered with the first design have been eliminated. The refined interface eliminates noise from the following ballast types: Motorola Helios, GE, and Advance Mark VII). Although we have not tested this installation on other types of controllable ballasts, we are confident that the optical isolation techniques that we have employed should work for most 0-10 VDC controllable ballasts on the market today.

One practical aspect of this demonstration needs further comment. The 5-100% dimming ballasts that we used could be dimmed past the point of reliable operation by supplying a very small voltage from the interface (about 2 volts). We found that at this low dim level, the lamps would blacken and fail rapidly since the ballast was unable to maintain sufficient cathode voltage at the lowest setting. Fortunately, this problem was easy to fix in the controlling software. Simply by limiting the dimming level to a more modest voltage (easily done in software), we could use the IBECS control software to prevent the ballast from operating in a range where good performance could not be guaranteed. This is another advantage to the IBECS approach. Even if the light equipment is physically capable of operating the lamps at too low a light level, the IBECS control software can be tweaked easily by the installer to prevent the lamps from dimming too low. Needless to say, this is much cheaper to change in software than in the ballast control circuitry.

Conclusion

We learned that newly available silicon microchips are a suitable platform for designing low-cost digital network/ballast interfaces that are useful for enabling network operation of commercially available dimming ballasts. We found that electrical noise generated by the ballast in the 0-10 VDC controllable loop can interfere with digital network operation unless the interface is hardened from this noise. Using optical isolation, we produced a refined IBECS network/ballast interface that can provide universal control of most available 0-10 VDC controllable ballasts. In quantities, we estimate that the cost of the universal IBECS network/ballast interface would be about $1 to $2 to OEMs. This is 5 to 10 times cheaper per unit than any other proposed communications system that we are familiar with.

Thus we successfully completed the task objectives by designing, developing, fabricating and demonstrating an IBECS network/ballast interface that is useful for economically dimming controllable ballasts.

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APPENDIX A: Parts Specifications

DALLAS SEMICONDUCTOR

DS2890
1-Wire® Digital Potentiometer

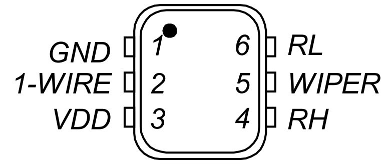
www.dalsemi.com

FEATURES

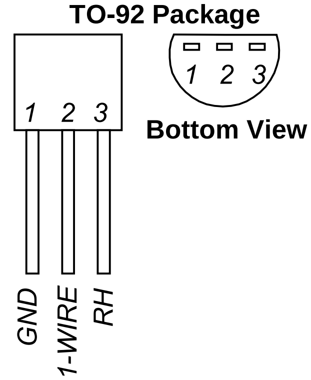
- Single element 256-position linear taper potentiometer
- Supports potentiometer terminal working voltages up to 11V
- Potentiometer terminal voltage independent of supply voltage
- Potentiometer wiper position controlled and read over minimal 1-Wire bus interface
- 100 kΩ resistor element value
- Provides 1-Wire and V_{DD} power modes
- Supports Conditional Search based on power-on default wiper position
- Multiple DS2890's can be identified on a common 1-Wire bus and operated independently
- Unique factory lasered 64-bit registration number assures error free device selection and absolute part identity
- Built-in multi-drop controller ensures compatibility with other 1-Wire Network products
- Supports Overdrive mode which boosts communication speed up to 142 kbits per second
- -40°C to +85°C operating temperature range
- 2.8V – 6.0V operating voltage range

PIN ASSIGNMENT

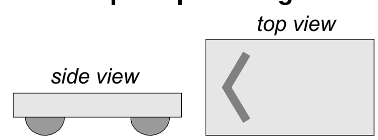
Top View
6-pin TSOC



TO-92 Package



Flip Chip Package



Visit www.dalsemi.com for Flip Chip pinout and mechanical data.

ORDERING INFORMATION

PART NUMBER	RESISTANCE*	PACKAGE DESCRIPTION
DS2890-000	100 kΩ	T0-92
DS2890P-000	100 kΩ	6-pin TSOC
DS2890X-000	100 kΩ	Flip Chip Pkg., Tape & Reel
DS2890T-000	100 kΩ	Tape & Reel of DS2890
DS2890V-000	100 kΩ	Tape & Reel of DS2890P

* Contact the factory for availability of alternate resistance values

PIN DESCRIPTION

SIGNAL NAME	TYPE	FUNCTION
1-WIRE	I/O	1-Wire bus interface. Open drain, requires external pull-up resistor. Range: 2.8V – 6.0V. See HARDWARE CONFIGURATION for pull-up resistor recommendations.
RH	I/O	High end terminal of potentiometer resistor element. Range: 0V – 11.0V. Range independent of 1-Wire or V_{DD} supply levels as well as the voltage levels applied to the other potentiometer terminals.
RL	I/O	Low end terminal of potentiometer resistor element. Range: 0V – 11.0V. Range independent of 1-Wire or V_{DD} supply levels as well as the voltage levels applied to the other potentiometer terminals.
WIPER	I/O	Potentiometer wiper terminal. Range 0V – 11.0V. Range independent of 1-Wire or V_{DD} supply levels as well as the voltage levels applied to the other potentiometer terminals.
V_{DD}	PWR	Auxiliary power supply input. Range: 2.8V – 6.0V
GND	PWR	Ground

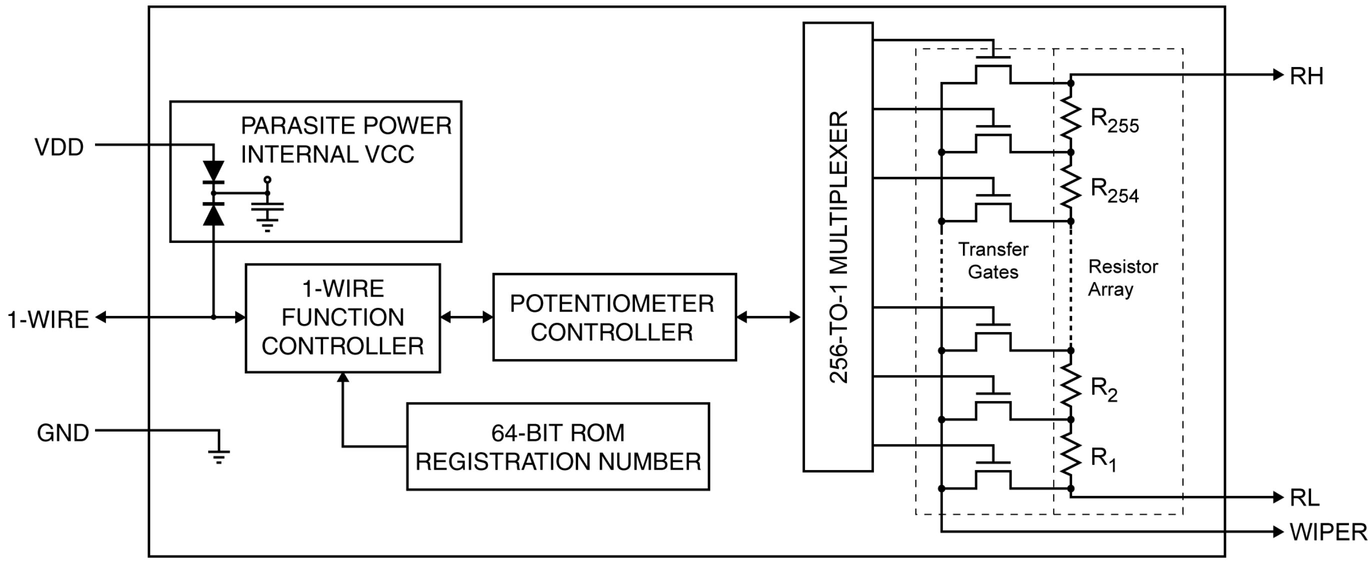
DESCRIPTION

The DS2890 is a linear taper digitally controlled potentiometer with 256 wiper positions. Device operation, including wiper position, is controlled over the single contact 1-Wire bus for the ultimate in electrical interface simplicity. With a wide 0–11 volt working voltage range for the potentiometer terminals, the DS2890 is ideal for a broad range of industrial and control applications. Potentiometer terminal voltage is independent of device supply voltage as well as the voltage applied to the other potentiometer terminals. Communication with the DS2890 follows the standard Dallas Semiconductor 1-Wire protocol and can be accomplished with minimal hardware such as a single port pin of a microcontroller. Multiple DS2890 devices can reside on a common 1-Wire bus and be operated independently of each other. Each DS2890 has its own unalterable 64-bit ROM registration number that is factory lasered into the chip. The registration number guarantees unique identification for absolute traceability and is used to address the device in a multi-drop 1-Wire Network environment. The DS2890 will respond to a 1-Wire Conditional Search command if the potentiometer wiper is set at the power-on default position. This feature enables the bus master to easily determine whether a potentiometer has gone through a power-on reset and needs to be re-configured with a required wiper position setting. The DS2890 supports two power modes: 1-Wire only mode in which device power is supplied parasitically from the 1-Wire bus or V_{DD} mode where power is supplied from an external supply; when operating from V_{DD} mode wiper resistance is reduced.

OPERATION

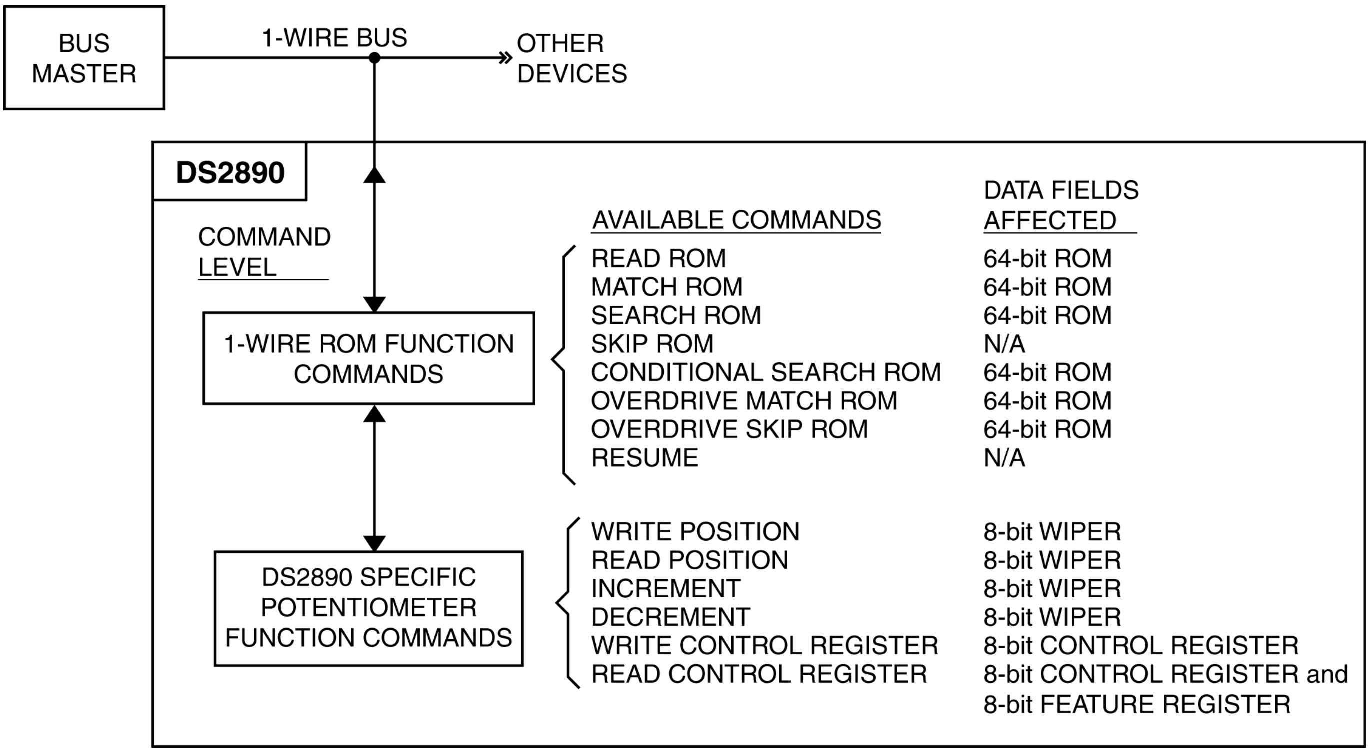
The DS2890 is a single element digital potentiometer; a block diagram of the device is shown in Figure 1. The device has a total of 256 linearly spaced tap points including the RL and RH terminals; a total of 255 resistive segments exist between the RL and RH terminals. These tap points are accessible to the WIPER terminal whose position is controlled via the 1-Wire bus interface. Wiper position and device state are maintained as long as the 1-Wire bus is active or the V_{DD} supply is applied within operating limits. Otherwise, a power-on reset will occur and the wiper position and operating state will return to power-on default conditions.

Figure 1. **DS2890 BLOCK DIAGRAM**



As shown in the figure the device has five major elements: the 1-Wire Function Controller, the Potentiometer Controller, the 64-bit ROM, the resistor array, and Parasite Power circuitry. Each of these elements is discussed in detail throughout the remainder of the data sheet. DS2890 control including device selection, positioning/reading the potentiometer wiper, and device operating state is performed over the 1-Wire bus. The hierarchical structure of the 1-Wire protocol as applicable to the DS2890 is shown in Figure 2. As shown, the control sequence starts with the 1-Wire bus master issuing one of eight ROM function commands. After a ROM function command is successfully completed potentiometer functions may be executed. The protocol for ROM and potentiometer functions are described in the "COMMAND FLOW" section. For the 3-pin TO-92 package configuration and operation see the "TO-92 PACKAGE OPERATION" section.

Figure 2. **1-WIRE COMMAND HIERARCHICAL STRUCTURE**



DATA I/O BIT ORDER

All data is read and written least significant bit (LSB) first.

POTENTIOMETER FEATURE REGISTER

Although the feature set of the DS2890 is primarily fixed, a mechanism to identify feature characteristics of future 1-Wire potentiometers has been developed and implemented in the DS2890. As shown in Figure 3, the feature register is an encoded read-only byte that describes the characteristics of the DS2890 and future 1-Wire potentiometers. Feature values that correspond to the DS2890 are highlighted. The feature register is read with the READ CONTROL REGISTER potentiometer function command (see "POTENTIOMETER FUNCTION COMMANDS").

Figure 3. 1-WIRE POTENTIOMETER FEATURE REGISTER

Feature Register Bit Encoding

b7	b6	b5	b4	b3	b2	b1	b0
PR		NWP		NP		WSV	PC

Feature Register Bit Definitions

Feature Description	Bit(s)	Definition
PC: potentiometer characteristic	b0	If 0: logarithmic potentiometer element(s)
		If 1: linear potentiometer element(s)
WSV: wiper setting volatility	b1	If 0: wiper setting(s) are non-volatile
		If 1: wiper setting(s) are volatile
NP: number of potentiometers	b3..b2	2 bit binary value representing number of potentiometers:
		If 00b: 1 potentiometer
		If 01b: 2 potentiometers
		If 10b: 3 potentiometers
		If 11b: 4 potentiometers
NWP: number of wiper positions	b5..b4	2 bit binary value representing number of wiper positions for each potentiometer:
		If 00b: 32 positions
		If 01b: 64 positions
		If 10b: 128 positions
		If 11b: 256 positions
PR: potentiometer resistance	b7..b6	2 bit binary value representing potentiometer resistance:
		If 00b: 5 kΩ
		If 01b: 10 kΩ
		If 10b: 50 kΩ
		If 11b: 100 kΩ

DS2890 feature values are highlighted: value

The DS2890 will respond with a feature register value of F3h when a READ CONTROL REGISTER command is executed, see section "POTENTIOMETER FUNCTION COMMANDS".

POTENTIOMETER CONTROL REGISTER

The potentiometer control register is used to turn on/off the DS2890 charge pump (see section "POTENTIOMETER WIPER RESISTANCE AND CHARGE PUMP CONSIDERATIONS" for a discussion of the charge pump) and has control capabilities for future 1-Wire potentiometers that could contain multiple resistor elements. The format of the control register is shown in Figure 4.

Figure 4. **POTENTIOMETER CONTROL REGISTER**

Control Register Bit Encoding

b7	b6	b5	b4	b3	b2	b1	b0
X	CPC	X	X	$\overline{WN}$		WN	

Control Register Bit Definitions*

Description	Bit(s)	Definition
WN: wiper number to control	b1..b0	2 bit binary value representing the potentiometer wiper to control:
		If 00b: potentiometer 1 wiper
		If 01b: potentiometer 2 wiper
		If 10b: potentiometer 3 wiper
		If 11b: potentiometer 4 wiper
$\overline{WN}$: inverted wiper number to control	b3..b2	1's complement of potentiometer wiper to control:
		If 11b: potentiometer 1 wiper
		If 10b: potentiometer 2 wiper
		If 01b: potentiometer 3 wiper
		If 00b: potentiometer 4 wiper
CPC: charge pump control	b6	If 0: the charge pump is OFF If 1: the charge pump is ON
X: don't care.	b4,b5,b7	These bits are reserved for future use by Dallas Semiconductor. These bits should be written to a value of 0.

*NOTE:

Control Register power-on defaults: Charge Pump is OFF (CPC=0), Wiper Number to control is wiper #1 (WN=00b, $\overline{\textbf{WN}}$ =11b).

Valid DS2890 control values are highlighted: value

Thus for the DS2890, valid control register values are:

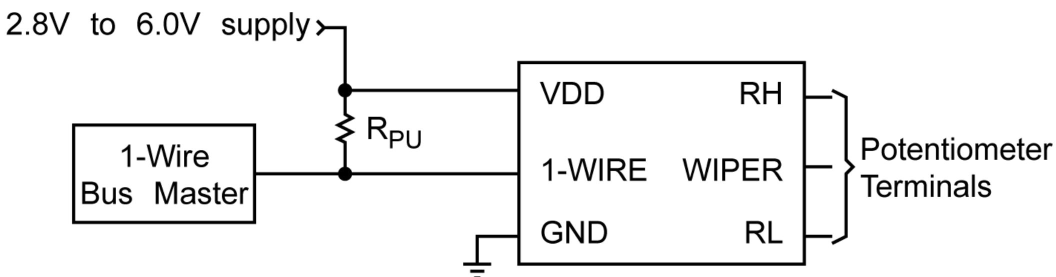
Control Register Value	Description
00001100b	charge pump off, potentiometer #1 wiper selected
01001100b	charge pump on, potentiometer #1 wiper selected

As shown in Figure 17 and discussed in the "POTENTIOMETER FUNCTION COMMANDS" section, no change in device state will occur if an invalid control register value is sent.

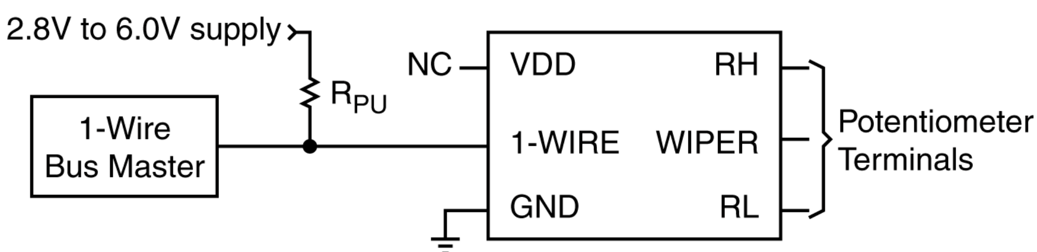
POWER

With the charge pump off, the DS2890 can derive its power entirely from the 1-Wire bus by storing energy on an internal capacitor during periods of time when the 1-Wire bus is in a high state. During bus low times the device continues to operate from the energy stored on the internal capacitor; the capacitor is then recharged when the bus returns to a high state. This technique of operating entirely from the 1-Wire bus by powering from energy stored on an internal capacitor during bus low times in known as "parasite powered" operation. As an option, an auxiliary power source may be connected to the V_{DD} power pin. The auxiliary power mode is appropriate for applications where device charge pump activation is necessary, the device may be temporarily disconnected from the 1-Wire bus, or bus low times may be very long. See Figure 5 for example configurations for both power modes.

Figure 5. **POWER SUPPLY CONFIGURATION OPTIONS**



(a) Auxiliary V_{DD} Supply Configuration



(b) 1-Wire Parasite Power Configuration

POTENTIOMETER WIPER RESISTANCE AND CHARGE PUMP CONSIDERATIONS

A simplified diagram of the DS2890 resistor array is shown in Figure 6. In this figure the r_{DS} resistance of the wiper transistors in Figure 1 are modeled as wiper resistance R_{WIPER}. The value of R_{WIPER} varies with device configuration, operational state, and wiper terminal voltage. If an auxiliary external V_{DD} supply configuration is used as shown In Figure 5a, the DS2890 charge pump may be enabled to reduce potentiometer wiper resistance. A consequence of enabling the charge pump is increased device power consumption. This increase is beyond the level that can be supported when operating in 1-Wire parasite power mode (see POWER section). Therefore if it is necessary to enable the charge pump in an application, the power supply configuration as shown in Figure 5a **must** be used. Figure 7 and Figure 8 are graphs of wiper resistance with the charge pump turned ON and OFF respectively.

Figure 6. **POTENTIOMETER RESISTOR MODEL**

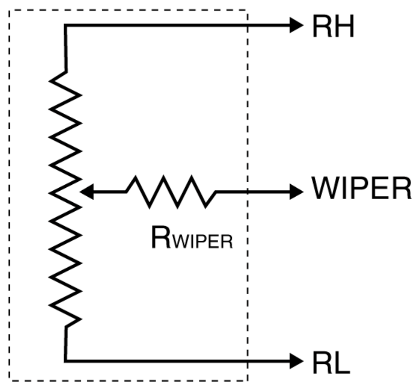


Figure 7. **TYPICAL WIPER RESISTANCE VS WIPER VOLTAGE, CHARGE PUMP ON**

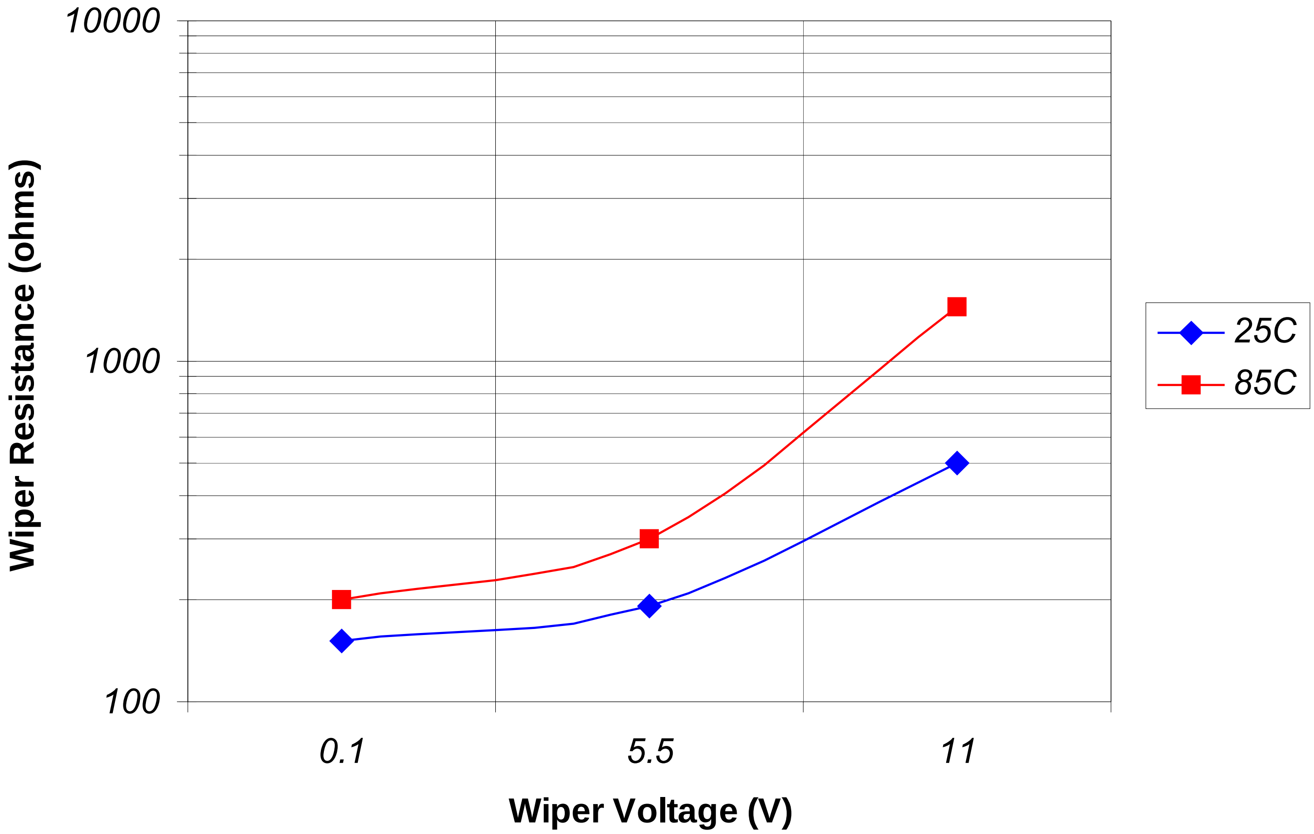
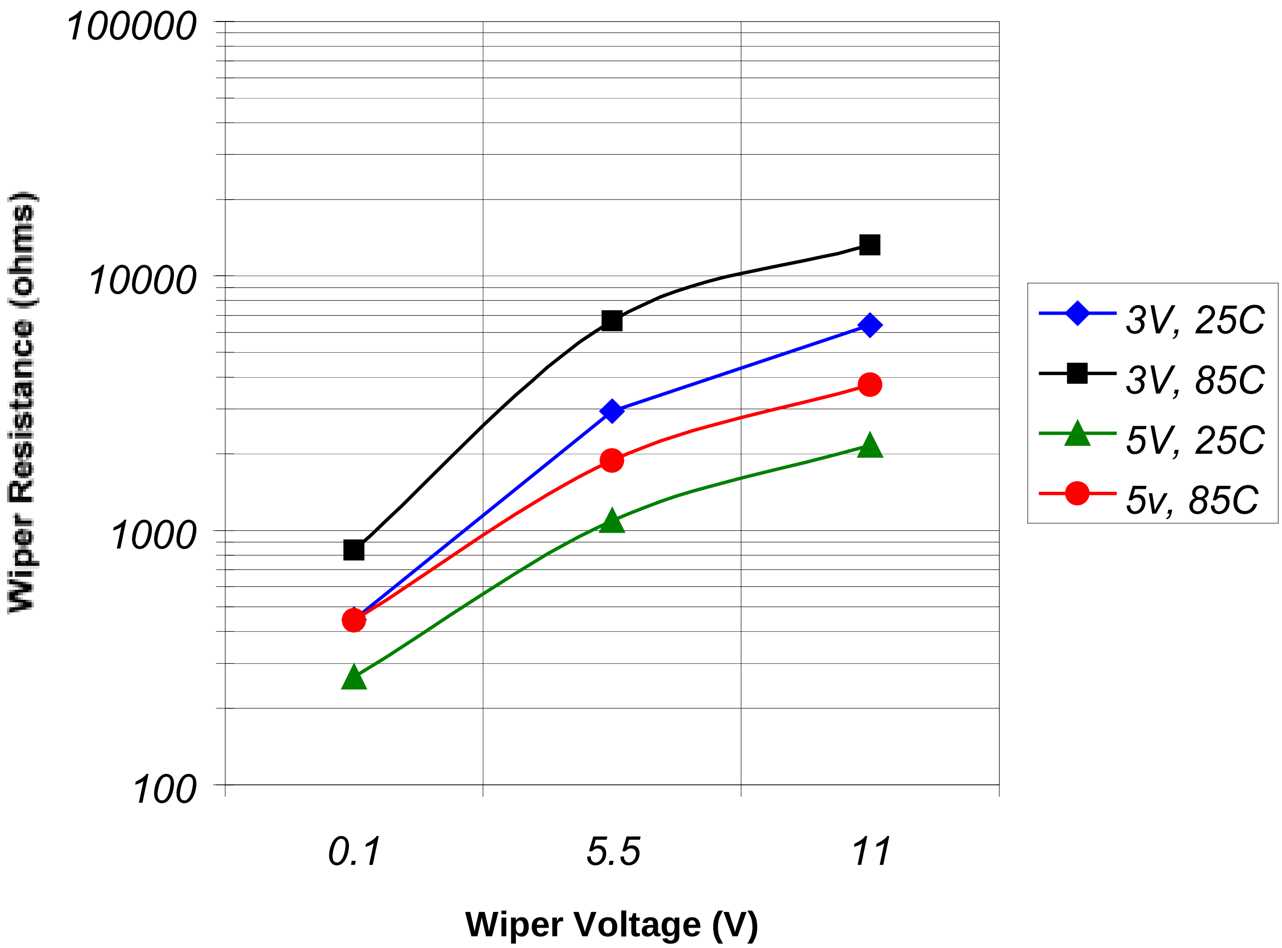


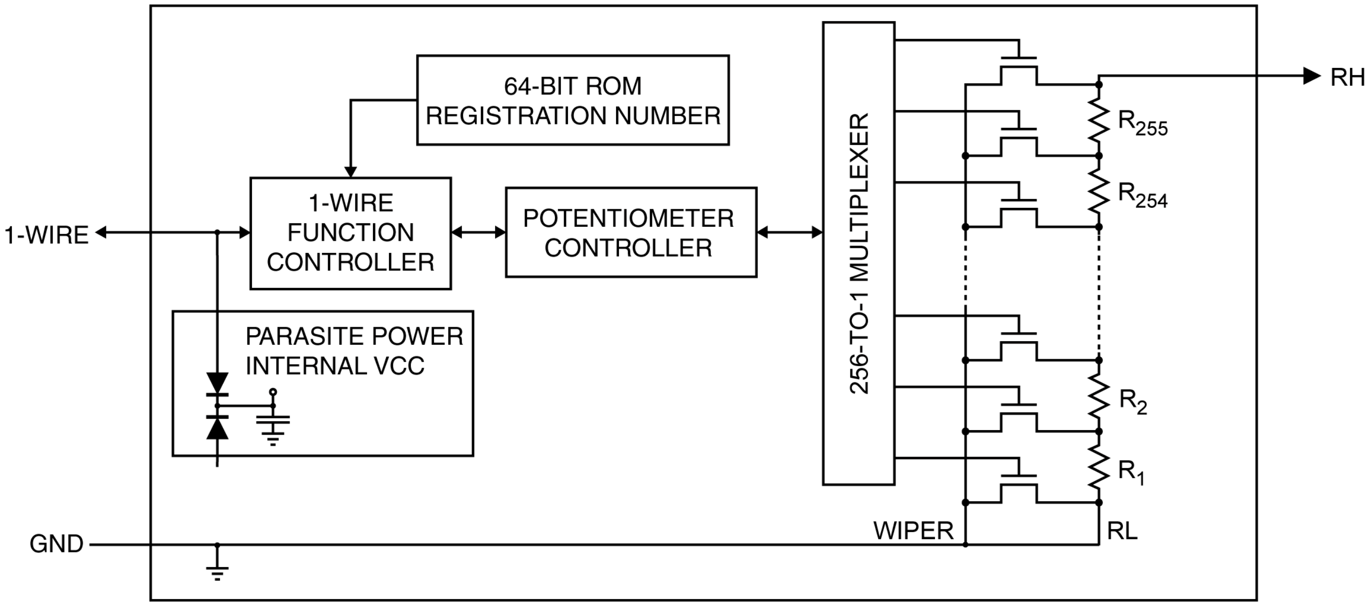
Figure 8. **TYPICAL WIPER RESISTANCE VS WIPER VOLTAGE, CHARGE PUMP OFF**



TO-92 PACKAGE OPERATION

When packaged in a 3-pin TO-92, the DS2890 takes on a configuration as shown in Figure 9. As shown, the RL and Wiper terminals and are connected to GND and the resistance between the RH terminal and GND is varied. Note that the DS2890 charge pump must be turned off (default state) for this configuration. (This is a power consumption issue as described in the section "POTENTIOMETER WIPER RESISTANCE AND CHARGE PUMP CONSIDERATIONS".)

Figure 9. **DS2890 TO-92 CONFIGURATION BLOCK DIAGRAM**



64-BIT LASTERED ROM

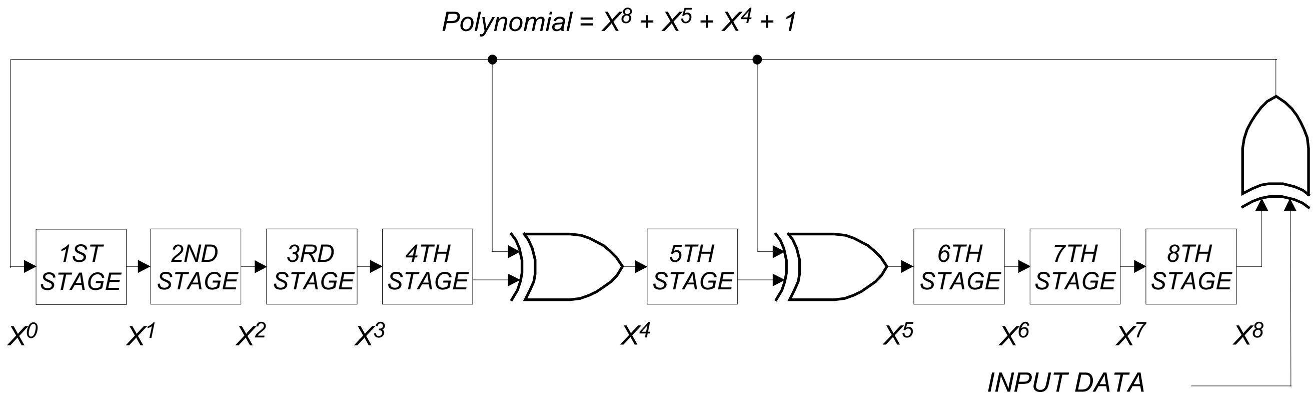
Each DS2890 contains a unique ROM registration number that is 64 bits long; the format of this value is shown in Figure 10. The first 8 bits are a 1-Wire family code; the family code for the DS2890 and future 1-Wire Potentiometers is 2Ch.. The next 48 bits are a unique serial number that is administered by Dallas Semiconductor. The last 8 bits are a CRC of the first 56 bits. The 1-Wire CRC is generated using a polynomial generator consisting of a shift register and XOR gates as shown in Figure 11. Operationally, the CRC generator works as follows: The shift register bits are first initialized to zero. Then starting with the least significant bit, the 8-bit family code is shifted in. After the 8th bit of the family code has been entered, the 48-bit serial number is shifted in. After shifting in the 48th bit of the serial number the shift register contains the CRC value. Shifting in the 8 bits of CRC should return the shift register to an all zeros value. Detailed information about the Dallas 1-Wire Cyclic Redundancy Check is available in the Book of DS19xx iButton Standards. The 64-bit ROM and the 1-Wire Function Controller portions of the DS2890 allow the device to operate as a 1-Wire device and follow the protocol detailed in the section "TRANSACTION SEQUENCE".

Figure 10. **64-BIT LASERED ROM**

MSB *LSB*

8-Bit CRC Code	*48-Bit Serial Number*	*8-Bit Family Code (2Ch)*
MSB *LSB*	*MSB* *LSB*	*MSB* *LSB*

Figure 11. **1-WIRE CRC GENERATOR**



POTENTIOMETER FUNCTION COMMANDS

Once the bus master has completed a ROM command sequence, one of six DS2890 potentiometer function commands can be issued. The Potentiometer Function Command flow charts, Figure 16 and Figure 17, describe the protocols necessary for adjusting or reading the potentiometer wiper position or controlling the operating state of the DS2890. All potentiometer functions consist of a single command byte followed by one or more bytes of data or control written/read by the bus master. All data transferred between the DS2890 and the bus master are communicated least significant bit first.

READ POSITION [F0H]

The Read Position command is used to obtain the wiper setting of the potentiometer currently addressed by the Control Register. Although the DS2890 is a single element potentiometer, wiper addressing still applies and the Control Register wiper number used for addressing must be set accordingly. In addition to wiper position, the Control Register byte will be returned with a Read Position command. This enables the bus master to easily confirm/determine the currently addressed potentiometer wiper. Following the Read Position command byte, the bus master reads 16 bits to obtain first the Control Register byte then the wiper position byte. The DS2890 will respond with 0's to additional reads after the 8 bit of the position byte. The Read Position command is terminated with a Reset pulse.

WRITE POSITION [0FH]

The Write Position command is used to set the position of the currently addressed potentiometer wiper. Although the DS2890 is a single element potentiometer, wiper addressing still applies and the Control Register wiper number used for addressing must be set accordingly. The bus master follows the Write Position command byte with an 8-bit wiper position value. Following the 8th bit of the position byte, the bus master reads back the 8-bit position value from the DS2890 to confirm that the value was received correctly by the device. If an incorrect value is read back, the bus master must issue a Reset pulse and repeat the sequence. If the value read back is correct, the bus master then sends the 8-bit release code (96h). If the DS2890 accurately receives the release code, the wiper position is updated and the device will respond with 0's to additional reads by the bus master. If an invalid release code is received, no change is made to the wiper position and the device will respond with 1's to additional reads by the bus master. The Write Position command is terminated with a Reset pulse.

READ CONTROL REGISTER [AAH]

The Read Control Register command is used to obtain both the Control Register and potentiometer Feature Register. Following the Read Control Register command byte, the bus master reads 16 bits to obtain first the Feature Register byte and then the Control Register byte. The DS2890 will respond with 0's to additional reads after the 8 bit of the Control Register byte. The Read Control Register command is terminated with a Reset pulse.

WRITE CONTROL REGISTER [55H]

The Write Control Register command is used to manipulate DS2890 state bits located in the Control Register. This command is used to set the potentiometer wiper address and charge pump state. The bus master follows the Write Control Register command byte with an 8-bit register value. Following the 8th bit of the register byte, the bus master reads back the 8-bit control value from the DS2890 to confirm that the device received the correct value (Note that if an invalid register value was received by the DS2890, the bus master will read all 1's (FFh) during the read back sequence.). If a value other than FFh is read, the bus master determines if the DS2890 received the correct value. If an incorrect value is read back, the bus master must issue a Reset pulse and repeat the sequence. If the value read back is correct, the bus master then sends the 8-bit release code (96h). If the DS2890 accurately receives the release code, the Control Register is updated and the device will respond with 0's to additional reads by the bus master. If an invalid release code is received, no change is made to the Control Register and the device will respond with 1's to additional reads by the bus master. The Write Control Register command is terminated with a Reset pulse.

INCREMENT [C3H]

The Increment command is used for a one step position increase of the currently addressed potentiometer wiper. Although the DS2890 is a single element potentiometer, wiper addressing still applies and the Control Register wiper number used for addressing must be set accordingly. The bus master follows the Increment command byte with an 8-bit read to which the DS2890 will respond with the new 8-bit wiper position set point. No position change is made if the DS2890 wiper is at the maximum position (FFh) and an Increment command is received. One difference between the Increment/Decrement commands and other potentiometer functions is that upon completion of either of these commands, 1-Wire command processing remains at the potentiometer function level. As shown in Figure 16, additional potentiometer commands may be sent without going through the ROM function flow.

DECREMENT [99H]

The Decrement command is used for a one step position decrease of the currently addressed potentiometer wiper. Although the DS2890 is a single element potentiometer, wiper addressing still applies and the Control Register wiper number used for addressing must be set accordingly. The bus master follows the Decrement command byte with an 8-bit read to which the DS2890 will respond with the new 8-bit wiper position set point. No position change is made if the DS2890 wiper is at the minimum position (00h) and a Decrement command is received. One difference between the Increment/Decrement commands and other potentiometer functions is that upon completion of either of these commands, 1-Wire command processing remains at the potentiometer function level. As shown in Figure 16, additional potentiometer commands may be sent without going through the ROM function flow.

1-WIRE BUS SYSTEM

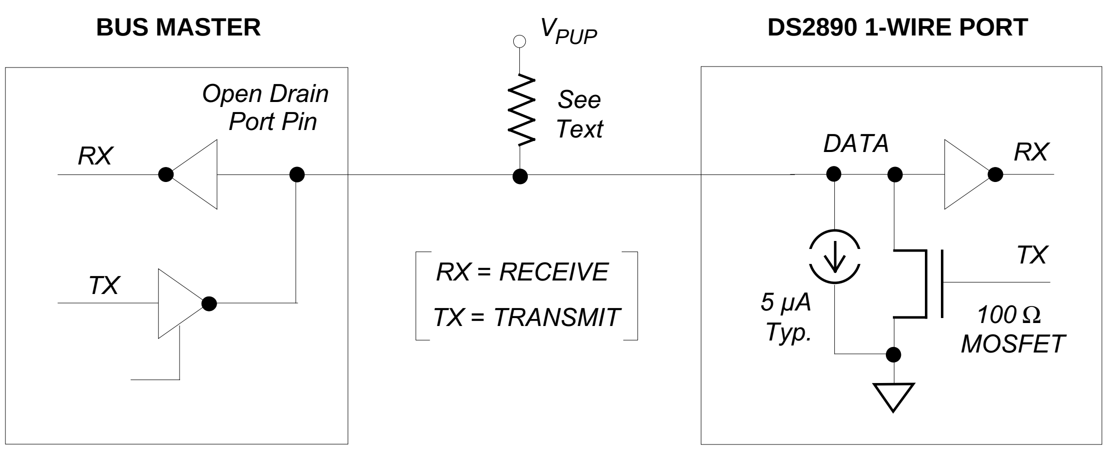
The 1-Wire bus is a system, which has a single bus master and one or more slaves. In all instances the DS2890 is a slave device. The bus master is typically a microcontroller. The discussion of this bus system is broken down into three topics: hardware configuration, transaction sequence, and 1-Wire signaling (signal types and timing). The 1-Wire protocol defines bus transactions in terms of the bus state during specific time slots that are initiated on the falling edge of sync pulses from the bus master. For a more detailed protocol description, refer to Chapter 4 of the Book of DS19xx iButton Standards.

HARDWARE CONFIGURATION

The 1-Wire bus has only a single line by definition; it is important that each device on the bus be able to drive it at the appropriate time. To facilitate this, each device attached to the 1-Wire bus must have open drain or 3-state outputs. The 1-Wire port of the DS2890 is open drain with an internal circuit equivalent to that shown in Figure 9. A multi-drop bus consists of a 1-Wire bus with multiple slaves attached. At regular speed the 1-Wire bus has a maximum data rate of 16.3 kbits per second. The speed can be boosted to 142 kbits per second by activating the Overdrive Mode. For a discrete bus master interface as in Figure 12, the 1-Wire bus requires a pull-up resistor with a minimum value of 2.2 kΩ. Depending on 1-Wire communication speed, regular or overdrive, and bus load characteristics, the optimal pull-up resistor value will be in the 1.5 kΩ to 5 kΩ range. Figure 13 shows a DS2480B bus master configuration with an interface to the host CPU serial port. Among many features, the DS2480B simplifies the 1-Wire interface design, generates slew-rate controlled 1-Wire waveforms, and off-loads 1-Wire timing generation overhead required in a discrete solution.

The idle state for the 1-Wire bus is high. If for any reason a transaction needs to be suspended, the bus MUST be left in the idle state if the transaction is to resume. If this does not occur and the bus is left low for more than 16 µs (Overdrive Speed) or more than 120 µs (regular speed), one or more devices on the bus may be reset.

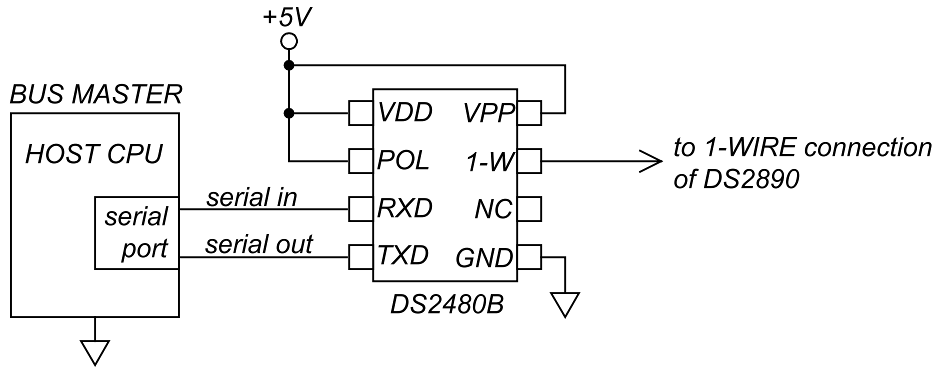
Figure 12. HARDWARE CONFIGURATION



NOTE:

Depending on 1-Wire communication speed, regular or overdrive, and bus load characteristics, the optimal pull-up resistor value will be in the 1.5 kΩ to 5 kΩ range.

Figure 13. BUS MASTER WITH DS2480B DRIVER



TRANSACTION SEQUENCE

The protocol for accessing the DS2890 via the 1-Wire port is as follows:

- Initialization
- ROM Function Command
- Potentiometer Function Command
- Transaction/Data

INITIALIZATION

All transactions on the 1-Wire bus begin with an initialization sequence. The initialization sequence consists of a reset pulse transmitted by the bus master followed by presence pulse(s) transmitted by the slave(s). The presence pulse lets the bus master know that the DS2890 is on the bus and is ready to operate. For more details, see the "1-WIRE SIGNALING" section.

ROM FUNCTION COMMANDS

Once the bus master has detected a presence, it can issue one of the eight ROM function commands that the DS2890 supports. All ROM function commands are 8 bits long. A list of these commands follows (refer to Figure 18 and Figure 19 flowcharts):

READ ROM [33H]

This command allows the bus master to read the DS2890's 8-bit family code, unique 48-bit serial number, and 8-bit CRC. This command should only be used if there is a single slave on the bus. If more than one slave is present on the bus, a data collision will occur when all slaves try to transmit at the same time (open drain will produce a wired-AND result). The resultant family code and 48-bit serial number read by the master will be invalid.

MATCH ROM [55H]

The match ROM command, followed by a 64-bit ROM sequence, allows the bus master to address a specific DS2890 on a multi-drop bus. Only the DS2890 that exactly matches the 64-bit ROM sequence will respond to the following memory function command. All slaves that do not match the 64-bit ROM sequence will wait for a reset pulse. This command can be used with a single or multiple devices on the bus.

SEARCH ROM [F0H]
When a multi-drop system is initially brought up, the bus master might not know the number of devices on the 1-Wire bus or their 64-bit ROM codes. The search ROM command allows the bus master to use a process of elimination to identify the 64-bit ROM codes of all slave devices on the bus. The search ROM process is the repetition of a simple 3-step routine: read a bit, read the complement of the bit, then write the desired value of that bit. The bus master performs this 3-step routine on each bit of the ROM. After one complete pass, the bus master knows the 64-bit ROM code of one device. Additional passes will identify the ROM codes of the remaining devices. See Chapter 5 of the Book of DS19xx iButton Standards for a comprehensive discussion of a search ROM, including an actual example.

CONDITIONAL SEARCH ROM [ECH]
The Conditional Search ROM command operates similarly to the Search ROM command except that only devices fulfilling the specified search condition will participate in the search. The device condition that will cause individual DS2890s to participate in a Conditional Search is a wiper position located at the power-on default setting (00h). This feature enables the bus master to easily determine whether a potentiometer has gone through a power-on reset and needs to be re-configured with a required wiper position setting.

SKIP ROM [CCH]
This command can save time in a single drop bus system by allowing the bus master to access potentiometer functions without providing the 64-bit ROM code. If more than one slave is present on the bus and, for example, a read command is issued following the Skip ROM command, data collision will occur on the bus as multiple slaves transmit simultaneously (open drain pull-downs will produce a wired-AND result).

OVERDRIVE SKIP ROM [3CH]
On a single-drop bus this command can save time by allowing the bus master to access the memory functions without providing the 64-bit ROM code. Unlike the normal Skip ROM command the Overdrive Skip ROM sets the DS2890 in the Overdrive Mode. All communication following this command code has to occur at Overdrive Speed until a reset pulse of minimum 480 µs duration resets all devices on the bus to regular speed.

When issued on a multi-drop bus this command will set all Overdrive-supporting devices into Overdrive mode. To subsequently address a specific Overdrive-supporting device, a reset pulse at Overdrive speed has to be issued followed by a Match ROM or Search ROM command sequence. This will speed up the search process. If more than one Overdrive-supporting slave is present on the bus and the Overdrive Skip ROM command is followed by a read command, data collision will occur on the bus as multiple slaves transmit simultaneously (open drain pull-downs will produce a wire-AND result).

OVERDRIVE MATCH ROM [69H]
The Overdrive Match ROM command, followed by a 64-bit ROM sequence transmitted at Overdrive Speed, allows the bus master to address a specific DS2890 on a multi-drop bus and to simultaneously set it in Overdrive Mode. Only the DS2890 that exactly matches the 64-bit ROM sequence will respond to the subsequent potentiometer function command. Slaves already in Overdrive mode from a previous Overdrive Skip or a successful Overdrive Match command will remain in Overdrive mode. All Over-drive-capable slaves will return to regular speed at the next Reset Pulse of minimum 480 µs duration. The Overdrive Match ROM command can be used with a single or multiple devices on the bus.

RESUME COMMAND [A5H]

In a typical application the DS2890 may be accessed several times to complete a control adjustment. In a multi-drop environment this means that the 64-bit ROM sequence of a Match ROM command has to be repeated for every access. To maximize the data throughput in a multi-drop environment the Resume Command function was implemented. As shown in Figure 19, this function checks the status of the RC flag and, if it is set, directly transfers control to the potentiometer functions, similar to a Skip ROM command. The only way to set the RC flag is through successfully executing the Match ROM, Search ROM, Conditional Search ROM, or Overdrive Match ROM command. Once the RC flag is set, the device can repeatedly be accessed through the Resume Command function. Accessing another device on the bus will clear the RC flag, preventing two or more devices from simultaneously responding to the Resume Command function.

POTENTIOMETER FUNCTION EXAMPLE

At regular speed with an auxiliary supply (V_{DD} within range): turn on the charge pump, set the wiper position to mid-point, increment the wiper twice, and decrement the wiper once.

MASTER MODE	DATA (LSB FIRST)	COMMENTS
TX	Reset	Reset Pulse (480 - 960 µs)
RX	Presence	Presence Pulse
TX	CCh	Issue Skip ROM Command
TX	55h	Issue Write Control Register Command
TX	4Ch	Issue Control Register value for WN=0, CPC=1
RX	<data byte>	Read back Control Register value (4Ch) and verify
TX	96h	Issue Release Code to update Control Register
RX	<data bits>	If 0's are read, update was successful; if 1's are read, the update failed
TX	Reset	Reset Pulse (480 - 960 µs)
RX	Presence	Presence Pulse
TX	CCh	Issue Skip ROM Command
TX	0Fh	Issue Write Position Command
TX	7Fh	Write Wiper Position value
RX	<data byte>	Read back Wiper Position byte and verify
TX	96h	Issue Release Code to update Wiper Position
RX	<data bits>	If 0's are read, update was successful; if 1's are read, the update failed
TX	Reset	Reset Pulse
RX	Presence	Presence Pulse
TX	CCh	Issue Skip ROM Command

MASTER MODE	DATA (LSB FIRST)	COMMENTS
TX	C3h	Issue Wiper Increment Command
RX	<data byte>	Read new wiper position
TX	C3h	Issue Wiper Increment Command
RX	<data byte>	Read new wiper position
TX	99h	Issue Wiper Decrement Command
RX	<data byte>	Read new wiper position
TX	Reset	Reset Pulse

1-WIRE SIGNALING

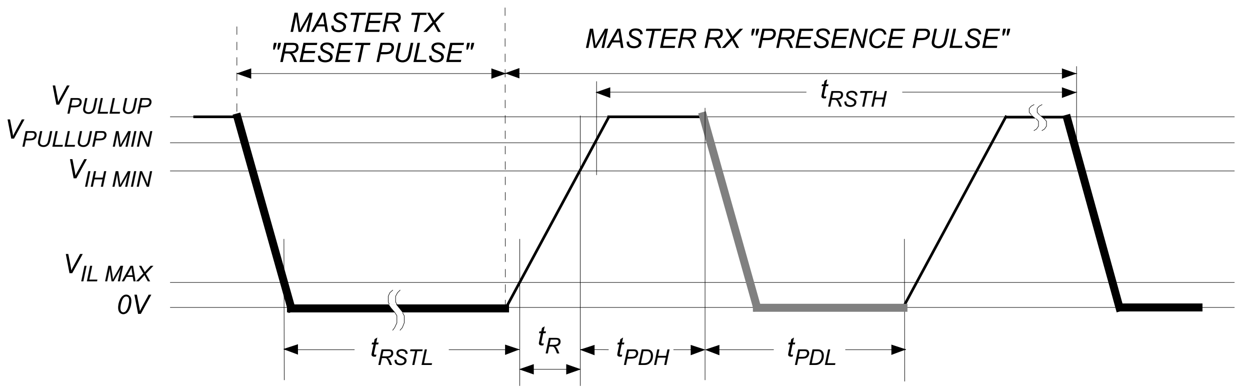
The DS2890 requires strict protocols to ensure data integrity. The protocol consists of four types of signaling on one line: Reset Sequence with Reset Pulse and Presence Pulse, Write 0, Write 1 and Read Data. Except for the presence pulse the bus master initiates all these signals. The DS2890 can communicate at two different speeds, regular speed and Overdrive Speed. If not explicitly set into the Overdrive mode, the DS2890 will communicate at regular speed. While in Overdrive Mode the fast timing applies to all waveforms.

The initialization sequence required to begin any communication with the DS2890 is shown in Figure 14. A Reset Pulse followed by a Presence Pulse indicates the DS2890 is ready to send or receive data. The bus master transmits (TX) a reset pulse (t_{RSTL}, minimum 480 µs at regular speed, 48 µs at Overdrive Speed). The bus master then releases the line and goes into receive mode (RX). The 1-Wire bus is pulled to a high state via the pull-up resistor. After detecting the rising edge on the data contact, the DS2890 waits (t_{PDH}, 15-60 µs at regular speed, 2-6 µs at Overdrive speed) and then transmits the Presence Pulse (t_{PDL}, 60-240 µs at regular speed, 8-24 µs at Overdrive Speed). A Reset Pulse of 480 µs or longer will exit the Overdrive Mode returning the device to regular speed. If the DS2890 is in Overdrive Mode and the Reset Pulse is no longer than 80 µs the device will remain in Overdrive Mode.

READ/WRITE TIME SLOTS

The definitions of write and read time slots are illustrated in Figure 15 (a-c). The master initiates all time slots by driving the data line low. The falling edge of the data line synchronizes the DS2890 to the master by triggering an internal timing circuit. During write time slots, the timing circuit determines when the DS2890 will sample the data line. For a read data time slot, if a “0” is to be transmitted, the timing circuit determines how long the DS2890 will hold the data line low. If the data bit is a “1”, the DS2890 will not hold the data line low at all.

Figure 14. INITIALIZATION PROCEDURE "RESET AND PRESENCE PULSES"



Legend
RESISTOR
MASTER
DS2890

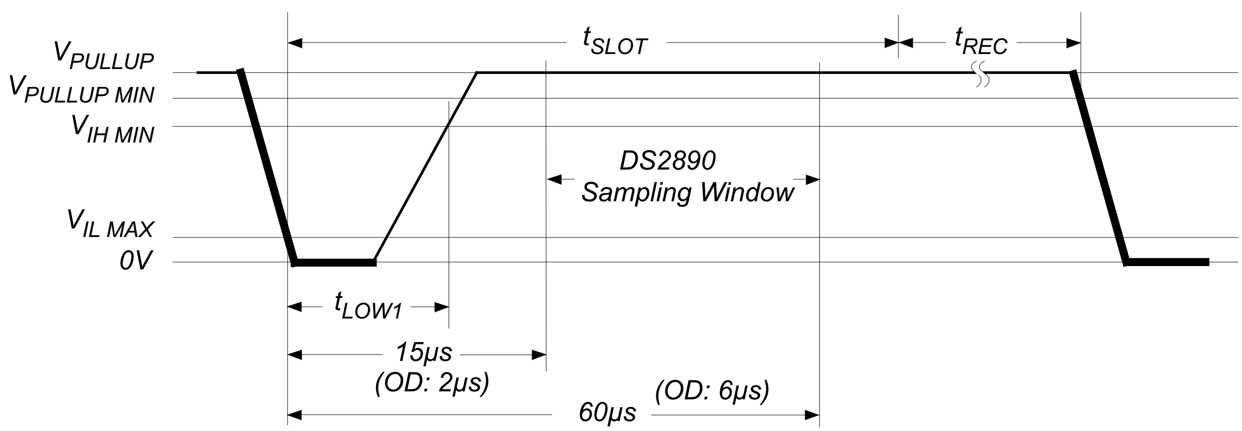
REGULAR SPEED	OVERDRIVE SPEED
$480\ \mu s \le t_{RSTL} < \infty$*	$48\ \mu s \le t_{RSTL} < 80\ \mu s$
$480\ \mu s \le t_{RSTH} < \infty$**	$48\ \mu s \le t_{RSTH} < \infty$**
$15\ \mu s \le t_{PDH} < 60\ \mu s$	$2\ \mu s \le t_{PDH} < 6\ \mu s$
$60 \le t_{PDL} < 240\ \mu s$	$8 \le t_{PDL} < 24\ \mu s$

* In order not to mask interrupt signaling by other devices on the 1-Wire bus and to prevent a power-on reset of the parasite powered circuit, $t_{RSTL} + t_R$ should always be less than 960 µs.

** Includes recovery time.

Figure 15. READ/WRITE TIMING DIAGRAMS

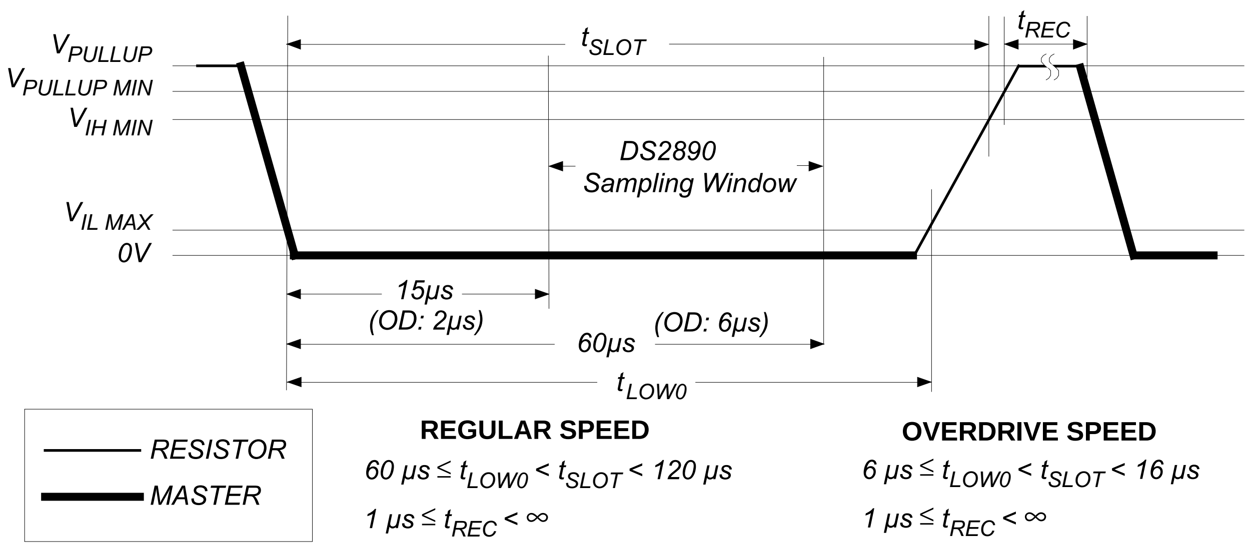
a) Write-one Time Slot



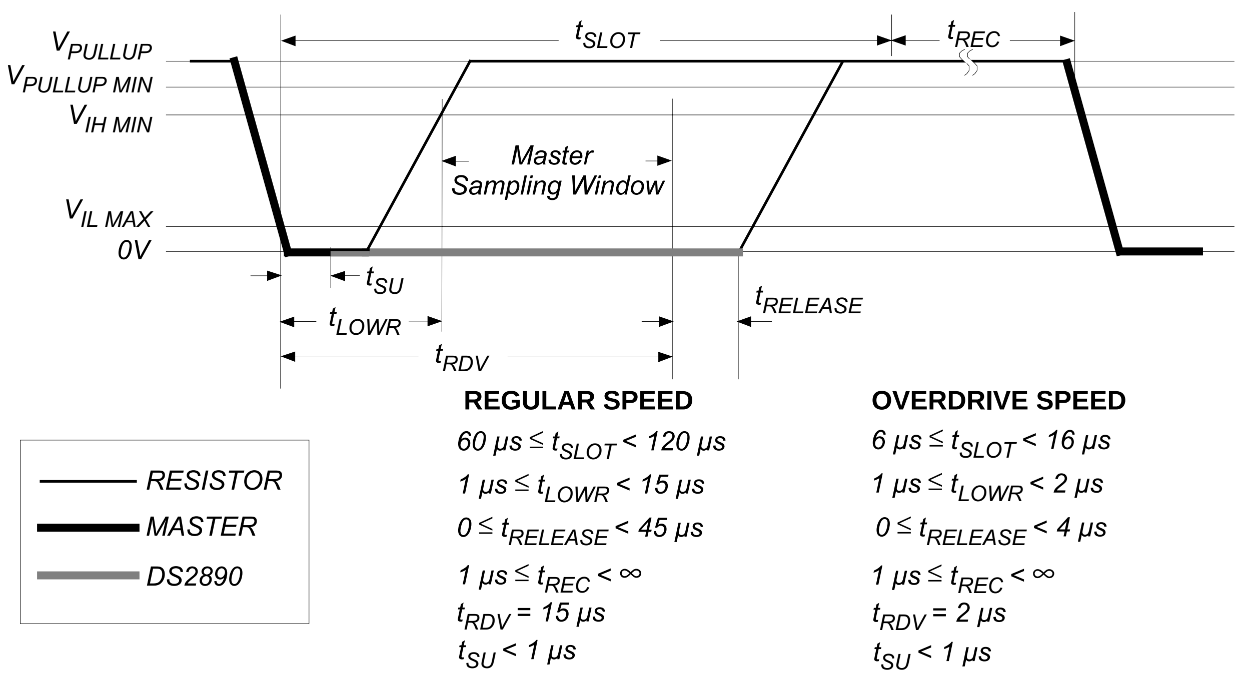
Legend
RESISTOR
MASTER

REGULAR SPEED	OVERDRIVE SPEED
$60\ \mu s \le t_{SLOT} < 120\ \mu s$	$6\ \mu s \le t_{SLOT} < 16\ \mu s$
$1\ \mu s \le t_{LOW1} < 15\ \mu s$	$1\ \mu s \le t_{LOW1} < 2\ \mu s$
$1\ \mu s \le t_{REC} < \infty$	$1\ \mu s \le t_{REC} < \infty$

b) Write-zero Time Slot

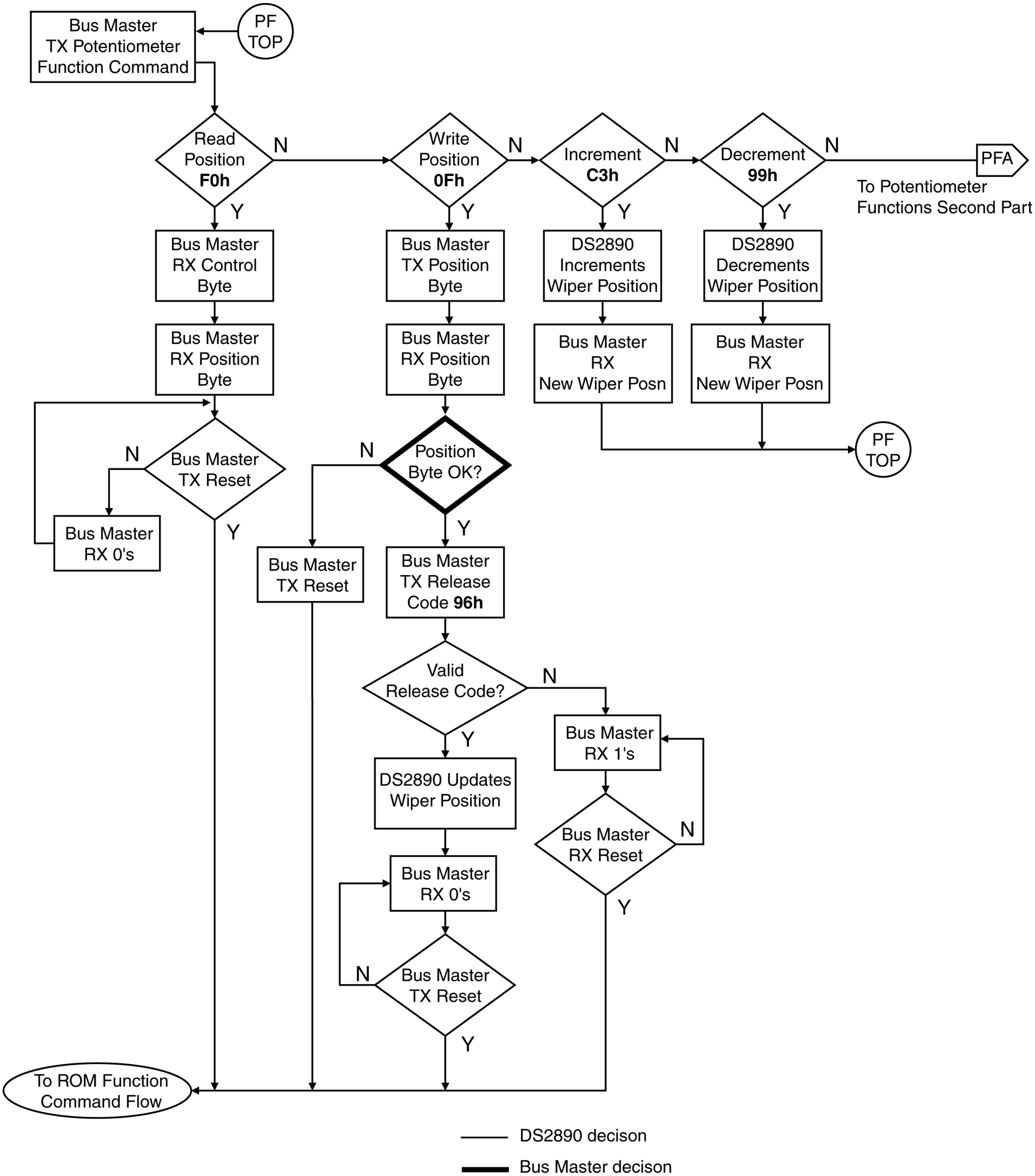


c) Read-data Time Slot



*The optimal sampling point for the master is as close as possible to the end time of the t_{RDV} period without exceeding t_{RDV}. For the case of a Read-one time slot, this maximizes the amount of time for the pull-up resistor to recover the line to a high level. For a Read-zero time slot it ensures that a read will occur before the fastest 1-Wire device(s) release the line ($t_{RELEASE} = 0$).

Figure 16. POTENTIOMETER FUNCTION COMMAND FLOW



All data is LSB first

Figure 17. **POTENTIOMETER FUNCTION COMMAND FLOW** *(continued)*

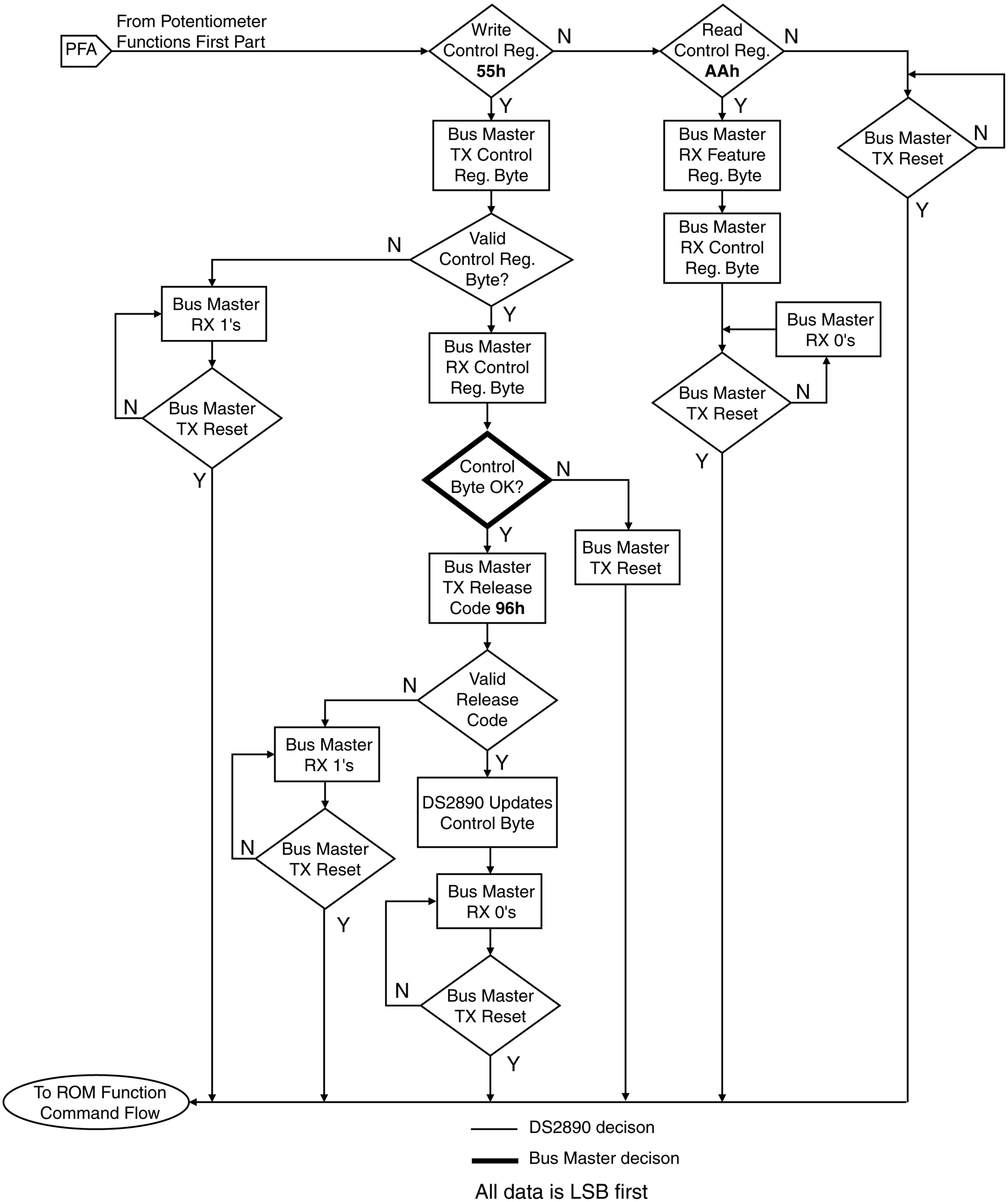


Figure 18. **ROM FUNCTION COMMAND FLOW**

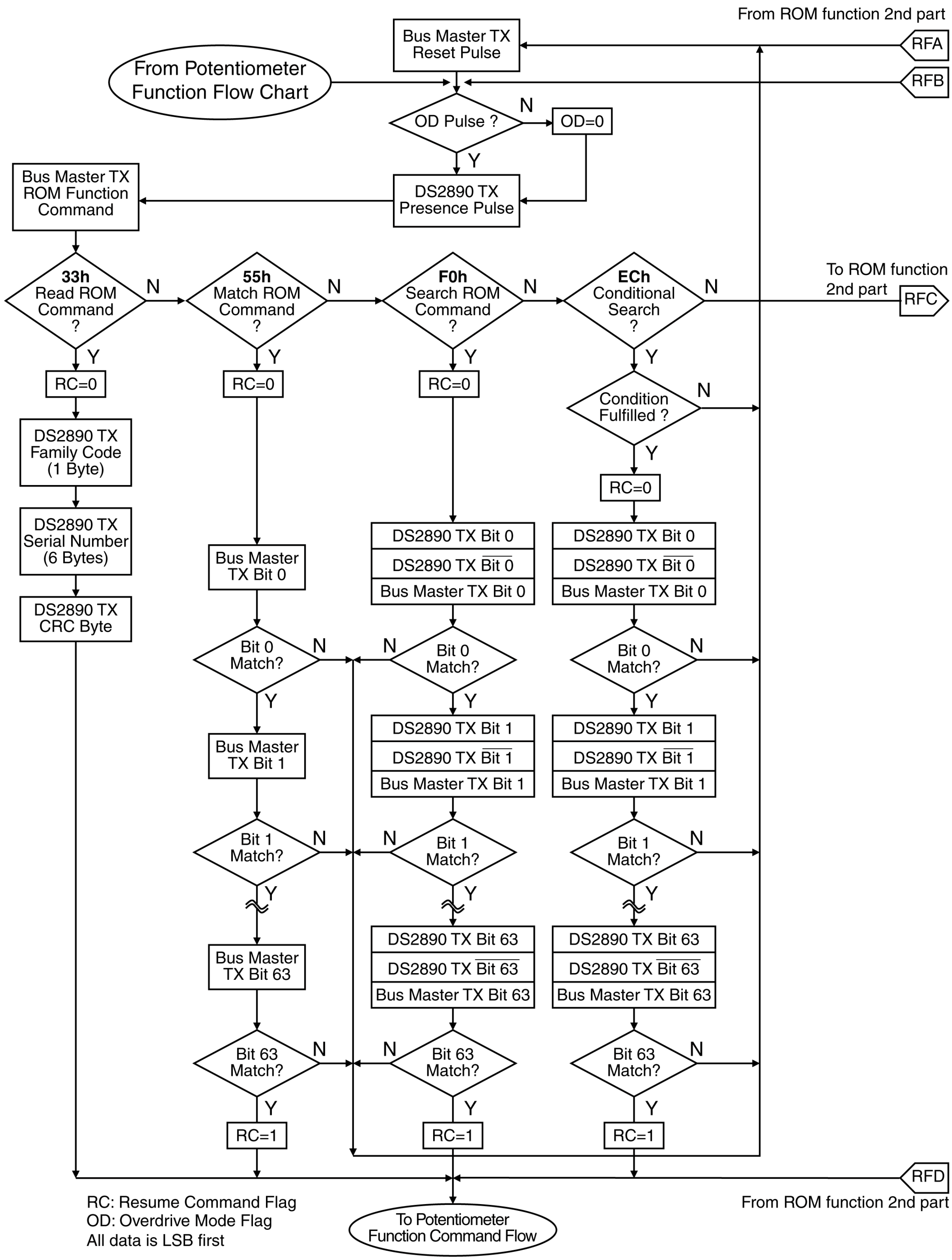
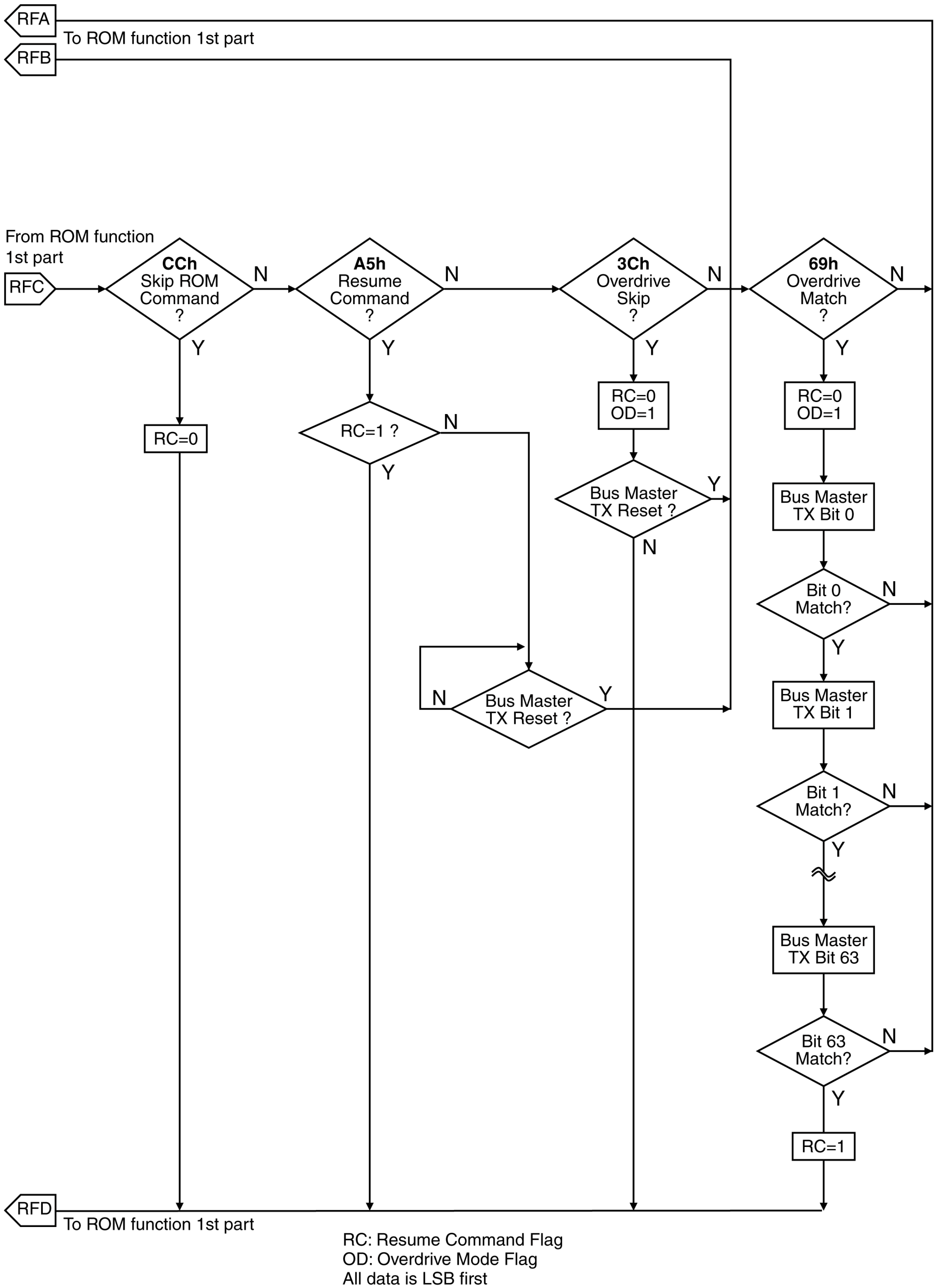


Figure 19. **ROM FUNCTION COMMAND FLOW** *(continued)*



ELECTRICAL CHARACTERISTICS

ABSOLUTE MAXIMUM RATINGS

Voltage on RH, RL, WIPER Relative to Ground	-0.5V to +11.0V
Voltage on Other Pins Relative to Ground	-0.5V to +6.0V
Operating Temperature	-40°C to +85°C
Storage Temperature	-55°C to +125°C
Soldering Temperature	See J-STD-020A specification

* This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operation sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect reliability.

RECOMMENDED DC OPERATING CONDITIONS

$-40°C \leq T_A \leq +85°C$

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
1-Wire Pull-Up Voltage	V_{PUP}	2.8		6.0	V	1
Auxiliary Supply Voltage	V_{DD}	2.8		6.0	V	1,2
		-0.3		0.8	V	1,3

NOTES:

1. Voltages are referenced to ground
2. Range applicable when an auxiliary V_{DD} supply is used
3. Range applicable when an auxiliary V_{DD} supply is not used

POTENTIOMETER CHARACTERISTIC

$2.8V \leq V_{PUP} \leq 6.0V$, $-40°C \leq T_A \leq +85°C$

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
Resistor Terminal Voltage		-0.3		11.0	V	1
End-to-End Total Resistance			100		kΩ	
End-to-End Resistance Tolerance		-25		25	%	2
Wiper Resistance:	R_{WIPER}					3
Absolute Linearity			±0.6		LSB	4
Relative Linearity			±0.25		LSB	5
-3 dB cutoff frequency	f_{CUTOFF}	100			kHz	
Temperature Coefficient			800		ppm/°C	

NOTES:

1. Voltage is referenced to ground.
2. Valid at 25°C only.
3. Wiper resistance is a function of operating characteristics. See section "POTENTIOMETER WIPER RESISTANCE AND CHARGE PUMP CONSIDERATIONS" for R_{WIPER} characteristics.
4. Absolute linearity is a measure of wiper output voltage versus expected wiper voltage as determined by wiper position.
5. Relative linearity is a measure of the output deviation between successive potentiometer tap points.

DC ELECTRICAL CHARACTERISTICS

$2.8V \leq V_{PUP} \leq 6.0V$, $-40°C \leq T_A \leq +85°C$

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
1-Wire Input High	V_{IH}	2.2			V	1
1-Wire Input Low	V_{IL}	-0.3		0.8	V	1,2
1-Wire Output High	V_{OH}		V_{PUP}	6.0	V	1,3
1-Wire Output Low @ 4 mA	V_{OL}			0.4	V	1
1-Wire Input Leakage Current	I_L		5		µA	4
V_{DD} Input Current, Charge Pump OFF	I_{DD}			4.0	µA	5
V_{DD} Input Current, charge Pump ON	I_{DD}			2.0	mA	6

NOTES:

1. Voltages are referenced to ground.
2. Under certain low voltage conditions V_{ILMAX} may have to be reduced to as much as 0.5V to always guarantee a presence pulse.
3. V_{PUP} is the external 1-Wire pull-up voltage.
4. Input load is to ground.
5. Input current when an auxiliary V_{DD} supply is used and the charge pump is turned OFF.
6. Input current when an auxiliary V_{DD} supply is used and the charge pump is turned ON.

AC ELECTRICAL CHARACTERISTICS - REGULAR 1-WIRE SPEED

$2.8V \le V_{PUP} \le 6.0V$, $-40°C \le T_A \le +85°C$

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
Time Slot	t_{SLOT}	60		120	µs	
Write 1 Low Time	t_{LOW1}	1		15	µs	
Write 0 Low Time	t_{LOW0}	60		120	µs	
Read Low Time	t_{LOWR}	1		15	µs	
Read Data Valid	t_{RDV}		15		µs	1
Release Time	$t_{RELEASE}$	0	15	45	µs	
Read Data Setup	t_{SU}			1	µs	2
Recovery Time	t_{REC}	1			µs	
Reset High Time	t_{RSTH}	480			µs	3
Reset Low Time	t_{RSTL}	480			µs	4
Presence Detect High	t_{PDH}	15		60	µs	
Presence Detect Low	t_{PDL}	60		240	µs	

NOTES:

1. The optimal sampling point for the master is as close as possible to the end time of the 15 µs t_{RDV} period without exceeding t_{RDV}. For the case of a Read-one time slot, this maximizes the amount of time for the pull-up resistor to recover the line to a high level. For a Read-zero time slot it ensures that a read will occur before the fastest 1-Wire device(s) release the line ($t_{RELEASE} = 0$).
2. Read data setup time refers to the time the host must pull the 1-Wire bus low to read a bit. Data is guaranteed to be valid within 1 µs of this falling edge.
3. An additional reset or communication sequence cannot begin until the reset high time (t_{RSTH}) has expired.
4. The reset low time (t_{RSTL}) should be restricted to a maximum of 960 µs, to allow interrupt signaling, otherwise, it could mask or conceal interrupt pulses.

AC ELECTRICAL CHARACTERISTICS - OVERDRIVE 1-WIRE SPEED

$2.8V \le V_{PUP} \le 6.0V$, $-40°C \le T_A \le +85°C$

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
Time Slot	t_{SLOT}	6		16	µs	
Write 1 Low Time	t_{LOW1}	1		2	µs	
Write 0 Low Time	t_{LOW0}	6		16	µs	
Read Low Time	t_{LOWR}	1		2	µs	
Read Data Valid	t_{RDV}		2		µs	9
Release Time	$t_{RELEASE}$	0	1.5	4	µs	
Read Data Setup	t_{SU}			1	µs	4

AC ELECTRICAL CHARACTERISTICS - OVERDRIVE 1-WIRE SPEED

$2.8V \le V_{PUP} \le 6.0V$, $-40°C \le T_A \le +85°C$

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
Recovery Time	t_{REC}	1			µs	
Reset High Time	t_{RSTH}	48			µs	
Reset Low Time	t_{RSTL}	48		80	µs	
Presence Detect High	t_{PDH}	2		6	µs	
Presence Detect Low	t_{PDL}	8		24	µs	

NOTES:

1. The optimal sampling point for the master is as close as possible to the end time of the 2 µs t_{RDV} period without exceeding t_{RDV}. For the case of a Read-one time slot, this maximizes the amount of time for the pull-up resistor to recover the line to a high level. For a Read-zero time slot it ensures that a read will occur before the fastest 1-Wire device(s) release the line ($t_{RELEASE} = 0$).
2. Read data setup time refers to the time the host must pull the 1-Wire bus low to read a bit. Data is guaranteed to be valid within 1 µs of this falling edge.
3. An additional reset or communication sequence cannot begin until the reset high time (t_{RSTH}) has expired.
4. The reset low time (t_{RSTL}) should be restricted to a maximum of 960 µs, to allow interrupt signaling, otherwise, it could mask or conceal interrupt pulses.

CAPACITANCE

TA = 25°C

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	NOTES
1-Wire Pin				800	pF	1
V_{DD} Pin			10		pF	
Resistor Terminals				10	pF	

NOTE:

1. Capacitance on the 1-Wire pin could be 800 pF when power is first applied. If a 5 kΩ is used to pull up the 1-Wire line to V_{PUP}, the capacitance will not affect communications after a 5 µs charge time.

DALLAS SEMICONDUCTOR

DS9097/DS9097E COM Port Adapter

www.dalsemi.com

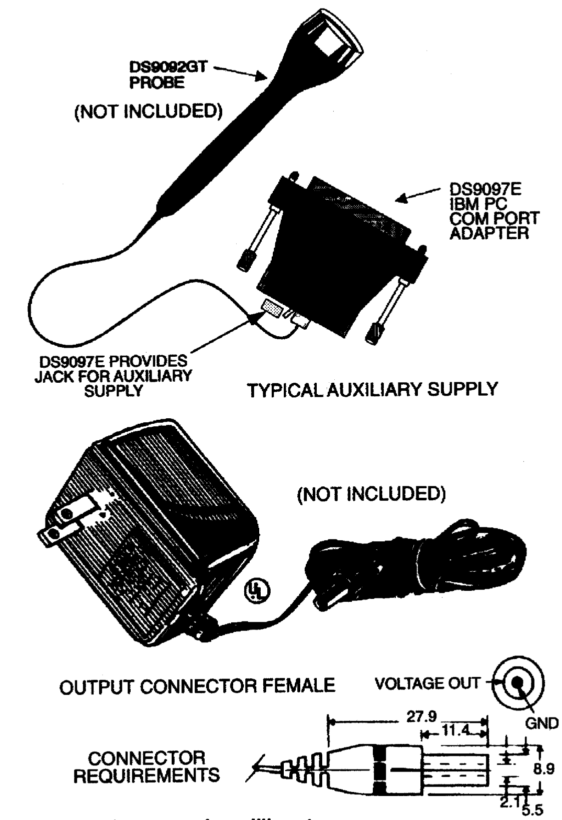
FEATURES

- Provides a simple, low-cost interface to an RS232C COM Port for reading and writing iButton™ devices (DS9097E required for programming DS198x Add-Only iButtons)
- Adapter is powered entirely from an RS232 interface (DS9097E may require optional auxiliary 12V supply)
- Standard DB-9 (DSD9097) or DB-25 (DS9097E) female connector for mating the adapter to the COM Port of a computer and RJ-11 connector for easy attachment of a probe such as the DS9092GT
- DS9097E has an additional 2.1 mm male power jack to allow for an auxiliary 12V DC supply for programming Add-Only iButtons

  Pin assignment DS9097, DB-9
  TXD (3), RXD (2), DTR (4), PC-Ground (5); all other pins not connected

  Pin assignment DS9097E, DB-25
  TXD (2), RXD (3), DTR (20), RTS (4), PC-Ground (7); all other pins not connected

  Auxiliary supply should be a regulated 12V @ 10 mA minimum, center=GND, outer ring=V+ (Newark Electronics Stock No. 84F2081, Allied Electronics Stock No. 928-9895, Stancor Model STA-300R, or equivalent)



All dimensions are in millimeters.

DESCRIPTION

The DS9097 COM Port Adapter is a simple, low-cost passive adapter which performs RS232C (±12V) level conversion, allowing an iButton probe to be connected to the serial port of a computer so that a non-EPROM iButton can be read and written directly. It can also read all EPROM-based iButtons. The serial port must support a data transmission rate of 115.2 kbits/s in order to create the 1-Wire™ time slots correctly. Nearly all PCs support the required data rate and are fully compatible with the DS9097. Since an 8-bit character (6 data bits plus start and stop bit) on the RS232 port operating at 115.2 kbits/s is used to form a single 1-Wire time slot, the maximum effective 1-Wire transfer rate is 14.4 kbits/s (regular speed). Details on the operation of the DS9097 including software examples are found in Application Note 74, Section V.

The DS9097E is an upgraded version of the DS9097 that is capable of supplying the 12 volts necessary to program the EPROM-based iButton products (DS198x Add-Only iButtons) in addition to reading and writing SRAM and EEPROM-based devices (DS199x, DS196x, DS197x). When combined with the appropriate software, the DS9097E can be used in a standalone mode where all of the programming current is supplied by the serial port itself. In this configuration, the maximum number of EPROM bits that can be programmed simultaneously is four on a typical serial port. For higher performance, the above mentioned 12V auxiliary supply can be plugged into the power jack on the DS9097E and with proper software enable the serial port to program up to eight EPROM bits simultaneously.

California Energy Commission
Public Interest Energy Research Program

LBNL No. 52198
HPCBS # E3P22T2c

HPCBS

High Performance Commercial Building Systems

Low-Cost Networking for Dynamic Window Systems

Element 3. Lighting, Envelope and Daylighting
Project 2.2 - Daylighting/Envelopes

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Lawrence Berkeley National Laboratory

August, 2003

Submitted to
Energy and Buildings Journal

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Submitted to Energy and Buildings. LBNL-52198

Low-Cost Networking for Dynamic Window Systems

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Abstract

A low-cost building communications network is needed that would allow individual window and lighting loads to be controlled from an existing enterprise LAN network. This building communications network concept, which we term IBECS™ (Integrated Building Environmental Communications System), would enable both occupant-based and building-wide control of individual window, lighting, and sensor devices. IBECS can reduce the cost of systemic control because it allows a drastic cost reduction in per point networking costs. This kind of effort is needed to encourage the control industry to make the commitment to build this technology and to demonstrate to prospective customers that this breakthrough approach to more comprehensive systemic control will provide them with high-quality, convenient control while saving them money.

The development and demonstration of network interfaces to DC- and AC-motorized shades and to an electrochromic window are described. The network interfaces enable one to control and monitor the condition of these fenestration appliances from a variety of sources, including a user's personal computer. By creating a functional specification for an IBECS network interface and testing a prototype, the ability to construct such an interface was demonstrated and the cost-effective price per point better understood. The network interfaces were demonstrated to be reliable in a full-scale test of three DC-motorized Venetian blinds in an open-plan office over two years and in limited bench-scale tests of an electrochromic window.

Keywords: Building energy-efficiency, electrochromic windows, motorized roller shades, motorized Venetian blinds, controls, networking.

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1. Introduction

Over the last twenty-five years, the US Department of Energy (DOE) in partnership with the window industry has revolutionized the window products available to consumers and specifiers. Low-E coated glass, unknown in the 1970s, is now used in over 40% of all residential windows sold in the US. Spectrally selective glazings are beginning to penetrate the commercial sector as well. Despite the impressive savings, windows still make a large contribution to the US annual building energy consumption of $265B in 2000 [1]. Further penetration of existing technologies will increase energy savings but will begin to have diminishing returns. In 2002, DOE worked with members of the window industry to create a roadmap that defined the technologies and tools that will be needed to create and sell the next generation of windows in the 21st century [2]. Window industry executives identified a new generation of dynamic, responsive "Smart Windows" as the number one top priority. The emerging concept of the window will be more as a multi-functional "appliance-in-the-wall" rather than simply a static piece of coated glass. These façade systems include smart windows and shading systems such as motorized shades, switchable electrochromic or gasochromic window coatings, and double-envelope window-wall systems that have variable optical and thermal properties that can be changed in response to climate,

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occupant preferences and building system requirements. By actively managing lighting and cooling, "smart windows" could reduce peak electric loads by 20-30% in many commercial buildings and increase daylighting benefits throughout the US, as well as improve comfort and potentially enhance productivity in our homes and offices. These technologies can provide maximum flexibility in aggressively managing demand and energy use in buildings in the emerging deregulated utility environment and can move the building community towards a goal of producing advanced buildings with minimal impact on the nation's energy resources. Customer choice and options will be further enhanced if they have the flexibility to dynamically control envelope-driven cooling loads and lighting loads.

There are significant R&D programs world-wide that are working toward technological solutions for dynamic window-lighting systems. The International Energy Agency Task 31: "Daylighting Buildings in the 21st Century" is investigating user acceptance of automated shading and daylighting systems [3] through a series of full-scale field and laboratory studies. Fuzzy logic and neural network control algorithms have been applied and demonstrated with an automated Venetian blind using European Installation Bus (EIB) Association Standards (http://www.konnex-knx.com/) at the Swiss institute, LESO-EPFL [4]. Philips Lighting BV and the Netherlands Organization for Applied Scientific Research (TNO-TUE) are conducting a user acceptance study of electrochromic windows as part of a larger EU study on chromogenic facades [5].

There has also been increased interest in motorized shading systems due to the recent architectural trend towards all-glass facades. These highly transparent facades typically specify floor-to-ceiling clear or low-iron clear glass to achieve a dematerialization of the façade. Motorized exterior or interior shading systems are frequently used to control the direct sun and glare that occurs with these designs. In high-profile buildings such as the debis Headquarters building in Berlin, the Environmental Building in Garston, UK, and RWE AG Headquarters in Essen, Germany, motorized louvers or blinds have been installed between a double-layer glazed wall to work as part of a heat extraction system [6]. Automated shade systems have also been installed in the Gregory Bateson Building in Sacramento, California, the Pacific Bell Center in San Ramon, California, and the San Francisco Main Public Library over the past several decades.

In the US, manufacturers have implemented stand-alone building-wide control of motorized shades using a variety of control solutions including proprietary RS232 and RS485 systems, and open protocol systems such as Echelon LonWorks. Most commercial motorized shading systems are not integrated with other building systems, although Lutron Electronics Inc. and Vimco, a subsidiary of Lutron, have developed a low voltage and radio frequency whole-home control system that includes both lighting and motorized roller shades. Somfy Systems Inc. offers a number of integrated control products developed for standard bus solutions: SCHNEIDER Group BatiBUS, EIB, and Echelon LonWorks. Other manufacturers, such as MechoShade Systems, can integrate proprietary individual control solutions with larger Energy Management System (EMS) products via gateways. Shades are most commonly group controlled via a series of relays; the more devices that can be put on a relay, the lower the capital cost for such a solution. Each group can be assigned a globally unique address and be controlled via the network through a user control interface or the central, master control system.

To attain the goal of complete flexibility in layout, reconfiguration, and operations, *individual* control and networking of interoperable devices (i.e., *each* motor, ballast, sensor, or window) is preferred. Integration of shading systems with the lighting system and even the infrastructure of the EMS, which is already in many buildings for the purpose of controlling the HVAC system, is desirable to realize the full energy-savings potential identified above. Commissioning, maintenance, and diagnostics are also facilitated by networking individual devices and sensors and by placing the control and diagnostic software customarily found on dedicated circuits upstream of the device. The downside of individual device networking is cost. Interoperable building equipment systems using the networking control solutions noted above (e.g., LonWorks) results in high costs per individual control point ($15-30/ control point) which, for lighting and window systems, competes with the total cost of the device itself. If the price per point can be reduced, then the challenge of doing systemic control can be accomplished.

A low-cost building communications network is needed that would allow individual window and lighting loads to be controlled from an existing enterprise LAN network. LBNL is developing a building communications network concept, which we term IBECS™ (Integrated Building Environmental Communications System), that would enable both occupant-based and building-wide control of individual window, lighting, and sensor devices. IBECS can reduce the cost of systemic control because it

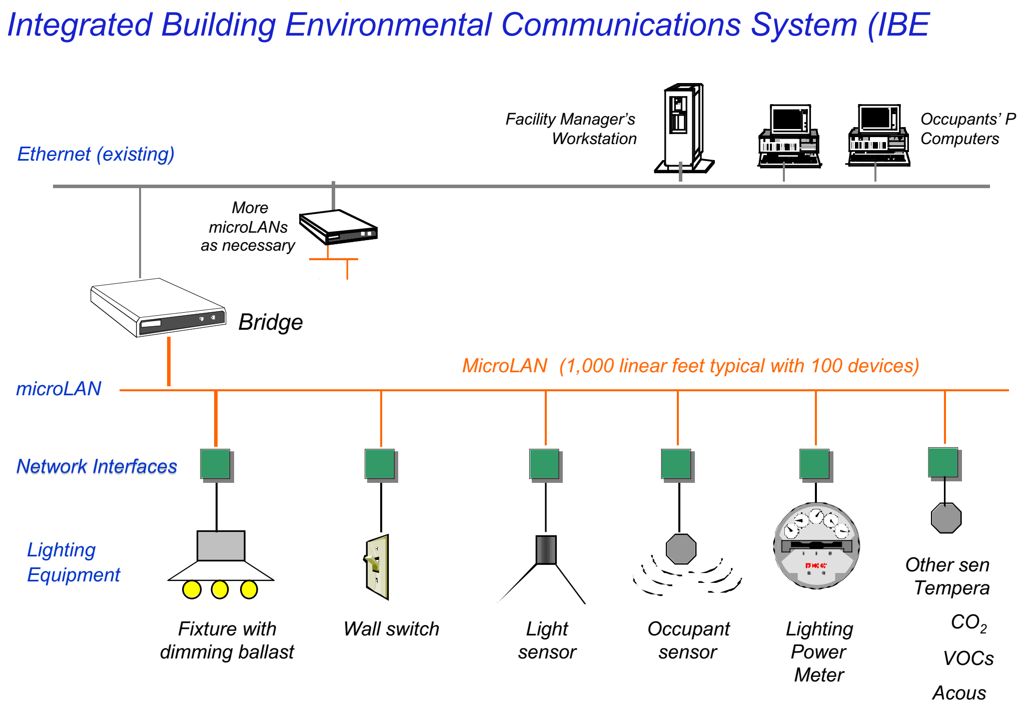

Fig. 1. Diagram of Integrated Building Environmental Communications System (IBECS).

allows a drastic cost reduction in per point networking costs and for some devices eliminates separate controllers per control zone.

This research was conducted as part of the High Performance Commercial Building Systems program under the California Energy Commission's buildings-related energy efficiency research, development and demonstration (RD&D) "programmatic" effort of the Public Interest Energy Research (PIER) Program [7]. The overall task for Element 3: Lighting, Envelope, and Daylighting of this program was to develop network interfaces that would enable one to control and monitor the condition of an overhead fluorescent light or fenestration appliance from a variety of sources, including a user's personal computer. By creating a functional specification for an IBECS network interface and testing a prototype, the ability to construct such an interface would be demonstrated and the cost-effective price per point better understood. This kind of effort is needed to encourage the control industry to make the commitment to build this technology and to demonstrate to prospective customers that this breakthrough approach to more comprehensive systemic control will provide them with high-quality, convenient control while saving them money.

In this paper, we describe our efforts to design, build and test cost-effective IBECS network interfaces to motorized shading and switchable window systems. Note that our development work focused on the direct interface to the shading or window device, or the direct **point of use** to the shade or window. This low-level interface can be married to any combination of upper-level hardware and software solutions. The basic design of the IBECS concept is explained. A detailed description of a network interface to a DC motorized shade is given. A brief description of a network interface designed for an AC motorized shade and an electrochromic window is also given. A discussion of the network interface designs outlines potential use in typical commercial office buildings and looks at the costs associated with such a system.

2. Background

Figure 1 illustrates a more comprehensive view of the entire IBECS concept as applied to the operation of electric lighting and operable window systems. In the diagram, it is assumed that IBECS will be installed in a building that already has an in-place TCP/IP network for integrating the enterprise's computer network. In this concept, the MicroLAN bridge is an intelligent device that couples the existing Ethernet

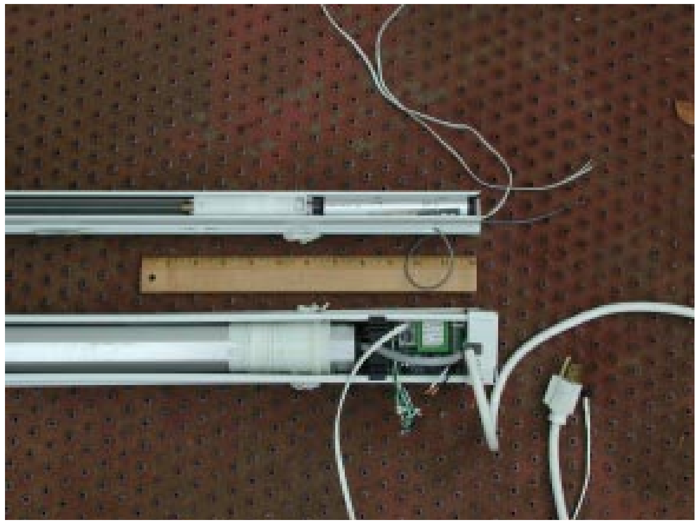

Fig. 2. Photograph of DC (top) and AC motor (bottom) in head rail of motorized Venetian blinds.

network to the new MicroLAN – a simple, low-cost field bus that networks together various devices and sensors for that building zone. The MicroLAN bridge, which can serve up to 200 network interface devices, must contain considerable computational horsepower since it needs to reliably coordinate communications between many networked devices and must also be capable of serving as a robust bridge to Ethernet. However, the network interface requires little embedded intelligence merely to operate a device and provide signal acknowledgment. This means that the network interfaces can be produced using inexpensive microchips. In IBECS, we are using the microchips from Dallas Semiconductor/ Maxim. A more detailed explanation of this concept can be found in [8].

This research also builds on prior work where a DC-motorized Venetian blind and lighting system was designed, built, and integrated with a dimmable fluorescent lighting system [9]. In this study, control was accomplished by a standard 0-10 V analog signal. The system was refined, tested, and monitored over several years in two full-scale unoccupied offices. Energy performance and user acceptance and satisfaction were evaluated for a non-retractable Venetian blind. A second series of studies was also conducted on an automated retractable and tilting AC-motorized Venetian blind but these results were not published. The existing controller relied on digital control and actuated using an analog voltage. In order to interface with the IBECS system, this controller was redesigned.

3. Motorized Shade Network Interface

There are many types of shading systems: interior or exterior shades, horizontal or vertical shades, roller shades, Venetian blinds (typically 1.27-7.62 cm, 0.5-3.0 in wide), louvers (~0.07-1 m, ~3-36 in wide), blind or louver systems with string ladders, tape ladders, or metal ladders for tilt angle adjustment and raise and lower function. While many types of shades can reduce solar heat gains and result in increased energy-efficiency compared to an unshaded window, we focused on developing a network interface to a common interior horizontal Venetian blind with string ladders and assumed that the shades could be polled and potentially activated as frequently as every 1-5 min.

A satisfactory solution for controlling this type of shade should have the following capabilities:

- tilt the slats or louvers rapidly and smoothly to a specified angle over the full tilt angle range,
- raise and lower the shade rapidly and smoothly to a specified height above the floor, and
- achieve movement with minimal noise.

Two types of motors are used predominantly in commercially-available shading systems: AC and DC tubular motors (Fig. 2). The motors are typically mounted in the head rail of the shade and sold as a unit (bottom-up retraction of Venetian blinds is also featured by some product lines, which is useful for daylighting applications). A 110 V or 277 V AC motor is typically used in applications where raising and lowering of a large heavy shade (11-140+ kg (25-300+ lb)) is required. Tilting requires much less power than raising a blind, but the latter function determines the size of the motor needed for installation in the blind header. For the application we were considering, AC motors proved to be less desireable than low-voltage DC motors because:

- moderating the power and speed of the AC motor is difficult for both tilt and lift functions and the speed control circuitry is expensive and not readily available;
- the AC motor is mechanically larger and requires a larger (5x5 cm, 2x2 in) header; and
- the lethal voltage of the AC motor increases wiring expense,
- the noise level is typically greater than DC motors.

At full power, both the AC and DC motor systems can rapidly perform tilting at a rate that can disturb occupants: e.g., full ~180˚ change in tilt within 1-2 s. This may be satisfactory for occasional daily adjustments, but this would not be acceptable for automated control where blinds may be activated several times per hour and fine adjustments to the tilt angle are required. Rapid motion also makes it difficult to accurately determine slat angle during closed loop operation. When changing the slat tilt, the speed must be adjusted for a slow rate of change to avoid visually distracting the occupant and to avoid jerky movements. For a DC motor, this can be done by halving the applied voltage and pulsing it at a low frequency with a variable duty cycle. Full speed operation, required when raising and lowering the blind, can be performed by applying the rated 24 V. Decreasing the speed of operation for an AC motor with very inexpensive controls requires pulsing the full 120 V power. This significantly increases motor noise. Gearing down an AC motor to achieve small tilt movements is also not feasible, since the gears do not have enough resolution.

A detailed study was performed on DC motors since they best met the requirements for tilting the blind. The designs for a network interface to an AC motorized shade and electrochromic window are presented following the discussion of the DC motor interface.

3.1. Network interface to a DC motorized Venetian blind

The minimum requirements for automated blind operation through the IBECS network were:

- activate the motor at full power for raising and lowering operation;
- determine when this operation is completed;
- activate the motor at a reduced power level when tilting the slats; and
- measure the slat tilt angle for closed-loop control of the tilt function.

These requirements were met by building and assembling a number of components as described below.

3.1.1. Blind Motor Control Circuitry

To assure proper operation of the blind in reaching the desired position without hesitation, hunting or overshoot, blind motor control circuitry was designed to operate in a local, closed-loop mode independent of the 1-Wire network. Doing so enabled us to precisely control the timing of how quickly and smoothly the Venetian blind slats were tilted. An algorithm could be designed around a global, central control system. This would reduce the complexity of the interface control at the blind and reduce costs. Power level and motor direction could be set centrally as well as activation. During tilting, the slat angle could be measured over the network and the motor stopped at the desired tilt.

This approach was not developed because of the inherent nature of the broad, low cost IBECS network. It is a relatively low speed communication conduit (about 9600 baud in “standard mode”) with the likelihood of having dozens of devices listening and talking on this simple “1-Wire” channel. The response time of the network may not be satisfactory for real-time control. For example, to operate a switch with IBECS one must consider the time it takes to open or release a switch. For closed-loop control functions that are critically time-sensitive (on the order of milliseconds), control must be implemented independent and downstream of the network. The IBECS network is best used to send a command for a device to change its state or transmit data back for monitoring purposes. The details of how a complex device like a Venetian blind is to change to this new state is best done at the local level.

3.1.2. IBECS Network Interface

The IBECS network interface was accomplished with two Dallas Semiconductor/ Maxim integrated circuits (IC)[1]: DS2890, a virtual potentiometer IC, and DS2450, a 4 channel voltage measuring IC (Fig. 3). The former delivers a command from the IBECS network to the blind control circuitry in the form of a control voltage. The latter’s voltage measurements monitor the blind’s:

- tilt angle through a low-g accelerometer chip mounted on one of the blind slats,
- tilt motion status by a digital high/low signal from the voltage window comparator, and

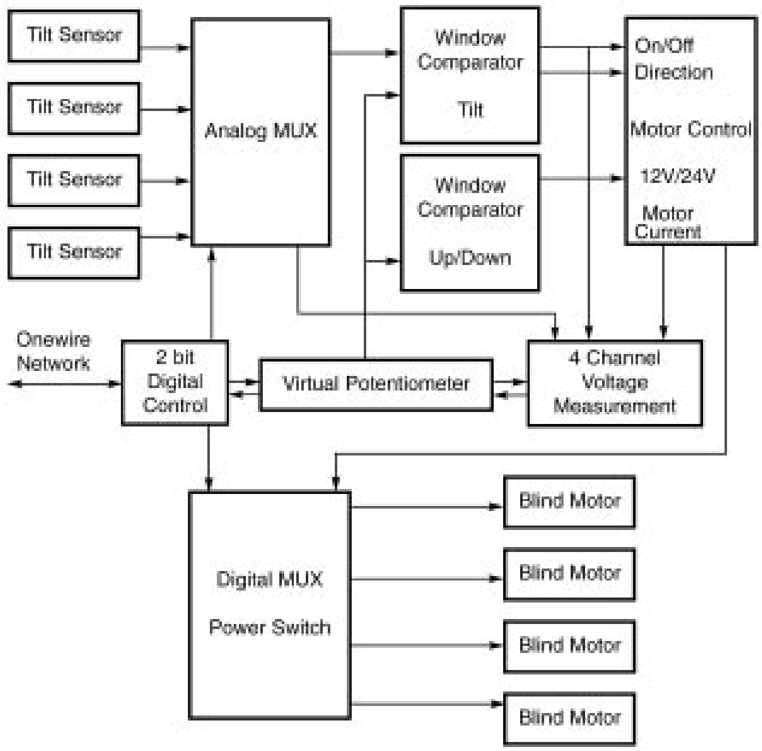

Fig. 3. Block circuit diagram of the network interface and multiplexing circuit for a DC-motorized Venetian blind.

- motor operation by measuring the current flowing through the motor.

A tilt sensor was constructed around the accelerometer IC, ADXL05, from Analog Devices Inc.[2] It was soldered onto an approximately 1.5 cm square circuit board with a few auxiliary components. This board was mounted on the blind's top slat, to minimize cable length changes when the blinds are raised and lowered. When powered by a 5 V supply, the output signal was 2.5 V when horizontal, varying by ±0.5 V when tilted ~±90˚ from the horizontal.

In applying the DS2890, we found it necessary to turn on the digital potentiometer's charge pump. The charge pump requires an external power source (typically 12 V DC) which is connected to one pin on the digital pot. Applying external power slightly increases the complexity of the network wiring since an additional conductor must be added to the network cable.

Power control of the blind motor was through a solid-state MOSFET AC relay, PVG612.[3] Using a solid state relay allowed the function of switching the blind motor on and off to be combined with pulsing the power to modulate the rate of blind motion.

The voltage control signal from the virtual potentiometer was compared to the actual tilt sensor signal by a window comparator, LTC1042. The comparator also has a deadband input adjustment to prevent excess hunting. When the tilt signal was outside the acceptable window, pulsed DC 12 V power is applied to the motor by an ubiquitous 555 IC oscillator circuit. A second window comparator is utilized to determine when the control signal is outside the tilt signal limits. When outside the limits, the control signal was interpreted as a command to raise or lower the blinds. This second comparator switched the power to 24 V DC and defeated the oscillator so that uninterrupted power was delivered to the blind motor. Note that for raise and lower functions, the particular blind motor we used incorporates automatic limit stopping to prevent motor burnout when the Venetian blind has been fully retracted or extended. The status of the raising and lowering operations is determined by monitoring the current flowing through the motor (i.e., when motion is complete).

Partial extension of the blind is more difficult to accomplish automatically and was not implemented in the scope of this project. This would involve either a timing function on the motor (commissioned for a particular window) or a sensor to determine the vertical position of the Venetian blind. DC motor speed is affected by the distance of the line to the power source transformer. Therefore, DC motors

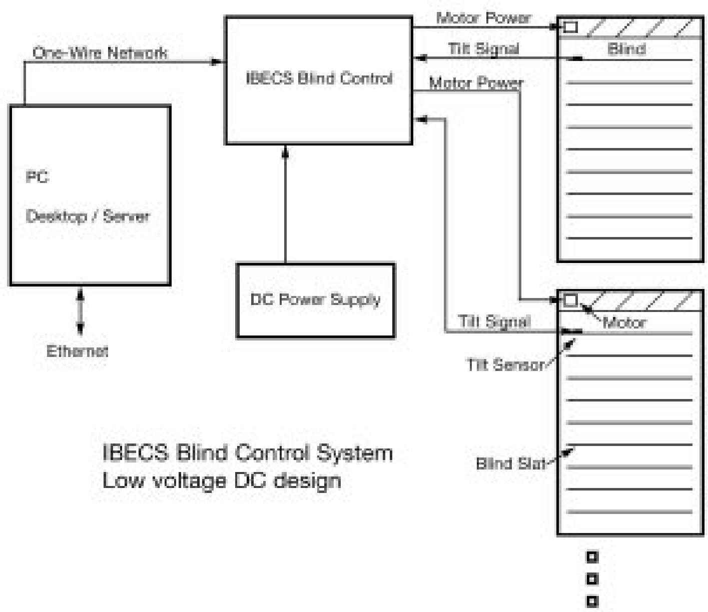

Fig. 4. Wiring diagram for multiplexed Venetian blinds (up to 8 or 16 blinds)

move at different rates. DC motors can also use "encoders" to get the correct alignment of the shades. The current implementation requires that the user manually set the vertical height of the blind; that is, lining up the bottom rail of side-by-side blinds.

3.1.3. Expansion

The blind motor control system, while able to operate independent of the IBECS network after a command is received, is relatively complex. Since a motorized blind is inherently a stable device when unpowered, multiplexing the blind motor control circuitry to operate a series of blinds through digital addressing over the 1-Wire network is an economical approach to control. One motor control circuit could be used to operate numerous blinds in a section of a building without compromising individual blind control (Fig. 4 and 5). While this required that blinds be adjusted sequentially (if the user wanted to activate a group of blinds simultaneously), this was not judged a serious limitation because:

- Simultaneous operation of a number of blinds increases the likelihood of disturbing occupants.
- Simultaneous operation requires a power supply be sized for the worse case of simultaneous operation. This could result in needing a 10 amp or more 24 V DC supply for a dozen blinds, not a trivial expense or an energy-efficient solution.
- Tilt speed can be adjusted so as to not require excessive time when a series of blinds are moved in sequence.
- While raising and lowering a blind does take a significant time, this operation is not performed often.

To demonstrate the concept of multiplexing, the circuit in Fig. 3 was designed. IBECS network interface was through a DS2407 IC, a two bit digital I/O chip that we utilized as output only. We used these 2 bits to address an analog multiplexer (MUX08) that switched which tilt sensor was read and a digital multiplexer, 74LS138 which determined which power relay was closed for motor activation.

Each IC (and therefore blind motor) has a unique networking address that is automatically commissioned via the 1-Wire network. The circuit interfaces to the network with a 1-Wire screw-on connection.

3.1.4. Blinds

To demonstrate the control system, three white, aluminum slat, Venetian blinds were mounted on west-facing windows in an open plan office in Building 90-3111 at the Lawrence Berkeley National Laboratory (Fig. 6). Each blind was 120 cm wide by 183 cm high with 2.54 cm wide slats (47x72x1 in). Motorization was done with Somfy 24 V DC tubular motors, Model LV25.[4] This compact motor fit in the 2.54 cm by 2.54 cm (1x1 in) headrail. The Somfy mechanism performs both tilt and lift functions with a single motor controlled only by its pair of power leads. These mechanisms have integral limits for raising and lowering the blinds but do not supply feedback as to the status of the motor or the tilt angle

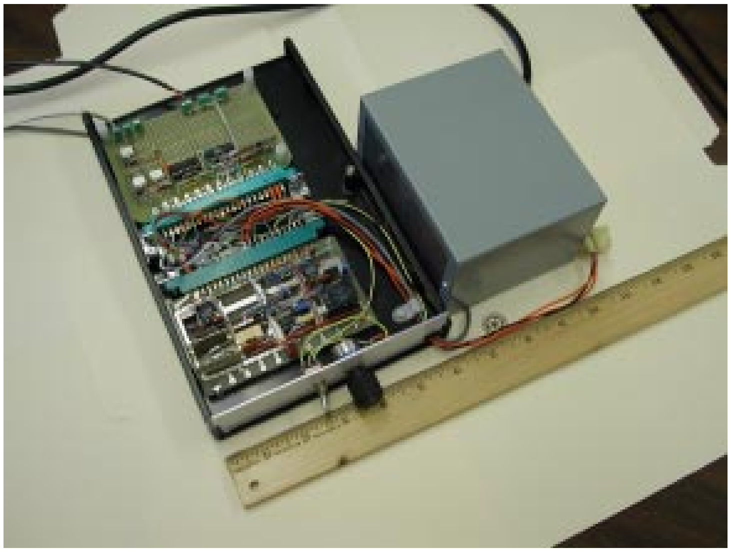

Fig. 5. Photograph of network interface and multiplexing circuit (left) and DC power supply (right).

of the slats.

In earlier work, a cheaper motor was used to demonstrate the concept of automation. Controllers were designed to step the motor to achiever quieter, smoother tilt angle motion. The Somfy motor drive is more expensive than other competing motors, but it makes less noise when actuated quickly. By slowing the rate of the Somfy motor, motor noise was increased slightly but the noise level still remained within the ambient level of a typical office environment.

3.1.5. User Interface

The three blinds were connected to a multiplexed control system with a network interface so they could be individually controlled. A low-voltage CAT-5 cable wire was used to connect all network interfaces, forming the IBECS microLAN. This microLAN was terminated with a RS232 microLAN bridge near the occupant's personal computer so that the occupant could control the Venetian blinds.

The IBECS network requires an interface or "bridge" to communicate through the common communication ports available on computers. For control through a single PC, simple bridges (also known as port adapters) are available that enable bidirectional data flow between a PC's serial port and the IBECS network. An HA-3 adapter from Point-Six, Inc. (http:///www.pointsix.com) was used to connect to a PC running Windows2000. DDE server software (also from Point Six) was developed to enable applications running under Windows to communicate with their adapter. (Note: the HA3 port adaptor has been superceded by subsequent port adaptor designs. The Maxim DS9097E port adaptor, for example, is equivalent to the earlier HA3 port adaptor.)

User control of the blinds was through a virtual instrument panel developed with National Instruments LabView 5.1 (Fig. 6), which communicated with the DDE server software. The user interface allowed for each desired motion command (tilt or raise/lower) to move one or all the blinds sequentially.

While the blind control circuitry independently operated the blinds, feedback to the user on the status of the blinds is also required. The control system was designed to return data on the slat tilt angle and whether the blinds are currently in motion. This information was transmitted over the 1-Wire network, received by the PC, and displayed on the user control panel. A quad A/D convertor chip, DS2450, also from Dallas Semiconductor/ Maxim, transmitted this data over the 1-Wire network. This integrated circuit proved to perform without deviation from its published specifications.

3.1.6. Operation

The objective of the demonstration was to check real-time operations and to identify problems that typically arise in the field (installation, wiring, electrical noise interference issues, etc.). Testing was initiated to check operations. There were several inconsistent glitches in operations that needed fine-tuning. Two out of three Venetian blinds operated improperly due to the drag placed on the string ladders by the head rail that houses the motor. We worked with Somfy to work around this design flaw.

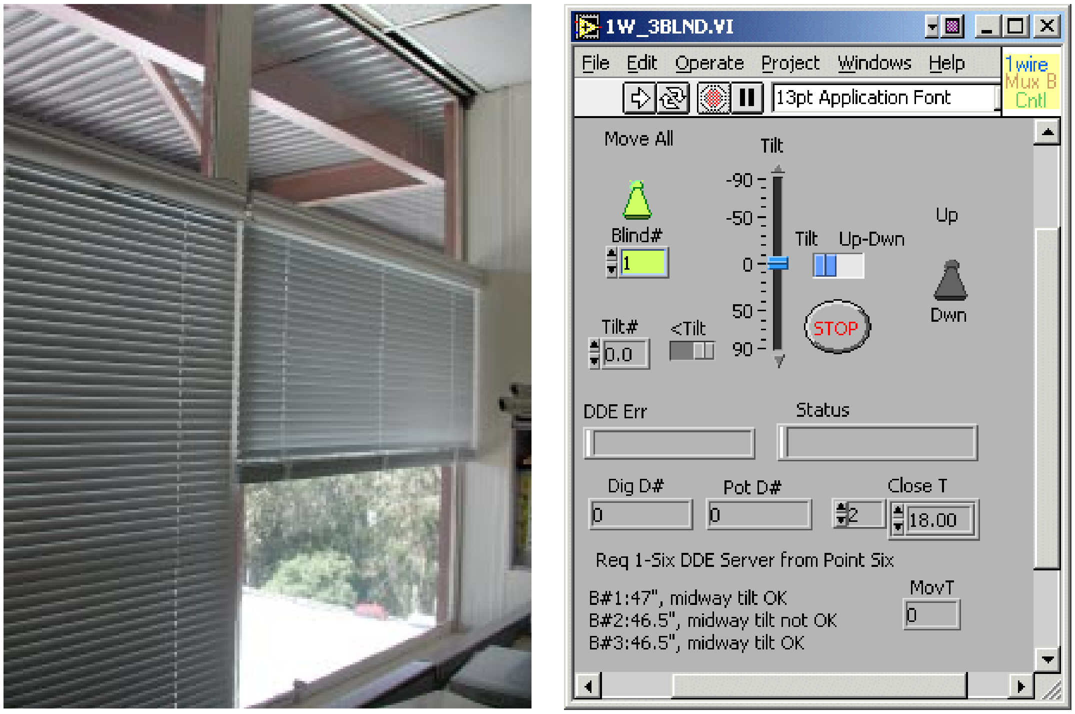

Fig. 6. Left: Photograph of the installed Venetian blind system at LBNL. The right-hand blind is shown partially retracted with the blades at 0˚ (horizontal). The center blind is fully extended but the blade angle is tilted 20˚ from horizontal. Right: Screen capture of the LabView "virtual instrument" control panel used to control the operation of the IBECS-controlled Venetian blinds.

The blinds were reinstalled and were then operated for over a year without glitches. Comments were solicited from users to improve the overall design of the interface and operations.

The IBECS network proved to reliably communicate with the blind control system. Control commands were implemented instantly. Adjustment of the pulsed power duty cycle allowed for a slow rate of tilt change that swept through the full range of tilt angle in as much as 30-45 s. This was judged to not disturb occupants in the vicinity of the blinds and proved to be quiet enough to blend in with the environmental noise level commonly found in an office setting.

3.2. Network interface to an AC motorized shade

Most AC tubular motor designs are appropriate for gross adjustments of a shade such as the raising and lowering of a roller shade to various pre-defined heights. The AC motor control with an IBECS interface would be similar to that designed and tested with a DC motor with the following modification. Speed control is not possible with the current type of AC motor so the complexity of multiple supply voltages (12V/24V) and pulsed power used in the DC system would be eliminated.

To use AC motors to lift and tilt Venetian blinds, the only economical, practical way to get a satisfactory rate of tilt change is to pulse the AC motor for a fraction of a second, long enough to result in a tilt change of 2-4°. To accomplish this, a solid state zero crossing AC power relay would be necessary. While more expensive than an electromechanical relay, it would be required for well controlled short power pulses. Closed-loop control could then read the tilt sensor and determine if additional tilting was necessary. Previous work with computer control of an AC powered blind used similar local power control circuitry. Experience with this blind system demonstrated that pulsed motion was noisy, augmented by the freeplay in the motor's geartrain. The resultant slat movement was undesirably jerky. For these reasons, this design was not built and tested.

Note that no changes would have been required in the AC motor IBECS interface from that used in the DC blind motor design. Modification is only needed in the power modulating, local control circuitry. If no detailed control of the AC motor is required (i.e., no tilting, only lift function required), there is no need for multiplexing the shades. Each AC motor could simply be equipped with a 2-bit digital control chip for the relay.

4. Electrochromic Window Network Interface

Electrochromic window control requires a dedicated low-voltage controller that can apply a low bipolar potential to its window. The controller must monitor current through the window and use this data to determine when the desired transmission value is reached. A satisfactory IBECS interface should be able to set a transmission value and monitor through the controller the status of window control. It is also desireable for the controller to estimate the current transmission value and be able to transmit this data through the network.

An EC controller and EC window was developed for the purpose of developing and testing an IBECS interface. The controller had an analog voltage input for transmission control and three binary status outputs. It could not output an estimate of the current window transmission. Status was outputted for "controller ready", "transmission request valid", and "window at desired transmission value". The input voltage control range was 0 to +1.4 V. The EC window measured 26 by 30 cm (10.25x12 in).

The IBECS interface used two Dallas integrated circuits: DS2890, a 100K ohms virtual potentiometer and DS2406, a two bit digital I/O IC. The former delivered an analog voltage of 0 to +1.4 V to the controller, the latter monitored two TTL logic level inputs and transmitted their state through the network. The controller had three binary outputs, but rather than add an additional DS2406, the output "controller ready" and "window at desired transmission value" were combined into an AND output. When the output is true, the controller is operating normally and the window is at a stable transmission value. Like the motorized blinds, the controller can be multiplexed to multiple EC windows.

Testing was performed by sending varied transmission requests to the controller through the IBECS interface while also monitoring the status and independently determining the transmission. Photometric sensors were placed in front of and behind the EC window while a daylight lamp was mounted in front of the window and illuminated it. Transmission was calculated from the ratio of illuminance values from these sensors. Independent monitoring was also performed of the EC controller operation by measuring the controller's voltage that was applied to the window.

Results demonstrated excellent operation of the controller through the IBECS network. During the hours of automated operation, no erroneous transmission values were set on the controller. Status was also monitored without error. Independent measurements of the control voltage generated by the DS2890 showed that it was correct for the command sent. Controller status read through the network always correlated properly with the measurement of control voltage from the controller.

5. Discussion

The IBECS concept is compelling because costs can be reduced if control ICs typically residing on a single device can be implemented upstream in software. This is the case for 0-10 V DC controllable electronic ballasts, where real-time operations of the device are not compromised by the speed of the network. The ballast controller, which typically group controls numerous ballasts, can be replaced by the IBECS system and software upstream at a higher level. With motorized shades and electrochromic windows, however, the complex details of actuation ("change tilt angle, check, change tilt angle, check…") are best realized at the device level, downstream of the IBECS network and next to the device so as to ensure proper real-time operations. The IBECS concept is still compelling for this class of devices. Global commands can be sent through the IBECS network to actuate individual devices ("go to tilt angle 30°") and device status can be monitored over the IBECS network. Control algorithms that integrate window and lighting systems (and their respective environmental sensors and actuators) can be implemented in software at the microLAN level.

We briefly touch on the broad topic of commissioning, maintenance and diagnostics, which is to be addressed in later work. The IBECS network system provides the flexibility to reconfigure the control layout and grouping of window systems over the life of the installation. Each IC has a globally unique address and is automatically commissioned via the 1-Wire network. However, like all networked control systems including IBECS, the physical location of each device (e.g., Building 90-3111, John Doe's office) must be input into the EMS to assign devices to user controllers and to facilitate centralized diagnostics and maintenance. Commissioning of blind motor control IC settings that relate blind motor characteristics to the tilt sensor output and the vertical height sensor output (when implemented) can be conducted via the network.

All OEM (large volume) costs were estimated, projected from our purchase price for small quantities. The OEM[5] added cost for networking is approximately \$3.75 per blind. This cost will be the same for AC motors. The OEM added cost for networking and obtaining closed-loop tilt/lift control function is approximately \$22 per blind (not including the cost of the blind or blind motor), where a significant percentage of this cost is due to the tilt sensor. For EC windows, the OEM added cost for networking is less than \$8 per window; e.g., \$1 per window with eight multiplexed EC windows. The value of the 1-Wire MicroLAN depends on its low cost compared to other control solutions. On the high end, solutions like Echelon's LonWorks provides powerful distributed control and I/O capabilities to each device at the estimated cost of \$15-30 per device. On the low end, RS485 provides extremely robust and reliable control and communications capabilities and has been the standard over the past several decades. At the device level, however, RS485 requires an IC to implement control and to transmit and receive information. For individual control of fairly simple and relatively cheap devices like an electronic ballast or sensor (temperature, occupancy, etc.), RS485 is too expensive since the device-level IC can overwhelm the cost of the device itself. For individual control of more complex and expensive devices such as window systems that require device-level microprocessor-based controls capable of communicating extensive status and diagnostic information, RS485 or products like LonWorks may be more appropriate because they deliver the computational power at the device. The incremental cost reduction provided by 1-Wire also becomes a small percentage of the total cost. The benefit of the IBECS concept is therefore dependent on the particulars of the automated window system design. For non-complex window devices, IBECS can provide a low-cost solution compared to other control solutions.

Several key design issues need to be resolved to achieve an acceptable commercial product, but are somewhat peripheral to this discussion. The tilt sensor is a prototype sensor. This sensor does not yet meet our aesthetic criteria. It is too big and is mounted directly on one vane of the Venetian blind. The sensor relies on a chip (\$5-10 OEM) that at present is purchased from a downstream vendor at a cost of \$160. We expect the cost to drop to ~\$10 since the same chip is used for air bags. Other solutions for determining the angle of tilt were not investigated in this scope of work. Sequential operations was also discussed earlier. If simultaneous control of multiple shades is desired, the cost for the DC motor power supply will increase. For AC motors, simultaneous operation is possible, subject to proper circuit design. Solutions that accurately control partial extension of DC motorized blinds (lining up of height between side-by-side blinds) also need to be investigated. Other practical matters for dynamic shading technologies and EC windows are discussed by industry, A/Es, and building owners in [10].

The solutions described above can be applied to all types of shading systems with some modifications to the interface between the motor and the shade ladders, tapes, or metal rungs. Vertically-hung shades tend to have no anchoring on its bottom edge so stepped tilt angle control will cause unacceptable jerky operation unless there is sufficient weight to quickly dampen out motion or the bottom edge is anchored. For heavier or more resistive slat support systems such as tapes or metal rungs, AC motors may be required to provide sufficient tilting and raising or lowering force (DC motors can be quite powerful but can be expensive due to the power supply).

6. Conclusion

By creating a functional specification for an IBECS network interface and testing the prototypes, the ability to construct such an interface was demonstrated and the cost-effective price per point better understood. Network interfaces were specified for the following devices:

- IBECS-enabled DC motorized Venetian blinds were demonstrated in an open plan. The system of three blinds were operated reliably for over two years. The interface enables one to control the tilt, raise and lower functions of a motorized blind via a 1-Wire® Dallas Semiconductor/ Maxim network from a virtual user LabView control panel mounted on a PC.
- An IBECS-enabled network interface to an AC-motorized shade was conceptualized. This design proved to be similar to that of the DC-motor network interface with modification needed in the power modulating, local control circuitry. This type of solution is appropriate to shades that do not require detailed control of the AC motor (e.g., no tilt, only lift function required).
- An IBECS-enabled network interface to an electrochromic (EC) window was prototyped and tested. The interface enabled one to switch the EC window to any state between clear and

colored with a simple transmission command. The network interface was of similar design to the DC motor implementation and functioned reliably under a series of bench-scale tests.

To conclude, the IBECS concept can be appropriate for the dynamic window industry and enables one to achieve a significant cost reduction in per point networking costs. The solutions described above can be applied to all types of motorized window shading systems with some modifications to the interface between the motor and the shade ladders, tapes, or metal rungs. Major shade and component manufacturers were informed of this research. Detailed specifications of the interface are included in this report so that manufacturers can pursue development of this networking concept if it meets their business plan. The LBNL demonstration has been showcased to numerous visitors over the past years. Further R&D is now in progress to demonstrate the higher-level integrated IBECS package that would include dimmable ballasts, photosensors, occupancy/ environmental sensors, automated shades, and switchable windows.

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Endnotes

[1] Technical specifications can be found at http://pdfserv.maxim-ic.com/arpdf/DS2890.pdf and http://pdfserv.maxim-ic.com/arpdf/D2450.pdf. Note the selection of this company's hardware to construct the interface does

not imply that there are not other companies that have similar products and capabilities.

[2] Recently, the ADXL05 has been replaced with the improved ADXL105 or ADXL202 IC. Technical specifications can be found at http://www.analog.com/.

[3] Technical specifications can be found at: http://ec.irf.com/v6/en/US/adirect/ir?cmd=catSearchFrame&domSendTo=byID&domProductQueryName=PVG612.

[4] For technical specifications, see: http://pro.somfy.com/pro_eng/mot/mot100.shtml#f_int.

[5] Original equipment manufacturer's (OEM) cost assumes orders by the thousands.