A Combined ISO/IEC/IEEE 21451-4 and -2 Data Acquisition Module

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***Abstract*— A prototype is described which combines the TEDS-only (-4) and point-to-point serial (-2) versions of the IEEE 1451 standard. The standard, now being renamed the *ISO/IEC/IEEE 21451-x smart transducer standards*, provides a protocol which permits auto-configuration (plug and play) and interoperability without operator intervention implemented. The Transducer Electronic Data Sheet (TEDS) is a key feature. While the TEDS-only version has achieved significant acceptance, there are drawbacks to the standard as it stands because it does not specify the digital data format and the TEDS format differs from the rest of the 1451 standard. Specifically, the ISO/IEC/ IEEE 21451-4 Mixed Mode Interface Smart Transducer Standard has a Plug and Play Sensor which includes a TEDS (Transducer Electronic Data Sheet). It is connected through the Mixed-Mode Interface (MMI) to an external data acquisition system whose specification are not specified by the standard. However, the ISO/IEC/IEEE 21450 Smart Transducer Standard does specify the digital data format in detail. Specifically described here is a prototype of the ISO/IEC/IEEE 21451-2 standard for point-to-point serial communication. It consists of a Transducer Interface Module (TIM) and a Network Capable Application Processor (NCAP). The TIM has a transducer (sensor or actuator), associated analog signal conditioner, analog-to-digital converter, TEDS, microcomputer and physical layer driver (RS232). The prototype consists of an NCAP (gateway) connected to a -2 style TIM which has with several -4 ports. The format of the -4 and -2 are differ significantly. Data from the TIM via the NCAP as seen from the Internet must have the 21450 format so that it is necessary to translate the -4 TEDS. An optional "virtual TEDS" is stored at an Internet site. The TEDS on the TIM stores only the address of the TEDS in addition to the Basic TEDS.**

***Index Terms*— Transducer Electronic Data Sheet (TEDS), Network Capable Application Processor (NCAP), IEEE 21451.**

I. Introduction

The purpose of this paper is to describe a prototype which combines the -4 (TEDS only) and -2 (Serial) versions of the IEEE 1451 standard. The aim of the original IEEE 1451 smart transducer standard is to provide a smart transducer (both sensor and actuator) protocol which permits auto-configuration (plug and play) and interoperability without operator intervention. An essential feature is the Transducer Electronic Data Sheet (TEDS) which completely specifies the transducer from the signal point of view. The original set of standards is being renamed the *ISO/IEC/IEEE 21451-x smart transducer standards* to be consistent with international standards nomenclature. The basic protocol and TEDS are now specified within the *ISO/IEC/IEEE 21450* section which was previously designated IEEE 1451.0 (Dot 0). Our focus for this paper is the are the parts (–x) of the standard designated -4 (TEDS only) together with the -2 (serial). For the purpose of this paper we will continue to use the older terminology interchangeable and also the shorthand notation of Dot 4, Dot 2 and Dot 0 to indicate the parts of the standard under discussion.

II. Summary of Standards

A. 21451-4 (Dot 4) TEDS-only Standard

The Dot 4 has achieved significant acceptance in some parts of the sensor industry (e.g. accelerometer manufacturers) and this is likely to expand in the future. However, there are drawbacks to the standard as it stands: (a) it is a TEDS-only standard (the a/d aspects and digital data are unspecified) and (b) the TEDS format differs from the rest of the 1451 standard (see ISO/IEC/IEEE 21450).

The ISO/IEC/ IEEE 21451-4 (Dot 4) Mixed Mode Interface Smart Transducer Standard has the block diagram shown in Fig. 1. The Dot 4 Transducer or Plug and Play Sensor includes a TEDS (Transducer Electronic Data Sheet) and is connected through the Mixed-Mode Interface (MMI) to an external data acquisition system [8]. Normally the system has an analog-to-digital converter, a digital interface capable of reading the 1-wire TEDS format, a microcomputer for signal processing (if needed) and a driver which interfaces with the rest of the system. The Dot 4 standard specifies the TEDS and MMI but not the data acquisition system which is left up to the manufacturer. In particular, the digital data format and means of communicating the data to the network or rest of the system is unspecified. Various vendors sell 2sensors with the Dot 4 TEDS/MMI compatibility [2].

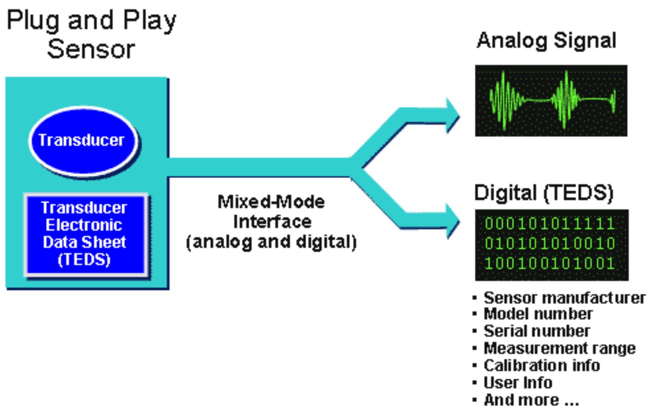


Fig.1. IEEE 1451.4 (ISO/IEC/IEEE 21451-x) Standard Block Diagram

B. 21451-2 (Dot 2) Serial Standard

The base ISO/IEC/IEEE 21450 (Dot 0) Smart Transducer Standard, in combination with a specific data bus or network physical layer, provides a complete smart sensor standard which includes the data acquisition section [6] and network interface. Specifically illustrated here is the *ISO/IEC/IEEE* 21451-2 (Dot 2) standard for point-to-point serial communication. As shown in Fig. 2, the system consists of a Transducer Interface Module (TIM) and a Network Capable Application Processor (NCAP). The TIM has a transducer (sensor or actuator), associated analog signal conditioner, analog-to-digital converter, TEDS, microcomputer and physical layer driver (e.g. RS232). This serial bus is connected to the NCAP which has a microcomputer which provides further data processing and handling the Internet network protocol, typically via Ethernet. The Dot 2 standard incorporates the Dot 0 TEDS format which is quite different from the Dot 4 TEDS.

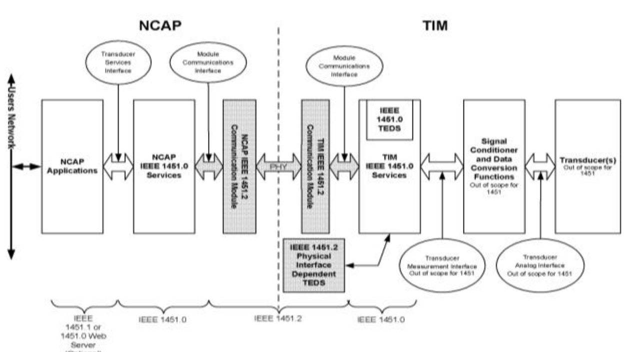


Fig.2. Block Diagram for an IEEE 1451.2 (ISO/IEC/IEEE 21451-2) Smart Transducer

III. Combination of Dot 4 and Dot 2

Upgrading Dot 4 transducers so that they are network capable is a clearly desirable goal, and the Dot 0 standard provides a path, but there are several problems in combining these two standards. The first is that the TEDS formats are quite different. Another is that the standards do not specify how a Dot 4 transducer is to be incorporated into a signal conditioner so that any implementation requires arbitrary choices. Recognizing these limitations, a prototype of a Dot 4 sensor with network capability has been developed and tested. In this paper a prototype of a Transducer Interface Module (TIM) which combines the -4 and -2 standards is given. It is basically a small data acquisition module which accommodates the -4 (Dot 4) sensor and has a serial (RS232 or USB) interface compliant with a -2 (Dot 2) format NCAP [3].

A block diagram of the prototype networked Dot 4 smart transducer is shown in Fig. 3. It consists of a modified Dot 2 TIM with an NCAP. The TIM consists of a standard, commercially available Dot 4 plug and play sensor with the addition of an analog signal conditioner and a microcomputer, including a serial bus. A digital interface which can read the Dot 4 TEDS via the MII is also present.

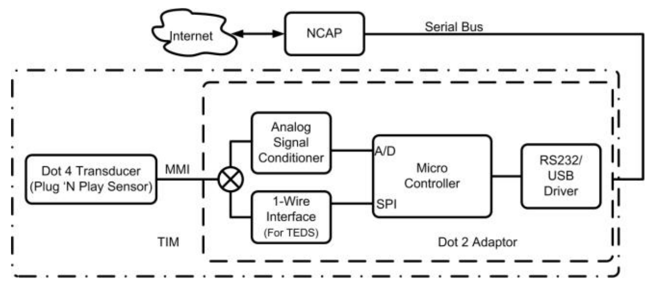


Fig.3. Block Diagram of Networked Dot 4 Transducer

The main difference between a conventional Dot 2 TIM and the Dot 2/4 combination TIM is (a) the transducer unit is separable and (b) the Dot 4 TEDS needs to be translated into the Dot 0 format. The translation utilizes a virtual TEDS, a feature which both Dot 0 and Dot 4 support as an option. This allows the Dot0/2 format TEDS to be located remotely on an Internet site ("cloud") which is accessed by an address pointer (URL) on the TIM or NCAP. With our version the TIM also has an internal default Dot 2 TEDS and a copy of the Dot 4 TEDS but this default Dot 2 TEDS is incomplete because the TIM or NCAP does not have a provision for reading and interpreting the Dot 4 TEDS and therefore does not know the type of sensor and cannot convert the a/d reading to engineering units. The sensor reading rather is in units of fraction of full scale of the a/d converter.

The virtual TEDS, which has the Dot 0 format, is intended to be stored at a website designated by the manufacturer. The Dot 4 basic TEDS which consists of a 64-bit binary number [2], expressed as a ASCI hexadecimal, which allows lookup of the specific Dot 2 TEDS at the remote site. In the future perhaps the NCAP could translate the Dot 4 template information into the Dot 0 TEDS format.

IV. Prototype Description

A. Block Diagram

The prototype (Fig. 4) consists of an NCAP (gateway) connected to a Dot 2 style TIM which has with several IEEE 1451.4 (Dot 4) ports. The circuits are open source and are available for download [6].

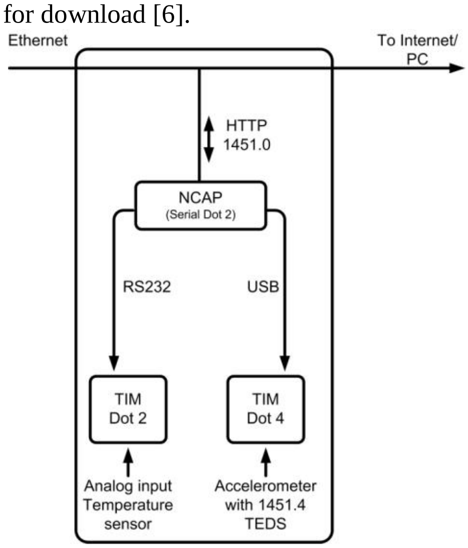


Fig.4. IEEE 1451.4 (ISO/IEC/IEEE 21451-4) Prototype Block Diagram

B. NCAP Hardware

The compatible NCAP has the block diagram shown in Fig. 5. It is described in another document [6].

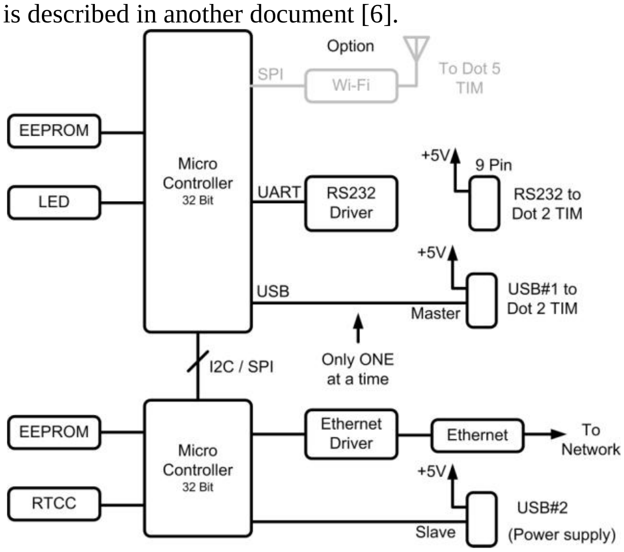


Fig.5. NCAP Block Diagram

C. Prototype TIM

The TIM board fabricated has a WiFi section in addition to the Dot 4 and Dot 2 sections but this will not be discussed here. The TIM has added features so that it appears compatible with the Dot 0 standard from the Internet (network) viewpoint and with the Dot 4 from the sensor viewpoint. Since the Dot 4 standard is TEDS-only the specification of the a/d needed in addition to generate the digital data for the Internet is added arbitrarily. We use the Dot 0 standard for this function. In effect, this is partly a Dot 0 TIM with the a/d, and partly a sensor with Dot 4 TEDS (Fig. 6).

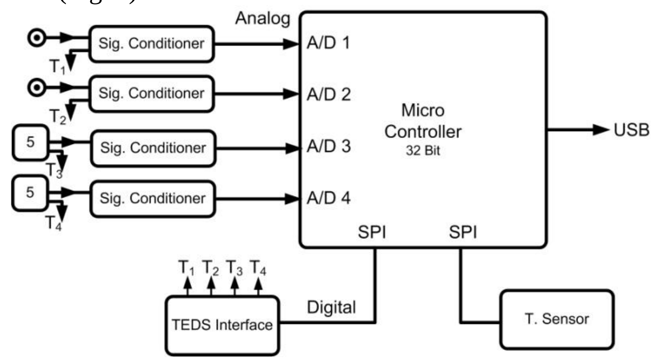


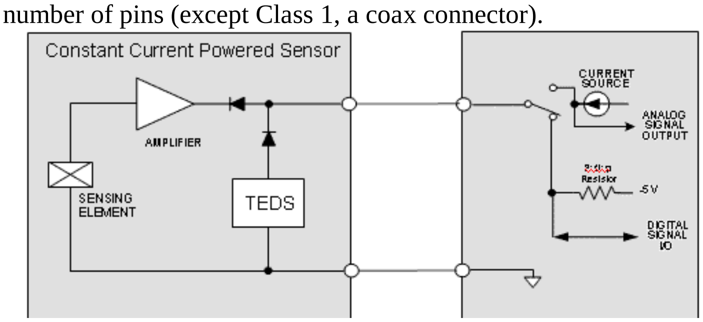
Fig.6. Block Diagram of Dot 4 TIM

A Dot 4 type sensor is an analog output sensor with a small EEPROM on a 1-wire bus as the TEDS. There are two types of interfaces, one with separate lines for the TEDS and data and another which has the analog and digital on the same wire (2 wires including ground). For the combined analog/digital interface, the analog signal is modulated on a current source for positive voltages (IEPE [7]) and the digital (TEDS) is connected for negative voltages. The TIM prototype has these ports:

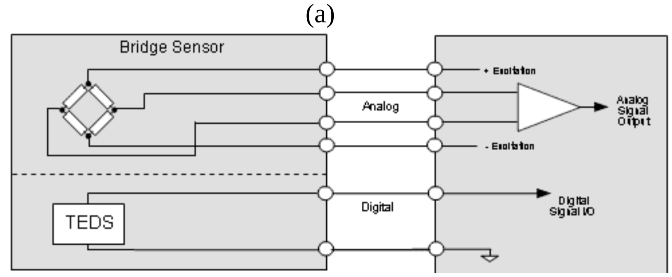
- Class 1 with IEPE (two of these)
  Connector is HD-BNC
- Class 2 with 4-20 mA signal input
  Connector (J5) is 5-pin header
- Class 2 with 0 to 5v signal input
  Connector (J6) is 5-pin header

D. Circuit Details for Dot 4 TIM

The Dot 4 standard [3] defines two classes of interfaces (Fig. 7). For the Class 1 sensors, a coax connector is used. For the Class 2 sensors two signal inputs have been provided (4-20 ma and 0-5 v). Each has 3 analog lines (in addition to the 2 TEDS lines). Note that for Class 1 the analog and digital/TEDS are on the same line but for Class 2 they are separate. The Dot 4 standard does not specify the connector or number of pins (except Class 1, a coax connector).



(a)



(b)

Fig.7. IEEE 1451.4 Interfaces (a) Class 1 and (b) Class 2

A block diagram of the Dot 4 TIM is shown in Fig. 8.

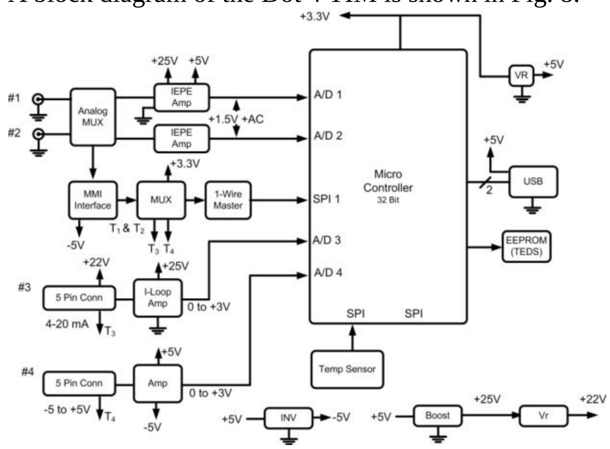


Fig.8. Detailed Block Diagram of Dot 4/2 TIM

1) Class 1 Interface Analog Section

The class 1 interface combines an analog line and a 1-wire digital line with a TEDS (Fig. 9). The analog part utilizes an Integrated Electronic Piezo Electric Interface (IEPE) developed originally by accelerometer (and other) manufacturers [4]). It is also known under other brand-names (e.g. ICP).''

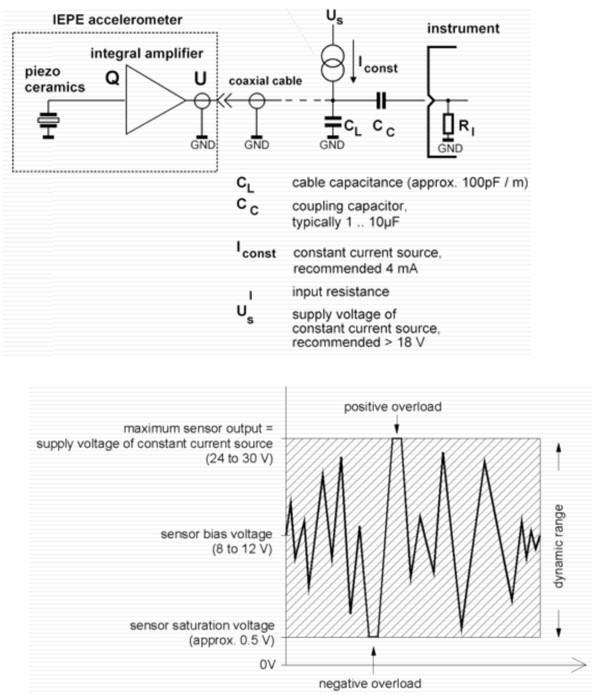


Fig.9. IEPE Interface

A constant current source is supplied by the signal conditioner (TIM) with an output voltage modulated by the sensor amplifier. The voltage on the wire is between +0.5 and +22 volts. Note that the analog signal, including the bias, is always positive, which is switched by the diode. The constant current supply is set at 4.0 mA and the effective load resistor for no signal is about 2kohms. The desired signal is the AC component riding on the bias voltage (6v). The AC signal is coupled through a capacitor to the following amplifier (response 0.3 to 1kHz, min). A detailed circuit is given in Fig. 10.

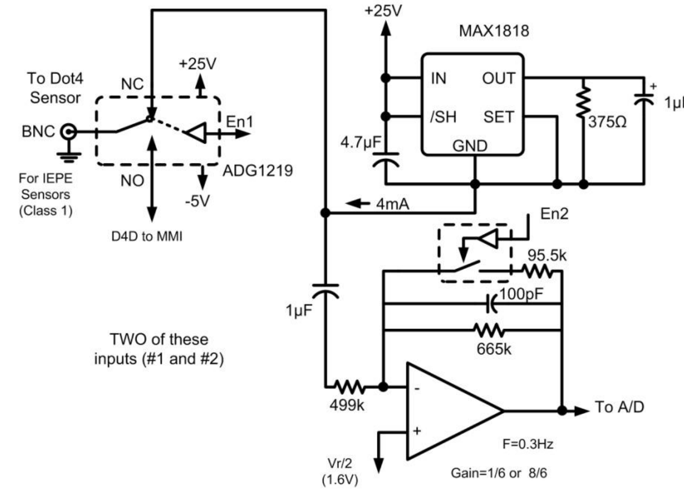


Fig.10. Circuit Diagram of IEPE Interface

If no sensor is present, the voltage at the connector will go to saturation (about +22 v). This condition is detected by a comparator. When the sensor comes back on line, the TEDS is read again. If the ID is different, a change in sensor is recorded.

2) Class 1 Digital (TEDS interface) Section

For the Class 1 interface, the TEDS is accessed when the voltage on the wire is negative. Diodes on the sensor side separate the digital (negative) from the analog (positive) signals. The reason for using a 1-wire cable (coax) is that it is much easier to install, especially for small sensors (such as accelerometers), than multi-wire cables. The TEDS is a special EEPROM with a 1-wire interface. Data is transmitted in both directions, depending on timing. The data pin on the EEPROM shifts between input and output (also provides chip power). The EEPROM is standard CMOS but is connected backward at the sensor end (+Vcc to ground). Timing is critical and is best implemented with a special interface "1-wire master". Converting the bi-directional signal from negative to positive requires a special MMI (mixed mode interface) driver (see [7]) which uses a mosfet pair (and analog switch). This is shown in Fig. 11.

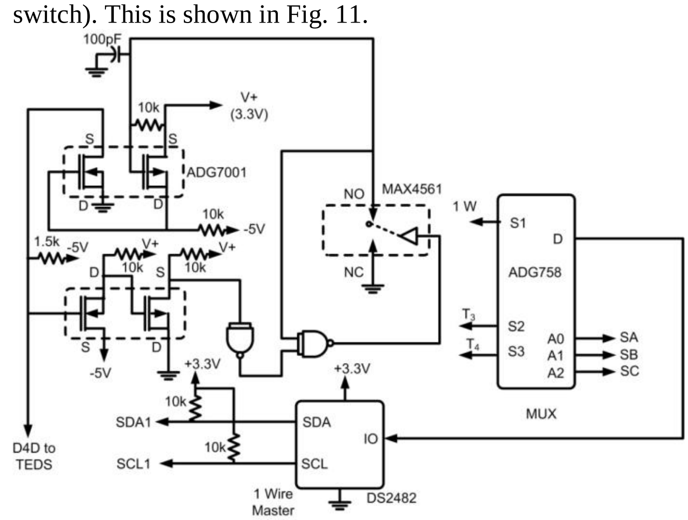


Fig.11. Circuit Diagram of Dot 4 Class 1 Interface

In effect, the MMI driver converts the backward connected EEPROM in the Dot 4 sensor to one forward connected so that it can be accessed by the 1-wire master chip. The master connects to a microcomputer via a SPI line. The combination of the two analog switches on inputs #1 and #2 plus the digital mux (#3 and #4) selects one of the four TEDS.

3) Class 2 Interface

The class 2 interface simply provides a separate pin for the 1-wire EEPROM (TEDS). It is connected directly to the 1-wire master (no additional interface needed). We have selected two representative inputs (another possibility is a strain sensor). A HD-BNC is the chosen coax connector.

Many industrial sensors have a 4-20 mA current loop (transmitter) as the output. There are two general types: (1) loop powered and (2) sensor excitation voltage external to the sensor. Input # 3 is of this type. The +24 volt supply on pin 5 is used for loop powered devices (pins 3 & 4 connected, pins 1 and 2 connected), see Fig. 12.

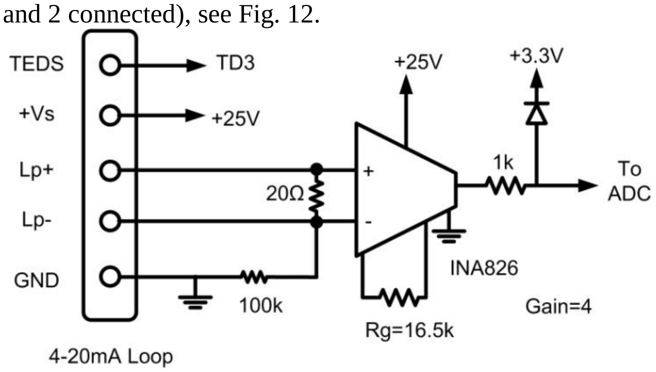


Fig.12. Circuit Diagram of 4-20 mA Current Loop Interface

Many sensors (with built-in signal conditioners) have a voltage as the output. Input #4 is of this type (Fig. 13).

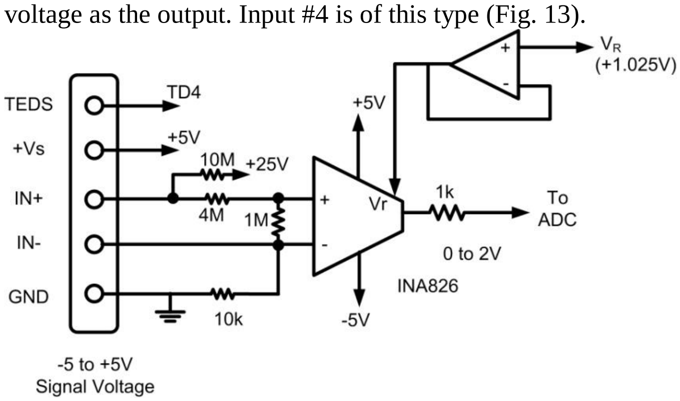


Fig.13. Circuit Diagram of 0-5v Input Interface

V. COMBINING DOT 0 AND DOT 4 TEDS

A. TEDS-only Need for TEDS translation

The format of the Dot 4 and Dot 0 (Dot 2) are quite different as a result of different paths of standards development. Since the data from the TIM via the NCAP as seen from the network (Internet) side must have the Dot 0 format, it is necessary to translate the Dot 4 TEDS to the Dot 0 TEDS format.

B. Dot 4 TEDS

The reading of the Dot 4 TEDS on the Plug and Play Sensor (Fig. 1) is done on power-up and occasionally thereafter, particularly if a sensor is removed and replaced (see Fig. 11 for circuit). The Dot 4 TEDS data is transferred to a cache TEDS (C-TEDS) on the TIM where it is more readily available. Each TEDS has a unique ID (48-bit UUID plus a chip family 8-bit ID) which allows the detection of change of sensor. This is in addition to the Basic TEDS (64-bits) and a sensor specific template.

C. Dot 2 TEDS

The Dot 0/2 Transducer Electronic Data Sheet (TEDS) is stored in the TIM. Here it is as a read-only file (mostly binary). The following TEDS are present:

- META-TEDS
- Transducer Channel TEDS (several)
- User's Transducer Name TEDS (ASCII)
- PHY TEDS
- Dot 4 TEDS (new)

The first four TEDS sections specify the characteristics of the Dot 2 adaptor part (Fig. 3) which contains the a/d. This can be considered a default TEDS since it describes the data acquisition part of the TIM and not the sensor. The Dot 4 TEDS is just copied from the Plug and Play sensor, as described above, into a cache memory on the TIM. It is not interpreted by the TIM so that no information on the sensor is known to the TIM and therefore the Dot 0 TEDS is not altered to provide this information. In the future the NCAP might do this but it was not implemented on the present prototype.

D. Virtual TEDS

The term "virtual TEDS" refers to the storage of the TEDS at a site external to the TIM, currently cloud data storage on the Internet. The TEDS on the TIM need store only information on the address or URL of the TEDS in addition to the Basic TEDS. The Dot 4 Basic TEDS has the required transducer identification and therefore the URL is needed. We suggest that the first 128 bits (16 bytes) of the Manufacturers TEDS be used for this purpose (the memory space for the Dot 4 TEDS is very limited and there is no immediate prospect for changing this). The URL extension should be the Basic TEDS (16 bytes in hex/ASCII format).

VI. TEST RESULTS

The wireless (Dot 3) TIM and wired (Dot 2/4) TIM were tested separately using the NCAP. The ability to digitally read the binary TEDS and display in human readable form on a dashboard was demonstrated. Also the reverse process, generating the binary TEDS from the readable format, was implemented. For testing of the Dot 4 TEDS a commercial accelerometer (PCB Piezotronics TLD356A17) was purchased and the ability to read the TEDS verified. For the WIFI wireless the ability to transmit the built-in accelerometer and TEDS data from the battery operated TIM to the NCAP was verified. For the RS232 the ability to transmit a 0 to 5v simulated signal from the TIM to the NCAP with readout on the dashboard was demonstrated.

VII. Conclusions and Recommendations

Our prototype NCAP and TIM have demonstrated that a combination of the -4 and -2 parts of the ISO/IEC/IEEE 21451 set of standards is possible but that additional protocols are needed which are not part of either standard. It is recommended that that a working group be formed to establish the standard for combining the TEDS and the overall protocol for the merged standards.

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