Embedded Dry Block Calibrator for Intermediate Temperature

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Abstract **Calibration is an important procedure that must always be considered to assure measurement system's accuracy measurement errors namely offset and linearization errors can be compensated as long as timely calibration routines are performed in the measurement system. The intent of this project is to test and calibrate temperature gauge and temperature transmitters. The calibrator is designed with a microcontroller (89C51ED2) provided with flash memory of 64KB. The microcontroller applies a correction factor to the converted data, thus increasing the overall accuracy. The controller is also interfaced with a keypad and a display. The converted digital data can be displayed in 15 different units of temperature. The switching the three physical quantities is done using MUX (DG408). Since the controller has a flash memory coding can be downloaded and future advancements can be made. The developed calibrator can calibrate temperature sensors in the intermediate temperature range of 50 to 800 degree centigrade at high accuracy of (±) 1°C of full-scale reading. Thus, an embedded based portable calibrator system is developed in our project.**

Keywords —Calibrator, Intermediate temperature range, embedded calibrator system.

I. Introduction

In industrial power plants, a number of temperature sensors and transmitters are fitted in the pipelines at various points in order to measure the temperature at those points. These transmitters and sensors have to be calibrated every 3 months, 6 months a year according to the need in order to maintain the measurement's accuracy and produce correct output. This is done with the help of temperature calibrator which is master, having it accuracy higher than that of the instrument to be calibrated.

II. CALIBRATION

The formal definition of calibration by the International Bureau of Weights and Measures (BIPM) is the following: "Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties (of the calibrated instrument or secondary standard) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. Calibration is the comparison between measurements – one of known quantity or correctness made with one device and another measurement made in a similar way as possible with a second device. The first device is known as the standard with high precision and the second device is known as the test instrument or unit under test.

The increasing need for known accuracy and uncertainty and the need to have consistent and comparable standards internationally has led to the establishment of national laboratories. In many countries a National Metrology Institute (NMI) will exist which will maintain primary standards of measurement (the main SI units plus a number of derived units) which will be used to provide traceability to customer's instruments by calibration.

The NMI supports the metrological infrastructure in that country (and often others) by establishing an unbroken chain, from the top level of standards to an instrument used for measurement. Examples of National Metrology Institutes are NPL in the UK, NIST in the United States, PTB in Germany and many others. Since the Mutual Recognition Agreement was signed it is now straightforward to take traceability from any participating NMI and it is no longer necessary for a company to obtain traceability for measurements from the NMI of the country in which it is situated, such as the National Physical Laboratory in the UK.

A. NEED FOR CALIBRATION

Calibration may be required for the following reasons, a new instrument After an instrument has been repaired or modified When a specified time period has elapsed When a specified usage (operating hours) has elapsed Before and/or after a critical measurement After an event, for example

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After an instrument has been exposed to a shock, vibration, or physical damage, which might potentially have compromised the integrity of its calibration Sudden changes in weather Whenever observations appear questionable or instrument indications do not match the output of surrogate instruments As specified by a requirement, e.g. customer specification, instrument manufacturer recommendation. Calibration is necessary for measuring devices as it enables precise measurement of values and allows greater accuracy. It removes and rectifies errors and corrects the problem of sloppy performance. Calibration defines the accuracy and quality of measurements recorded using a piece of equipment. Over time there is a tendency for results and accuracy to 'drift' particularly when using particular technologies or measuring particular parameters such as temperature and humidity. To be confident in the results being measured there is an ongoing need to maintain the calibration of equipment throughout its lifetime for reliable, accurate and repeatable measurements. The goal of calibration is to minimize any measurement uncertainty by ensuring the accuracy of test equipment. Calibration quantifies and controls errors or uncertainties within measurement processes to an acceptable level.

B. TEMPERATURE CALIBRATION

Temperature calibration can be accomplished in a variety of ways and with various degrees of accuracy. As with any calibration, a standard must be used. The standards used in temperature calibration can come in different forms but must be certified with an accuracy that is traceable to a national standard. In industrial applications temperature calibration usually involves thermistors, thermocouples or Platinum resistance thermometers (PRTs), also called resistance temperature devices (RTDs). These are devices used to accurately measure temperature. Readings from these devices can be compared with less accurate field temperature sensors and used to evaluate the viability of those devices or to perform a temperature calibration. For a manufacturing facility, it is important to maintain quality assurance and cGMP. One of the main areas to be considered is calibration of temperature equipment. Temperature instrument calibration, which is a process of comparing measurements from a test temperature device against a standard must be carried out regularly. The standard is a device that has a known frequency, which is traceable to national or international standards. If there is any deviation from the standard, it is recorded. And, that drift must be corrected. Temperature instrument calibration, which is a process of comparing measurements from a test temperature device against a standard must be carried out regularly. The standard is a device that has a known frequency, which is traceable to national or international standards. If there is any deviation from the standard, it is recorded. And, that drift must be corrected.

Temperature calibration can be done using the following ways:

Intrinsic Standards: This process will be heavy on your pockets and is generally limited to calibration labs. It is also adapted in plants which house a department specializing in high-end metrology. However, these intrinsic standards are the most accurate forms of temperature calibrators. They include triple point of water or melting point of metals such as zinc, indium, and aluminum. All these methods occur naturally. You will require multiple standards to cover the entire range of the typical temperature calibrations.

Liquid Bath Calibrators: These calibrators comprise of a liquid (generally oil), a stirring mechanism and a heating/cooling element. You can expect uniform specifications throughout, as the liquid is constantly stirred and circulated through the bath. Liquid bath calibrators are the best to calibrate odd-shaped or extremely small sensors due to the uniform circulation of the liquid.

Dry block calibrators: As the name suggests, dry block calibrators consist of a heating block, an internal sensor and control mechanism to reach and maintain the desired temperature range. They have a heating and cooling element as well, but no liquid is used in this process. This makes them portable and easy to maintain. One of the major advantages of these calibrators is that they can reach the desired temperature much faster as compared to traditional baths; however, they are less accurate and stable than them. Thanks to technological developments, the performance of dry block calibrators is improving in terms of accuracy and stability.

Electronic calibrators: These calibrators can simulate the Sensors under Test (SUT) and provide the readout results on the sensor's performance. Their main drawback is that the integrity of the sensor cannot be tested as there is no temperature source to which the sensor can be subjected. However, they are more affordable as compared to traditional liquid baths or dry-block calibrators, and are also quite portable.

Thus, calibrating temperature sensors is of great importance. And in industries such as pharmaceutical, food and beverage, it holds much more significance. So, you must understand how to calibrate an instrument and which calibration methods suit your instruments and processes the best.

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III. WORKINGTHEORY

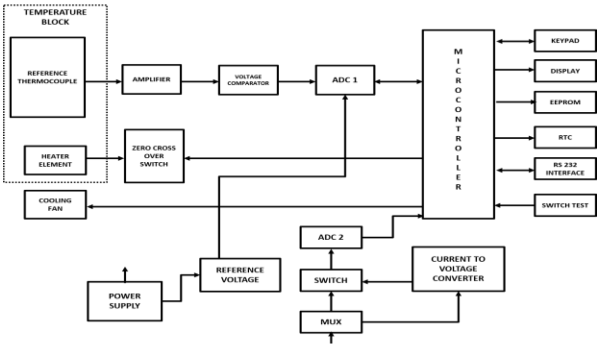

FIG 1: BLOCK DIAGRAM

Thermowell is used to produce the reference heat supplied. The RTD is used as a sensor to convert temperature to resistance. The constant current generator is used to produce an output in terms of mA. The signal conditioning circuit converts the analog to digital signal and then amplifies it to the micro controller. A 230v supply is given to the whole circuit. Each module in the calibrator requires appropriate power supply in order to achieve optimum results. The power supply circuit is divided into four segments. The first segment generates +15v. The second generates -5v. The third generates +12v for the micro controller. The POR/PFD function monitors the internal power-supply of the CPU core memories and the peripherals, and if needed, suspends their activity when the internal power supply falls below a safety threshold. This is achieved by applying an internal reset to them. By generating the Reset the Power Monitor insures a correct start up when AT89C51ED2is powered up. In order to startup and maintain the microcontroller in correct operating mode, VCC has to be stabilized in the VCC operating range and the oscillator has to be stabilized with a nominal amplitude compatible with logic level VIH/VIL. Idle mode is a power reduction mode that reduces the power consumption. In this mode, program execution halts. Idle mode freezes the clock to the CPU at known states while the peripherals continue to be clocked. The CPU status before entering idle mode is preserved, i.e. the program counter and program status word register retain their data for the duration of idle mode. The contents of the SFRs and RAM are also retained. Generation of reference voltage The reference voltage is created using the IC LT1014. This circuit is known as the Amplification circuit. The AD581 is used as the trim part of the circuit.

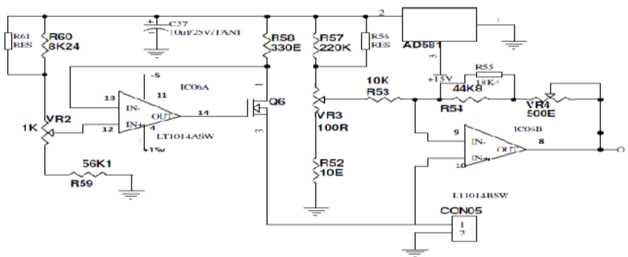

Fig 2: Amplifier Circuit

The LT1014, LT1014A, and LT1014D are quad precision operational amplifiers with 14-pinindustry-standard configuration. They feature low offset-voltage temperature coefficient, high gain, low supply current, and low noise. The LT1014, LT1014A, and LT1014D can be operated with both dual ±15V AND -5V. The common-mode input voltage range includes ground, and the output voltage can also swing to within a few millivolts of ground. The AD5811 is a 3-pin, temperature compensated, monolithic, band gap voltage reference that provides a precise 10.00 V output from an unregulated input level ranging from 12 V to 30 V. Laser wafer trimming (LWT) is used to trim both the initial error at +25°C as well as the temperature coefficient, resulting in high precision performance previously available only in expensive hybrids or oven regulated modules. The 5mV initial error tolerance and 5 ppm/°C guaranteed temperature coefficient of the AD581L is available in a monolithic voltage reference. The band gap circuit design used in the AD581 offers several advantages over classical Zener breakdown diode techniques. Most important, no external components are required to achieve full accuracy and significant stability to low power systems. In addition, total supply current to the device, including the output buffer amplifier (which can supply up to 10 mA) is typically 750 µA. The long-term stability of the band gap design is equivalent to selected Zener reference diodes. The AD581 is recommended for use as a reference for 8-, 10- or 12-bit digital-to-analog converters (DACs) that require an external precision reference. The device is also ideal for all types of analog-to-digital converters (ADCs) up to 14-bit accuracy, either successive approximation or integrating designs, and can generally offer better performance than that provided by standard self-contained references. The AD7703 is a 20-bit ADC which uses a sigma delta conversion technique. The analog input is continuously sampled by an analog modulator whose mean output duty cycle is proportional to the input signal.

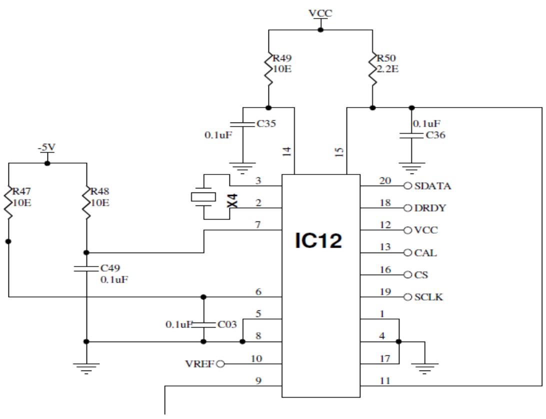

Fig 3: ADC Circuit

The inherent linearity of the ADC is excellent, and end point accuracy is ensured by self-calibration of zero and full scale which may be initiated at any time. The output data is accessed through a serial port, which has two synchronous modes suitable for interfacing to shift registers or the serial

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ports of industry standard microcontrollers. CMOS construction ensures low power dissipation, and a power down mode reduces the idle power consumption to only 10 MW. In operation, the sampled analog signal is fed to the Subtract, along with the output of the 1-bit DAC. The filtered difference signal is fed to the comparator, whose output samples the difference signal at a frequency many times that of the analog signal frequency. Oversampling is fundamental to the operation of sigma-delta.

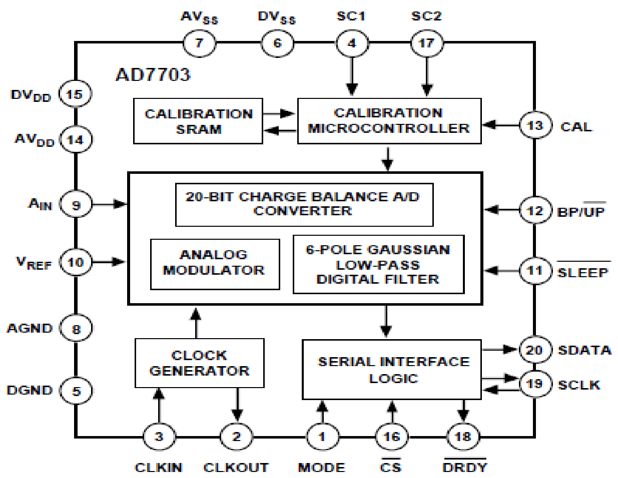

Fig 4: Functional Diagram of ADC

The AD7703 is a 20-bit A/D converter with on-chip digital filtering, intended for the measurement of wide dynamic range, low frequency signals such as those representing chemical, physical or biological processes. It contains a charge-balancing (sigma-delta) ADC, calibration microcontroller with on-chip static RAM, a clock oscillator and a serial communications port. The analog input signal to the AD7703 is continuously sampled at a data rate determined by the frequency of the master clock, CLKIN. A charge-balancing A/D converter (sigma-delta modulator) converts the sampled analog signal to digital signal. Band gap references are the high-performance solution for low supply voltage and low power voltage reference applications. In this technique a voltage with a positive temperature coefficient is combined with the negative coefficient of a transistor's Vbe to produce a constant band gap voltage. In the AD780, the band gap cell contains two NPN transistors (Q6 and Q7) which differ in emitter area by 12_. The difference in their Vbe produces a PTAT current in R5. This in-turn produces a PTAT voltage across R4, which when combined with the Vbe of Q7, produces a voltage Vbg that does not vary with temperature.

IV. HARDWARE

A. OPERATIONAL AMPLIFIER

An Operational amplifier (op amp) is a DC-coupled high gain electronic voltage amplifier with a differential input and usually a single ended output. In this configuration an op-amp produces an output potential (relative to circuit ground) that is typically hundreds of thousands of times larger than the potential difference between its input terminals.

B. A/D CONVERTOR

The AD7703 is a 20-bit A/D converter with on-chip digital filtering, intended for the measurement of wide dynamic range, low frequency signals such as those representing chemical, physical or biological processes. It contains a charge-balancing (sigma-delta) ADC, calibration microcontroller with on-chip static RAM, a clock oscillator and a serial communications port. The analog input signal to the AD7703 is continuously sampled at a data rate determined by the frequency of the master clock, CLKIN. A charge-balancing A/D converter (sigma-delta modulator) converts the sampled analog signal to digital signal.

C. MICROCONTROLLER

AT89C51RD2/ED2 is high performance CMOS Flash version of the 80C51 CMOS single chip 8-bit microcontroller. It contains a 64-Kbyte Flash memory block for code and for data. The 64-Kbytes Flash memory can be programmed either in parallel mode or in serial mode With the ISP capability or with software. The programming voltage is internally generated from the standard VCC pin. The AT89C51RD2/ED2 retains all of the features of the Atmel 80C52 with 256 bytes of internal RAM, a 9-source 4-level interrupt controller and three timer/counters. The AT89C51ED2 provides 2048 bytes of EEPROM for nonvolatile data storage. It is a 64-pin microcontroller with 5 ports.

V. SOFTWARE

An embedded system can in general be defined as software driven, microprocessor embedded hardware, designed to perform a dedicated application under real time constraints. **KEIL C** is one such software development tool which s used for coding purpose. The program coded is embedded in the chip using **SUPER PRO** embedded software. The entire process can be understood from the flow chart given in the upcoming slide. **CODING** KEIL C software is a software development tool for 8051, 251, USB 166 microcontroller families. Tools include C compilers, assemblers, real time executives, debuggers and simulation integrated environment and evaluation boards. There are a number of device options that must be specified in the Device Options Box in the Device Database dialog box. The device options are used by the assembler, compiler, and linker when you create a project using that device. Using this software, a 'C' files is created and compiled.

A. EMBEDDING (SUPERPRO)

Embedding or encoding of the software on to the chip can be done using a suitable tool like SUPERPRO. This is a universal chip programmer which supports over 3000

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devices, including EPROM, EEPROM, and FLASH memories, Programmable logic and Microcontrollers The SUPERPRO is a family of affordable, reliable, and fast universal device programmers. They are designed to communicate with the parallel port or USB and to operate with the Intel 80386-, 80486-, and Pentium based IBM compatible desktop computers and notebook computers. The menu-driven software interface makes them easy to operate. Any kind of modifications to the coding can be done by any number of embedding and de-embedding. The 'C' file that was created by KEIL C is converted to a 'HEX' file by this software.

B. ALGORITHM

Step 1: Assign appropriate ports of micro-controller to CSO, CSI, CS2, CAL, LBAT, and switch and also the pressure scan time and ma, voltage scan time and their respective over range values are defined.

Step 2: In the next step the function blocks to, initialize ports to check over pressure, to check milliamp range, voltage range and the battery are declared and defined. And also, the test switch and its menu are declared and defined.

Step3: When the device is switched on, the function block for initializing ports is called. Then the micro-controller reads the unit and pressure from their respective addresses. After execution of each function block, the status of the battery is checked by calling its function block.

Step 4: Then either pressure or current or voltage can be measured by calling their function blocks within their respective scan time. The mean pack can also be measured.

Step 5: After the measurement of pressure, the analog result is then sent to ADC for conversion. "ADC_INTO" is used to call ADC module and its initialization.

Step 6: The graphic display is also initialized and kept ready by calling "INITGLEDO" function.

Step 7: In ADC, the ready pin is active low. Hence, when data is ready to be received for conversion, "READY" is made low.

Step 8: CS of ADC is made low since micro controller should not access ADC during conversion process.

Step 9: The input of the ADC is got as serial bits and these bits entre a loop of 20 iteration which does the conversion.

Step 10: CS of ADC is made high after the digital output is achieved after conversion so that the micro controller can access it.

Table 1 Before application of correction factor

MASTER READING	TEST READING	ERROR(T-M)
100.00	100.62	0.62
200.00	200.8	0.80
300.00	300.5	0.50
400.00	400.7	0.70
500.00	500.82	0.82
650.00	650.58	0.58

The correction factor is calculated in order to increase the accuracy of the test instrument. It is calculated by dividing the master reading with the test instrument reading. Then this factor is multiplied with the test instrument reading to obtain a more accurate result.

Correction Factor = master reading / test reading

Final Reading= correction factor **x** test instrument reading

Table 2 After application of correction factor

MASTER READING	TEST READING	ERROR(T-M)
100	100.05	0.05
200	200.04	0.04
300	300.03	0.03
400	400.03	0.03
500	500.04	0.04
650	650.05	0.05

VI. SALIENT FEATURES

- Range: 25°C above Ambient to 800°C
- Accuracy: ±0.1°C
- Immersion Depth : 150mm
- Heavy Duty Portable / Bench-top Model
- Rugged Field Use & for Calibration at Site
- Auto-tune PID Control
- Switch Test Capability
- Fast and Reliable
- Interchangeable Thermowell Inserts, Single / Multi hole
- USB Computer Interface
- It is portable and hence can be used to calibrate temperature measuring devices in defense systems.
- High accuracy ensures it is useful in petrochemical industries
- Due to its high rigidity it is used in automobile industries
- Due to in system programming it does not require more human labor
- Low cost of the calibrators enables it to be used in college premises

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VII. RESULTS AND CONCLUSION

The temperature calibrator designed is used as a high accuracy master standard to calibrate resistance thermometer and transmitter. This calibrator has an accuracy of 0.02% and therefore can be used to calibrate wide range of temperatures. The calibration process is carried out for the resistance thermometer and thermocouple. The error is calculated comparing with the master and the reading are noted down. The readings are shown in the next slide Measurement errors namely offset and linearization errors were compensated as long as timely calibration routines are performed in the measurement system. This project tests and calibrates temperature gauge and temperature transmitters. It is easily portable and provided with an internal thermowell for temperature generation. This device can calibrate temperature sensor from 60 to 350 degree centigrade at high accuracy of +0.025% of full-scale reading. A pt100 sensor converts the physical quantity into an electrical signal. The analog data is converted to digital form using a 20-bit Analog to Digital Converter. This calibrator is designed with a Microcontroller (89C61RD2) provided with flash memory of 64KB so that the coding can be downloaded and any future advancements be made for this calibrator. The micro controller applies a correction factor to the converted data, thus increasing the overall accuracy. This controller is also interfaced with a keypad and a display. The converted digital data can be displayed in 15 different units of temperature. The switching between the three physical quantities is done using MUX (DG408).

TABLE 2 RESULT ANALYSIS

S No	Read Value (Degree Celcius)	Actual Value (Degree Celcius)	Deviation	Remarks
1	100	100.02	0.02	PASS
2	200	200.03	0.03	ACCEPTED
3	300	300.01	0.01	ACCEPTED
4	400	400.12	0.12	REJECTED
5	500	500.02	0.02	ACCEPTED
6	650	650.01	0.01	ACCEPTED
7	670	670.03	0.03	ACCEPTED
8	700	700.07	0.07	ACCEPTED
9	730	730.03	0.03	ACCEPTED
10	750	750.05	0.05	ACCEPTED

From the above table, it can be inferred that the unit under test passed the calibration test 9 out of 10 times. Hence it is concluded that it has an accuracy of 90%. The accuracy of the unit can be improved by taking a more number of calibrating measurements. The future scope for temperature calibrator is based on the micro controller used and the analog to digital converter used. The heating rods used could be of higher resistance to corrosion. Higher range of temperature calibration could be made possible by using different components. Safety measures for the apparatus could be developed by placing sticker near bath and power supply area. Development in the software side can be done by using other software tool to program the micro controller to reduce to random access memory

REFERENCES

[1] Orzylowski M., Sankowski D, "Automated Calibration of Temperature Sensors" The 16th IEEE Instrumentation and Measurement Technology Conference, IMTC'99, pp. 16-21, 24-26 May, 1999, Venice, Italy.

[2] NajidahHambali ShahrizalSaat, MohdAshraf Ahmad, MohdSyakirin Ramli, "Computer-based System for Calibration of Temperature Transmitter using RTD", 2010 3rd International Conference on Information Management, Innovation Management and Industrial Engineering

[3] NajidahHambali, ShahrizalSaat, MohdSyakirinRamli, MustaqimHazmi, "Automatic Detection Computer-based (ADCob)System for Temperature Measurement Calibrationof RTD", International Conference on Electrical, Control and Computer Engineering, Pahang, Malaysia, June 21-22, 2011

[4] Yi Xianjun, Liu Cuimei, "Development of High-precision Temperature Measurement System Based on ARM", The Ninth International Conference on Electronic Measurement & Instruments.

[5] Michiel A. P. Pertijs, André L. Aita, Kofi A. A. Makinwa, and Johan H. Huijsing, "Low-Cost Calibration Techniques forSmart Temperature Sensors", IEEE SENSORS JOURNAL, VOL. 10, NO. 6, JUNE 2010.

[6] R. A. Koestoer[a)], Y. A. Saleh, I. Roihan, and Harinaldi "A simple method for calibration of temperature sensor DS18B20 waterproof in oil bath based on Arduino data acquisition system" , AIP Conference Proceedings 2062, 020006 (2019).

[7] Chua-Chin Wang, Zong-You Hou, and Jhih-Cheng You, "A High-Precision CMOS Temperature Sensor with Thermistor Linear Calibration in the (−5 °C, 120 °C) Temperature Range" Sensors 2018, 18(7), 2165.

[8] http://www.alldatasheet.com

[9] http://www.fluke.com

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