# A Sensor Network for Buildings Based on the DALI Bus

#### Yuan Ma and <u>Darold Wobschall</u> Esensors Inc. and University at Buffalo Buffalo, NY

www.eesensors.com

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Sensor/DALI Bus

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# Goals

- To develop and demonstrate a an extended version of the DALI bus suitable for sensor data acquisition.
- To provide a conversion of the DALI to IEEE 1451 format.

# Description of Standard DALI Bus

- DALI: Digital Addressable Lighting Interface
- Developed for building lighting control, especially ballasts
- Two-wire bus: 12/15 volts with 250 mA current limit
- Master data is standard RRZ (like UART, but bi-phase encoding, 1200 bits/sec)
- Slave (remote) device shorts bus for logic 0.
- 16-bit command with 8-bit return, with timeouts
- Operates up to 300 meters (14 to 22 gage wire)

## Standard DALI Block Diagram



#### **DALI Bus Waveform**



### **DALI Bus Characteristics**

- Data and power on two wires
- Oriented to lighting control
- Many DALI device suppliers
- Noise immune (low data rate, higher voltage/current bus)
- Data return too slow and limited for sensor data

### DALI Master (Driver) Interface Circuit



### DALI Remote (Slave) Interface Circuit



# Extended DALI Concept

- Use same voltage/current limit as standard DALI
- Be compatible with standard DALI (co-existence on same bus)
- Increase speed to 9600 Bits/sec (standard DALI ignores)
- Increase data return (7+ bytes)
- Provide TEDS (IEEE 1451.4) for ID
- Provide gateway to IEEE 1451.0 (Dot 0) protocol
- Also provide wireless option

#### A review of the IEEE 1451 Smart Transducer Concept



From Smart Sensor Systems

#### Master=NCAP, Slave=TIM

# IEEE 1451.0 (Dot 0) Format

- Required: Transducer Electronic Data Sheet (TEDS) [Memory block with defined format]
  - MetaTEDS
  - Channel TEDS
  - Calibration TEDS (unless SI units)
  - Xdr-name TEDS
  - Phy TEDS
  - Also optional TEDS
- Data Transmission [specific octet format]
  - TEDS/Status requests
  - Triggering and configuration
  - Sensor read commands and data return
  - Actuator write commands and data sending

# Dot 0 Command/Response Structure

Byte Number	Description		
1	Destination Transducer Channel Number (Most significant byte)		
2	Destination Transducer Channel Number (Least significant byte)		
3	Command Class		
4	Command Function		
5	Length (Most significant byte)		
6	Length (Least significant byte)		
7-N	Command dependent bytes		
NCAP Command Message Structure			

Byte Number	Description
1	Success/Fail Flag
2	Length (Most significant byte)
3	Length (Least significant byte)
4-N	Reply dependent bytes

TIM Reply Message Structure

#### Simplified (Dot 4) TEDS (developed for IEEE 1451.4)

- UUID (Universal Unique Identifier)
   Supplied by EEPROM (DS2433) manufacturer (6 bytes)
- Basic TEDS (8 bytes)
  - □ Model Number (15 bits)
  - □ Version Letter (5 bits, A-Z)
  - version Number (6 bits)
  - □ Manufacturer ID (14 bits)
  - □ Serial Number (6 bits)
- Manufacturer's TEDS

Sensor type and calibration parameters (16 bytes)

Conversion to Dot 0 TEDS done in NCAP

Dot 4

# Block Diagram of Extended DALI Bus



## Extended DALI Data Frame Format

Control Field	Data Field	CRC Field	ACK Filed
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Arbitration	Description +	Slave ID	Command/Data	CRC	FF hex
(1-byte)	Length (1byte)	(1 byte)	(N bytes)	(2 bytes)	(1 byte)

# Examples of Master Slave Responses

#### Master Requests Illumination and Temperature from Slave

		Data Field	
Slave	0x01(inquiry	Illumination code	Temperature code
address	Command)		

#### Slave Response (Illumination and Temperature Data to Master)

Data Field					
Slave 0x01(Answer Illumination Illumination Temperature Tempera					
address Inquiry) code Data code Dat					

#### Data Readout Examples (via Internet)

ATA From DAL	:				
Juery Lamp Status, R	esult=0H :				~
it 0 = 0 Local switch is	OFF				
iit1=0 Lamp is workir	ng;				
it 2 = 0 Lamp is OFF;					
it 3 = 0 Last requester	arc power level is between	MINMAX LEVEL;			
it 4 = 0 Fade is ready					
it 5 = 0 Lamp is ready	to be reseted;				
it b = 0 Short address	IS UK;				
It / = 0 RESET or cer	tain arc power control comma	ands have been receivi	ed aπer last power-on;		
tivo moccado from m	actor: Soncor 002 Switch ON	11 12-53-12 DM			
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## Amperometric Sensor on DALI bus



#### Prototype DALI Master and Slave Circuit Boards



## **TEDS** Compiler

- Part of Ph. D. thesis
   Wai Liu
   (Univ. at Buffalo)
- Copy of thesis is available free



# References

- Wai Liu, "Design of TEDS Writer, Reader and Testing System for Transducer Interface Modules based on the IEEE 1451 Standard", Ph. D. thesis (SUNY/Buffalo, EE Dept), May 2006.
- IEEE Std.

- D. Wobschall, "A Minimal Dot4 NCAP with a Compatible Sensor Bus", SiCon/05 (Houston).
- <u>www.eesensors.com/IEEE1451</u>

# Summary

- We have developed an extension of the DALI bus which is suitable for acquiring sensor data.
- Bus was tested with bus consisting of mix of sensors and conventional DALI lighting devices
- The IEEE 1451 protocol with the Dot 4 TEDS and Dot 0 on the network was demonstrated.

Further information: designer@eesensors.com

# **Backup Slides**

#### www.eesensors.com

## IEEE 1451 – the Universal Transducer Language

- Over 100 sensor network protocols in common use
- Narrow solutions and borrowed protocols have not worked
- IEEE 1451 is the best universal solution
- Sensor engineers in the fragmented sensor industry need a simple method of implementation
- How can it be done?



The Tower of Babel

# IEEE 145.0 (Dot 0) Advantages

- Comprehensive enough to cover nearly all sensors and actuators in use today (not 20/80% approach)
- Many operating modes
   (buffered, no-buffer, grouped sensors, timestamps, timed data, streaming ...)
- Extensive units, linearization and calibration options
- Multiple timing and data block size constraints handled.
- Compatible with most wired and wireless sensor buses and networks (point-to-point, mesh, TIM-to-TIM, mixed networks).
- Efficient binary protocol (especially suitable for wireless)

# But the Complexity!

- A comprehensive standard is necessarily complex
- There was little adoption of the original IEEE 1451.2 (TII) standard because of its perceived complexity
  - Manual preparation of the TEDS is not practical
- A TEDS compiler is needed
  - A compliance test procedure is also desirable to prove that the design is correct



Munch – The scream

### **TEDS** Format

#### • General format for each TEDS section:

Field	Description	Data Type	Number of Bytes
	TEDS Length	UInt32	4 bytes
1 to N	Data Block	Variable	Variable
	Checksum	Uint16	2 bytes

• Binary TEDS Tuple format for each data block:

Type-Length-value (TLV)

Example: 01 02 A3 04

Field type is 1, Length is 2 bytes, field value is "A304" hex

• Field example: Meta-TEDS (TEDS # 1)

13: Number of Implemented Transducer Channels (default=1)

## **TEDS Sections Implemented**

- Meta TEDS
- Meta ID TEDS
- Transducer Channel TEDS
- Transducer Channel ID TEDS
- Calibration TEDS
- Calibration ID TEDS
- XdrcName TEDS

Referenced by TEDS section/access code (e.g. #1 for Meta-TEDS)

#### Standard Transducer Units (binary format)

#### SI Based Units

Base Quantity	Name	Unit Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	S
Electric current	ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cđ

Field	Description	Data Type	Number of octets
1	Physical units interpretation	UInt8	1
2	(2 * <exponent of="" radians="">) + 128</exponent>	UInt8	1
3	(2 * <exponent of="" steradians="">) + 128</exponent>	UInt8	1
4	(2 * < exponent of meters >) + 128	UInt8	1
5	(2 * <exponent kilograms="" of="">) + 128</exponent>	UInt8	1
6	(2 * <exponent of="" seconds="">) + 128</exponent>	UInt8	1
7	(2 * <exponent amperes="" of="">) + 128</exponent>	UInt8	1
8	(2 * <exponent kelvins="" of="">) + 128</exponent>	UInt8	1
9	(2 * <exponent moles="" of="">) + 128</exponent>	UInt8	1
10	(2 * <exponent candelas="" of="">) + 128</exponent>	UInt8	1

#### Meta-TEDS Writer Screen

University at Buffalo The

META TED

META ID TEI

CHANNEL ID T

Xder NAME TE

CHANNEL/CALIBRA

4	University at Buffalo The State University of New York	×	
	Access Code 1		
	META TEDS		
The State University of Ne	Change Default Value as Desired		
IEEE 1451 TE	Enter ZIPCODE For UUID	14228	
EDS	Number of Implemented Transc	ducer Channels	
		1	
D TEDS	Operational Time-Out (Sec)	1.0	
N ID TEDS	Slow Access Time-Out (Sec)	1.0	
	Self-Test Time (Sec)	1.0	
COP	Using Control/Vector/Proxy Gro	oups NO 🔽	
	NEXT COPYRIGHT@2005WeiLiu, University a	t Buffalo All rights reserved	30

# Channel/Calibration TEDS (for linear sensors)

University at Buffalo The State University

META TEDS META ID TEDS CHANNEL/CALIBRATION TEDS CHANNEL ID TEDS CALIBRATION ID TEDS Xdcr NAME TEDS

**IEEE 1451** 

Чдэ	niversity at Buffalo The State University of New York	×	
Access	Code 3 CHANNEL TE	DS	
	Change Default Value as Desired		
	Channel	1	
	Sensor Type	Temperature Sens	
E	Units	Celsius 💌	
	Zero/Mininum Value	0.0	
	Full Scale Value	100.0	
	OError/Uncertainty	0.1	
	Chose Data Format		
	C Integer • Floating Point	C Other	
	Solf Tost/Multi Papao	No	
ח	Sampling/Buffer		
	Not Default Timing		
-	NEXT		31

Text Based TEDS (human readable)

- Meta ID TEDS
- Transducer Channel ID TEDS
- Calibration ID TEDS
- XdcrName TEDS (required)
  - ASCII or XML multiple languages available EN: English QC: computer language (additional data)

#### **TEDS** Reader



# IEEE 451 TIM Compliance Tester

• TIM (Transducer Interface Module) is most complex and done by sensor design engineers

(TIM tester can be used by the few NCAP designers)

- Tester verifies compliance of a TIM to IEEE 1451.0 (Dot 0) protocol
- Focus is on TEDS checking and data transfer format
- Physical device compliance not checked (part of other standards, e.g. RS485, Bluetooth)
- Tester uses serial bus (RS232)
- Testing may be done by Internet

# Network side (NCAP) options (wired)





TEDS Compliance Tester Retrieval Sequence

- Read TIM Version
- Read IEEE p1451.0 Version
- Query Meta ID TEDS
- Query Meta TEDS
- Get Meta TEDS Content
- Query Transducer Channel TEDS
- Get Transducer Channel TEDS Content
- Query Calibration TEDS
- Get Calibration TEDS Content
- Query Transducer Channel ID TEDS
- Query Calibration ID TEDS

#### TIM Tester (Operating Mode)

Query Channel TEDS from Channel 3: 00000c000400000054o2970000098

Bitatementing at Batflata The Man Chainerary of West Land

Get Channel TEDS Content from Channel 3: 90006c0000000000000640304000301010x01000601000 100101120a2801042901032a02000114043dcccccd1604 37d1b71717043dcccccd188441100889190437d1b7171a0 440a00001103310101e207

Query Calibration TEDS from Channel 3: 

Query Channel ID TEDS from Channel 3: 000002010400000000000000000000

Query Calibration ID TEDS from Channel 3: 00000c0104000000000000000000000

00000500000000000



#### Similar test sequence for Idle Mode

#### TIM Tester – Data retrieval



#### Serial Bus Format and Relation to other Networks

- Tester uses RS232 serial bus only but...
- Interfaces to other physical devices (USB, RS485, Bluetooth, Zigbee, ....) available.
- TEDS retrieval is one feature
- Sensor data read (protocol check) for each channel: *Idle mode* – full scale value of sensor reading (Checked against TEDS, error flag is not correct) *Operating mode* – actual sensor reading (Must be within sensor range)

#### Example – Wireless Connection

- <u>Wireless modules with RS232 I/O</u> when connected to Dot 2 TIMS are similar to IEEE 1451.5 TIMs (wireless version of IEEE 1451).
- Data format and TEDS are the same (both follow the Dot 0 standard)..



Dot 5 TIM built from a Dot 2 TIM and wireless transceiver

#### Alternative Tester for Dot 4 TEDS

IEEE 1451.4 (only) does not use the Dot 0 format TEDS. This is a small, TEDS-only version (no digital data format is specified by the standard).



Dot 4 TED	S Writer and Reader (PC Screens)				
Esensors Inc IEEE 1451.4 Minimal NCAP Module TEDS WRITER	Esensors Inc IEEE 1451.4 Minimal NCAP Module TEDS READER				
Serial Number [24 BITS]       Version Number [6 BITS]       Version Letter [5 BITS]       Model Number [15 BITS]       Manufacturer ID [ [0011001100110011001101]         Interview       Intervie	Family Code     Unique Serial Code     CRC       14     22D534010000     B6       BASIC TEDS:     SERIAL NO ~101     VERSION NUMBER ~1       VERSION LETTER ~E     MODEL NO ~6       MANUFACTURER ID ~34				
STATUS: 2:15:58 PM Reset Passed Verified Passed ProgrammedPassed TEDS OK failed	STATUS:4 2:51:12 PM RESETPassed TEDS READPassed CRC TESTPassed				
CONVERT VERIFY PROGRAM RESET BACK	READ RESET BACK				
Writer	Dot 4 Reader				
Sensor/DALI Bus					

# Harmonization of IEEE 1451 with other sensor standards



### **UUID** Format

Bit Number	Data Description
Bit 1	Bit 1=0(North)Bit 1=1(South)
Bit 2-Bit 21	Manufacturer Latitude (Binary format)
Bit 22	Bit 22=0(East)Bit 22=1(West)
Bit 23-Bit 42	Manufacturer Longitude (Binary format)
Bit 43-Bit 46	Arbitrary Field=0000 (Binary format)
Bit 47-Bit 58	Year (Binary format)
Bit 59-Bit 80	Time (Binary format)

Meta-TEDS (#1), field 4 (10 bytes)

#### Block Diagram of a Prototype Dot 2 TIM or Smart Transducer



#### Prototype Dot 2 (RS232) TIM (with 2 sensors and 1 actuator)







Photo Sensor/DALI Bus



Hall effect

#### TEDS/Test Data File Save

elect TEDS File	Ч	niversity at I	Buffalo The St	ate Unive	rsity of Ne	w York			
Look in: My Recent Documents Desktop My Documents My Computer Q	<ul> <li>NEW VOLUN</li> <li>test</li> <li>vbuzzer</li> <li>技師考試</li> <li>父亲</li> <li>冬E5%BD%B1</li> <li>Aawsepersona</li> <li>admin</li> <li>ATC</li> <li>cteds</li> <li>down</li> <li>existing_accept</li> <li>fe_civil_engine</li> <li>fe_civil_engine</li> <li>fe_reference_</li> <li>FixBlast</li> </ul>	4E (D:) %E8%A7%86%E5%B I ht_tos ering s handbook	▼ ← È	28bbs.cnxp.cc	rm%29%E4%I	on 1.0 EDs File to			
My Network Places	File name: Files of type:	cteds		▼ [ ▼ ]	Open Cancel	5 Wei Liu, Univers	ity at Buffalo All right	s reserved	48

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- Wai Liu, "Design of TEDS Writer, Reader and Testing System for Transducer Interface Modules based on the IEEE 1451 Standard", Ph. D. thesis (SUNY/Buffalo, EE Dept), May 2006.
- R. Johnson, et al "A Standard Smart Transducer Interface" http://ieee1451.nist.gov/Workshop\_04Oct01/1451\_overview.pdf
- IEEE Std. 1451.2-1907 "IEEE Standard for a Smart Transducer Interface for Sensors and Actuators – Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Format" <u>http://ihome.ust.hk/~yangrd/pdf/ieee14512.pdf</u>
- R. Frank "Understanding Smart Sensors", 2<sup>nd</sup> ed, Artech House (2000)
- D. Wobschall, "Websensor Design Smart sensors with an Internet Address" Proceeding Sensors Expo (Philadelphia, Oct. 2001)
- D. Wobschall, "A Minimal Dot4 NCAP with a Compatible Sensor Bus", SiCon/05 (Houston).
- <u>www.eesensors.com/IEEE1451</u>

#### Original IEEE 1451.2 (Dot 2) With 10-pin Transducer Independent Interface (TII)



Note: New name is TIM (Transducer Interface Module)

# IEEE 1451 Parts

- IEEE 1451.0 Protocols & formats (final ballot, 2006)
- IEEE 1451.1 Object model
- IEEE 1451.2 Serial

- IEEE 1451.3 Local network
- IEEE 1451.4 Analog & TEDS
- IEEE 1451.5 Wireless
- IEEE 1451.6 Open CAN

(approved 1999)
(approved 1997)\*
(approved 2003)
(approved 2004)
(close to final)
(early approval process)

\* Enhancement /revision working group in process

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