California Energy Commission
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HPCBS # E3P2.1T3c
& E3P2.1T4c

HPCBS

High Performance Commercial Building Systems

Development of the IBECS Environmental Sensor and the Circuit Demand Monitor

Element 3 - Lighting, Envelope and Daylighting
Project 2.1 - Lighting Controls
Task 2.1.3 – Advanced Sensor
Task 2.1.4 – Lighting Panel Meter

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Development of the IBECS Environmental Sensor and the Circuit Demand Monitor

(In Fulfillment of CEC/PIER Deliverables E3P2.1T3c and E3P2.1T4c)

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This report deliverable summarizes progress on the development and prototype fabrication of two key components of the IBECS (Integrated Building Environmental Communications System) system. The first section of the report discusses the development of the *environmental sensor* (referred to as the "advanced occupant sensor" in the Scope of Work). The second section discusses the development of the IBECS circuit demand monitor (referred to as the "lighting panel meter" in the Scope of Work).

Environmental Sensor

The objective of this subtask is to create an IBECS-ready sensor from an existing occupant sensor.

Initially we planned to modify an existing commercially available occupant sensor to add IBECS capability. This would allow the occupant sensor to provide information to the IBECS network on occupancy or vacancy depending on the state as detected by the PIR (passive infrared) detector. While such a device would be useful in its own right, there are other environmental parameters (especially ambient light level and temperature) that are more critically tied to occupant comfort and performance than mere occupancy. With the increased attention to the use of daylighting for moderating electric lighting demand in buildings, we decided to add light level sensing capability to our advanced sensor. Moreover, many recent studies have indicated the importance of workspace temperature as a key determinant of occupant comfort. Therefore we elected to expand the capability of the sensor so that it would be capable of light level detection, temperature AND occupancy and transmitting this information digitally to the IBECS network. With this expansion of the initial design concept, we designed and constructed two types of multi-purpose environmental sensors that will be capable of measuring three key environmental variables (occupancy, light level and temperature) and transmitting this information onto the microLAN.

The workstation multisensor was designed to measure environmental parameters near the occupant's workstation. It has a short cable that plugs into a "port adaptor" that fits to the serial communications port on the PC. The ceiling-mounted multisensor is intended to measure the occupancy in larger spaces (500 -1000 square feet).

Figure 1. Prototype workstation multisensor designed to measure desktop illuminance, temperature and occupancy. This workspace multisensor measures the three key environmental variables and outputs this digital data onto the IBECS network. The Multisensor is designed to be mounted near the primary work area and plugs into a port adaptor that is attached to the serial port on the user's PC.

Figure 2. Prototype ceiling-mounted multisensor designed to measure desktop illuminance, temperature and occupancy. This multisensor is designed to be either ceiling- or wall-mounted. It measures the three key environmental variables and outputs this digital data onto the IBECS network. The Multisensor has a long cord so that it can be ceiling-mounted and plugged into a port adaptor that is attached to the serial port on the host PC.

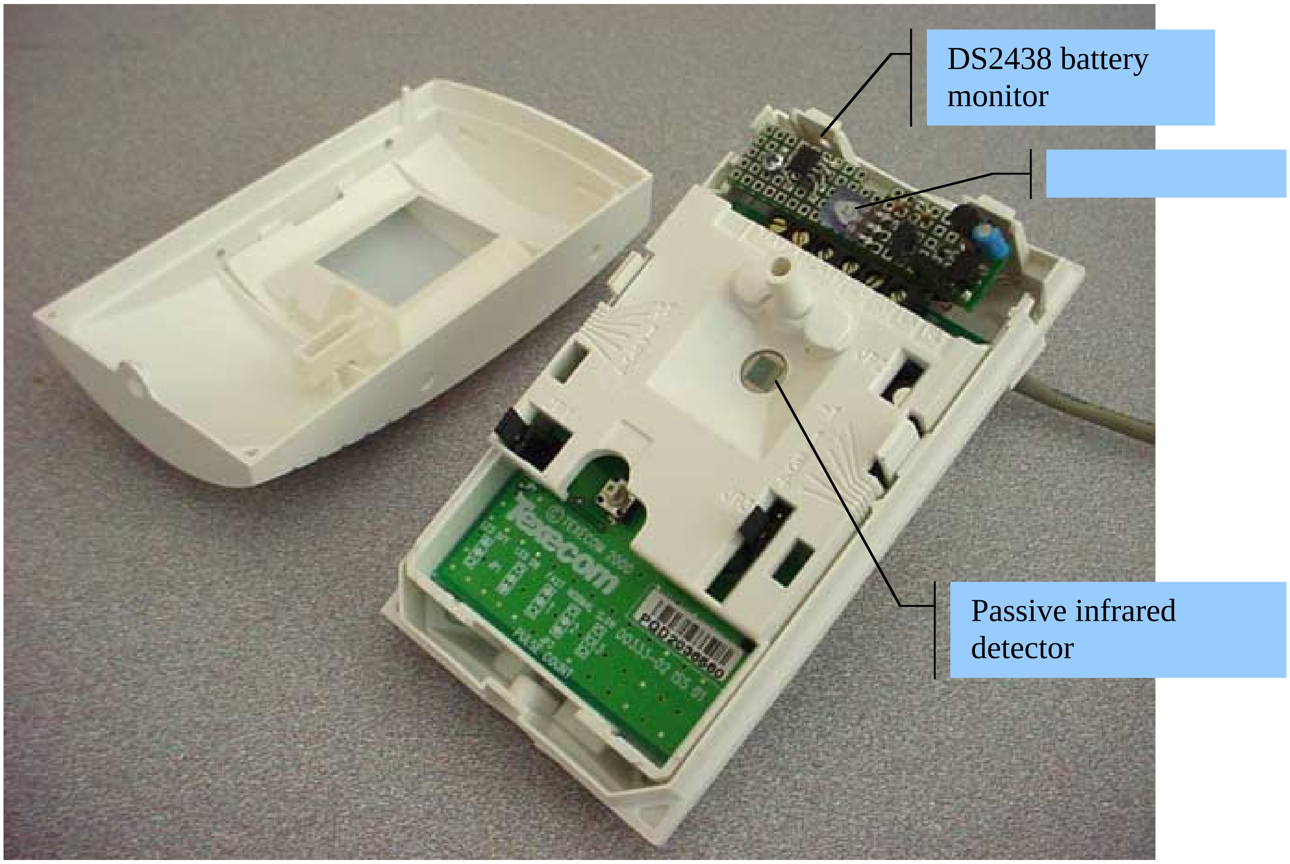

Figure 3. Prototype ceiling-mounted multisensor with the front panel removed to show the added circuit board (upper right). The callouts show the location of the key electronic components.

Both types of IBECS Multisensor were designed as inexpensive accessories for PC workstations and are capable of simultaneously measuring three key environmental variables: 1) illuminance, 2) occupancy and 3) temperature and outputting this data onto IBECS. The Multisensor measures light level as well as ambient temperature and includes a local (short range) PIR occupancy senor. In the current embodiment, the Multisensor is plugged into a "port adaptor" (AAG Type DS9097U-S09-X Port Adaptor, http://www.aag.com.mx/Adp9097.html) that fits to the serial port on the user's PC. The port adaptor takes the digital IBECS signal from the three sensors and converts it to an RS-232 signal that is accepted by the PC. Note that the port adaptor receives power (+5 VDC) from the power supply internal to the PC. For general usage where the workstation's serial port may not be available, other types of port adaptors could alternately be used to interface with the workstation via either its USB or parallel (printer) port. The TMEX software, available free from http://www.ibutton.com, allows one to read the environmental parameters on a virtual "control panel" on the computer's desktop (see Figure 4)

The small size of the workstation multisensor makes it relatively inconspicuous. With an appropriate adhesive, it could even be affixed to the frame of the CRT monitor at the workstation. Its translucent lens serves for both the occupancy detector and for sensing diffuse illumination.

Workstation Multisensor Specifications (preliminary, subject to change)

Sensor Size: 2” long x 1.5” wide x 1.25” high (less adaptor and cable)

Cost to Manufacture Sensor: Under $18

Adaptor Cost: $14.95 (single unit purchase from AAG)

Measures: Illuminance, temperature and detected motion (occupancy)

Illuminance: The Illuminance sensor section utilizes an amplified silicon diode with an integral blue filter for spectral correction.

Temperature: The ambient temperature measurement range is –40ºC to +85ºC., with an accuracy of ±2 ºC. and a resolution of 0.03ºC.

Motion: Detected motion is measured with a short-range passive infrared detector. Range is about 6 feet.

The illuminance sensor section utilizes an amplified silicon diode with an integral blue filter for spectral correction. Its measurement is linearly encoded as V_{sens} over the range of 0 to 250 millivolts to a resolution of 0.4 millivolts. V_{sens} is shown plotted in Figure 7. The measured illuminance is equivalent to (TBD, roughly 5) Lux per millivolt over the range (-300 mV to +300 mV) with an angular orientation of the sensor to the light source (TBD, roughly cosine distribution). Low-pass filtering in the sensor limits the speed of response of the light level measurements to approximately 1 second.

The ambient temperature measurement range is –40ºC to +85ºC., with an accuracy of ±2 ºC. and a resolution of 0.03ºC. A look-up table in the TMEX viewer software can be used for conversions to Fahrenheit temperature.

Detected motion is reflected in the value of VAD measurement. Each instant of movement detected by the PIR sensor will cause the indicated VAD value to rapidly increase to approximately 4.5 volts. In the absence of any further detected movement, this indication will then begin to exponentially fall toward a baseline level of approximately 1.5 volts (which is the lowest VAD measurement level specified for the chip). The time constant of this decay is approximately 2 minutes. This slow decay will permit a program running on the building’s IBECS server to easy perform an estimate of the time that has elapsed since the most recent detection of movement by each sensor in the building.

This unit is designed for easy plug connection to the ubiquitous computer workstations that are distributed about the office areas of most contemporary enterprises. These workstations typically reside as nodes interconnected through a server on a private LAN, or communicate with each other via the Internet. The Multisensor is an inexpensive accessory, which can bootstrap the functionality of distributed building automation sensing to the existing enterprise infrastructure.

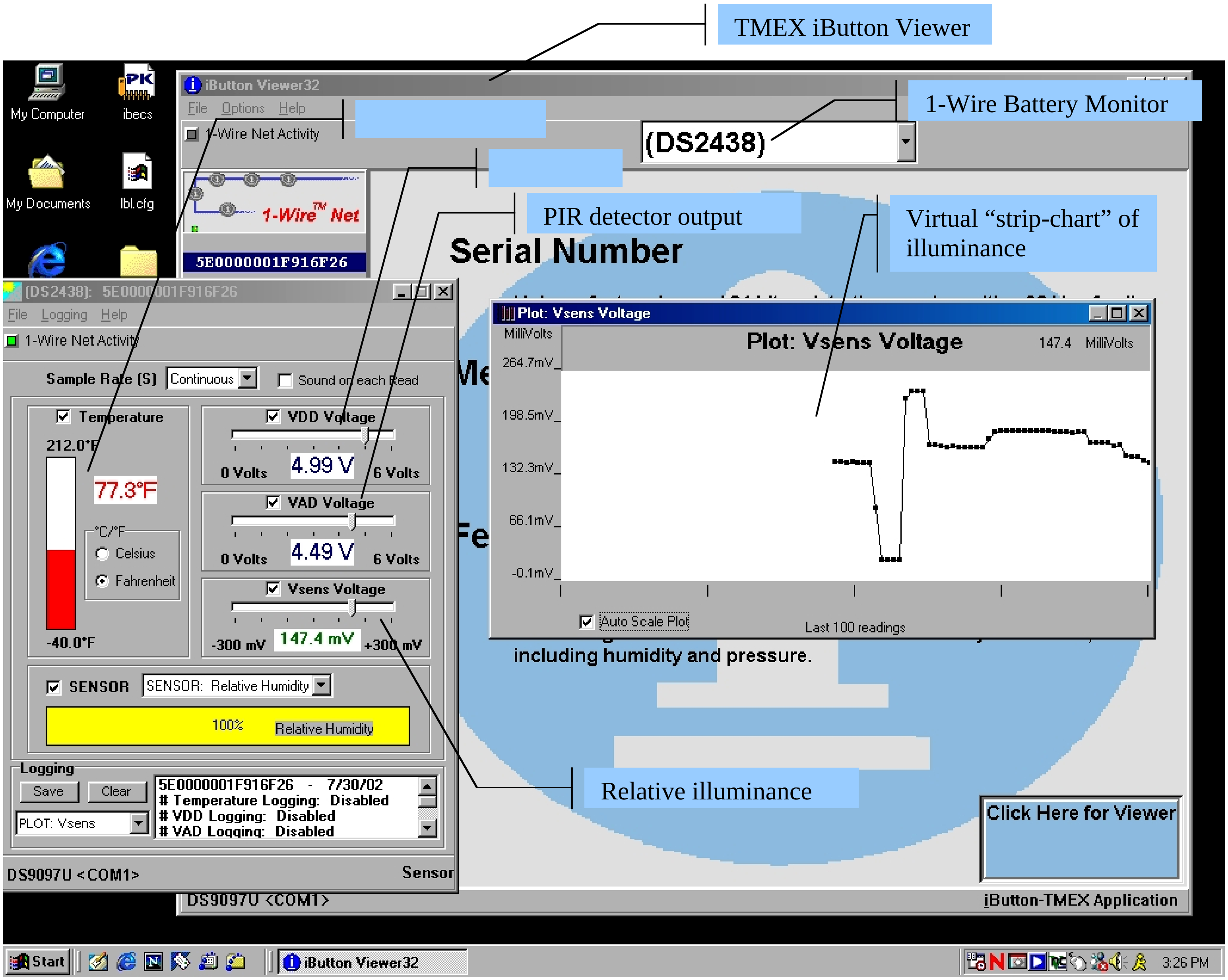

Figure 4. Screen capture showing the TMEX software with the viewer set to show the parameters from the DS2438 battery monitor chip. The annotations show the meaning of each of the control panel elements. The software is also capable of writing the collected sensor data to an ASCII text file, creating a "poor man's" data acquistion system.

DS2438 Battery Monitor Chip

In *The TINI Specification and Developer's Guide*, Loomis writes:

> *The DS2438 includes an A/D converter, a temperature sensor, an elapsed time meter, and 40 bytes of nonvolatile memory.* ***The practical uses for a device that measures analog voltage and currents as well as sense temperature are nearly unlimited*** *[emphasis added]. For example, the DS2438 can be used to create sensors that monitor various environmental conditions, including temperature, solar radiance, humidity and barometric pressure.*

A single Dallas Semiconductor chip, the DS2438, which was developed and is used today in many cell-phone battery packs, digitizes all three of our building automation measurements. The DS2438 is a particularly useful chip for general purpose sensing device since it combines 2 A/D (analog-to-digital) converters, an elapsed time clock, a temperature sensor and small amount of nonvolatile RAM . The technical specifications for the DS 2438 Battery Monitor chip are given in Appendix A of this report (see also http://www.ibutton.com). At time of this writing, the DS2438 is available for $1.60/unit (quantity 1000).

Using the DS2438's integral temperature sensor as a starting point, we adapted the charge/discharge current measurement input to illuminance measurement and its battery terminal voltage measurement input for occupancy status. Thus we re-purposed the battery monitor chip and associated software to form an inexpensive data acquisition system capable of recording the most important indicators of building environmental quality.

Like all members of the IBECS (1-wire) family, this sensor includes an internal unique 64 bit (16 byte) electronic serial number. For purposes of the visible label, we have elected to use bytes # 8 through #14 to identify the module. The last two digits (#15 and #16) of all DS 2438-based devices carry a common family code number of 26.

There are several capabilities of the DS2438 chip that could be exploited in future elaborations of the sensor. The first is a 40-byte non-volatile memory, which could be used to store either alpha or numeric data about the calibration constants and/or physical location of the sensor. Additionally, the chip contains several timers and accumulators that were intended for use in storing battery status. Its elapsed time meter (ETM) can be used to keep a record of the time (in seconds) that the host workstation has been turned ON. This register will be reset each time the workstation is turned OFF.

Using Sensors for Multiple Purposes

The use of environmental sensors is a key advantage to the IBECS concept. Since any device connected onto the IBECS network can provide its data to any other device (or program) that needs it, sensors are able to provide multi-function capabilities. For example, the environmental sensor we have designed can act under routine conditions in a similar manner as today's occupant sensor -- turning off lights when a space becomes unoccupied for more than a set time. But in a time of emergency, building security software could scan all environmental sensors throughout a building to obtain an instant snapshot of which spaces are occupied at that critical moment. In this manner, sensors can provide more than one duty across different building trades, significantly increasing sensor functionality and usefulness at only a modest increase in cost.

IBECS Circuit Demand Monitor

The objective of this subtask is to demonstrate the benefits of installing sub-meters at the branch circuit level for purposes of monitoring, verification and building code compliance, using inexpensive IBECS-ready meters.

In order to minimize development costs as well as sensor cost, we elected to produce a sensor capable of measuring RMS current, not true RMS power. True RMS power requires measuring the cross product of current and voltage, which would have made for a more expensive development cycle. Limiting the sensor to RMS current only greatly simplifies the development of the sensor albeit at the expense of accuracy.

Several prototype current measuring sensors have been designed for low-cost, networked measurements of AC current in branch or switch-leg electrical distribution circuits. All designs use a split-core current transformer permanently tethered to a small measurement module, which directly connects to an IBECS network. The units are parasitically powered from the network and from the circuit-under-test. These sensors also utilize the DS2438 (“Smart Battery Monitor”) chip as its interface to the IBECS network (see description of the DS2438 in the previous section).

Figure 5. Prototype RMS Current Monitor showing split-core transformer opened for illustrative purposes. In a real installation, the conductor carrying the current to be measured is placed in the transformer and the cover snapped shut. The black cable is standard Telco cable (4 conductor, RJ-11 terminator) and plugs into an IBECS network.

As with the Multisensor, the Dallas Semiconductor iButton viewer software can be used to demonstrate the operation of this sensor. In the case of the Current Sensor, the V_{Sens} reading will convey the measurement of current   For the delivered engineering sample, the empirically measured scale factor is:

V_{sens} = 4.33 millivolts/ RMS Ampere over the range 0-50 Amperes.

Future versions of the sensor circuit will incorporate a trimming adjustment so that all units can be manufactured with a standardized sensitivity of 5.0 millivolts per ampere. In all cases the measurement resolution, as determined by the DS2438 chip is 0.2441 millivolt or approximately 0.1 Ampere. The overall measurement accuracy should be approximately ±5%.

Although not always relevant, the temperature sensor resident in the DS2438 chip does indicate the ambient temperature within current sensor's measurement module. In some instances this may be used to give an indication of the approximate temperature of the air surrounding the sensor's measurement module.

The elapsed time register in the DS2438 chip can be utilized to store the time that has been accumulated since the sensor has been connected to an operating IBECS network. This register will be reset each time the network becomes inoperative. The ICA register in the DS2438 is normally used to accumulate the voltage x time product of V_{Sens} in its intended smart battery application. In the IBECS current sensor, we can use this register to store the value of the ampere-hour consumption of the metered load. In the design of the engineering prototype this value is volatile, so that the register will be reset to zero each time the IBECS network is powered down. The memory could be made to operate on a non-volatile basis, but this would necessitate including a back-up lithium battery in the measurement module, which in turn would increase its size and manufacturing cost.

Specifications (preliminary, subject to change):

Current Transformer Size:	1.1" x 1.1" x 1.6"
Measurement Module Size:	1.3" x 1.6" 0.8"
Tether Cable Length:	5"
Estimated Mfg. Cost:	$20
Current Measurement Frequency:	50/60 Hz
Maximum Continuous Current:	75 Amps AC
Current Transformer Dielectric:	1000 volts max.
Split Core Transformer Window:	0.4" diameter

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A more capable RMS current sensor was also developed and a prototype produced. This sensor (Figure 6) has a more fully-featured current transformer that can have its sensitivity changed using jumpers. In addition, the second current sensor has the ability to store a small number of current readings using the small amount of RAM available on the DS2438. However, this sensor is more expensive than the first since it requires a lithium battery to keep the memory hot.

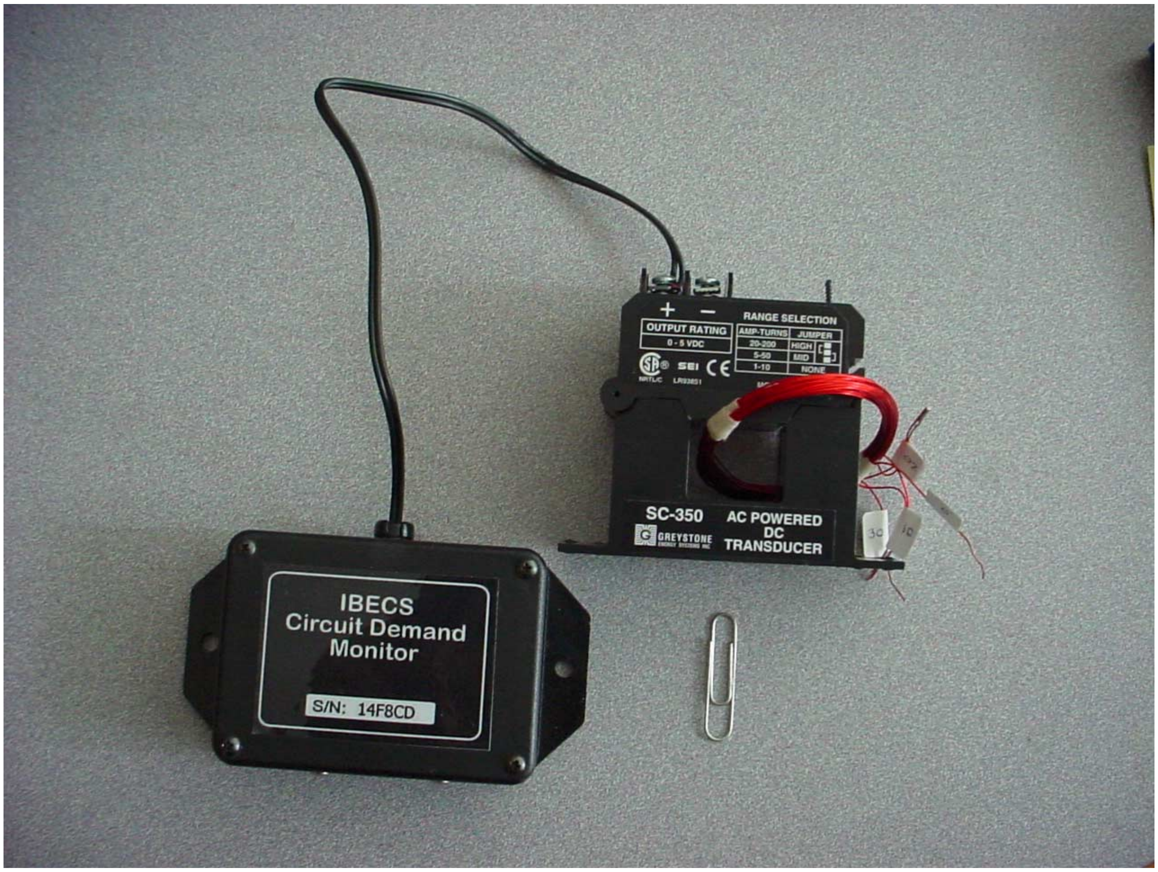

Figure 6. Prototype Circuit Demand Monitor showing attached split-core transformer (upper right). The red coil of wire in the transformer is used to inductively boost the output of the transformer so that it can accurately measure small loads..