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An Optical Watthour Meter Digitizer

W. H. Andrews

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INSTRUMENTATION AND CONTROLS DIVISION

AN OPTICAL WATTHOUR METER DIGITIZER

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HIGHLIGHTS

As concern about energy conservation and energy-use efficiency increases, a simple and inexpensive instrument that would provide accurate, reliable and high-resolution data on electrical energy usage should find widespread application in research and industrial facilities. An instrument that would also provide one or more outputs compatible with a wide range of digital data acquisition systems would be especially appropriate, since the use of automatic data logging equipment is now common, even in small-scale and low-budget operations.

An optical watthour meter digitizer was developed which meets these criteria. Based on the induction-type watthour meter, the digitizer provides an output pulse for a fixed amount of energy use. The digitizer senses the motion of the rotor disc of the meter by optically detecting passage of a nonreflective area painted on the underside of the disc. The passage of such area initiates a logic-compatible output pulse that can be used to measure power or energy usage in a variety of ways.

The accuracy of the measurement is determined by the watthour meter. The resolution of the measurement is determined by the K_h constant (in watthours per revolution) of the meter and the number of equally spaced targets painted on the disc. The resolution of this device can be as small as a fraction of a watthour; the resolution of the manually read register on a watthour meter is typically a fraction of a kilowatthour.

Several digitizers were fabricated, bench-tested, and installed in the field for long-term performance testing. All are performing satisfactorily.

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CONTENTS

1. INTRODUCTION

The reasons for using a spinning-disc, induction-type watthour meter are several: (1) it is rugged, reliable, inexpensive, readily available, and accurate (typically to 0.5%) over a wide range of source, load, and environmental conditions; (2) it is relatively small and light, and easy to install, use, and calibrate; and (3) its drain on most systems is negligible ($\sim$1 W). Its main disadvantage is that it is designed to be read manually, which makes it unsuitable for many research and industrial applications where an automatic data acquisition system to monitor power consumption or totalized energy usage is desired. A less important, but still bothersome, disadvantage is that the register on the face of the meter is not easily reset. Thus, the meter readings at the beginning and end of a measurement must be recorded and subtracted to determine the energy usage for the period of measurement.

An optical digitizer was developed to overcome the disadvantages, without losing the advantages, of the watthour meter. It attaches to any standard watthour meter and consists of a sensor mounted inside the meter cover (Fig. 1) and an electronics package connected to the sensor by a shielded cable (Fig. 2). The digitizer was developed for use in a facility where watthour meters were already in place. Three units were fabricated and installed for testing in the facility, and a portable version was fabricated for experimental testing.

2. GENERAL DESIGN CONSIDERATIONS

Installation of a sensor on an existing watthour meter requires three minor modifications to the meter: (1) one or more areas of flat black paint is applied to the underside of the rotor disc, (2) a small mounting bracket made from nonferromagnetic material is installed to rigidly fix the position of the sensor (the design of this bracket varies from one meter model to another), and (3) a small hole is drilled in the transparent meter cover to allow penetration by the sensor cable. Because of these modifications, utility companies may be reluctant to

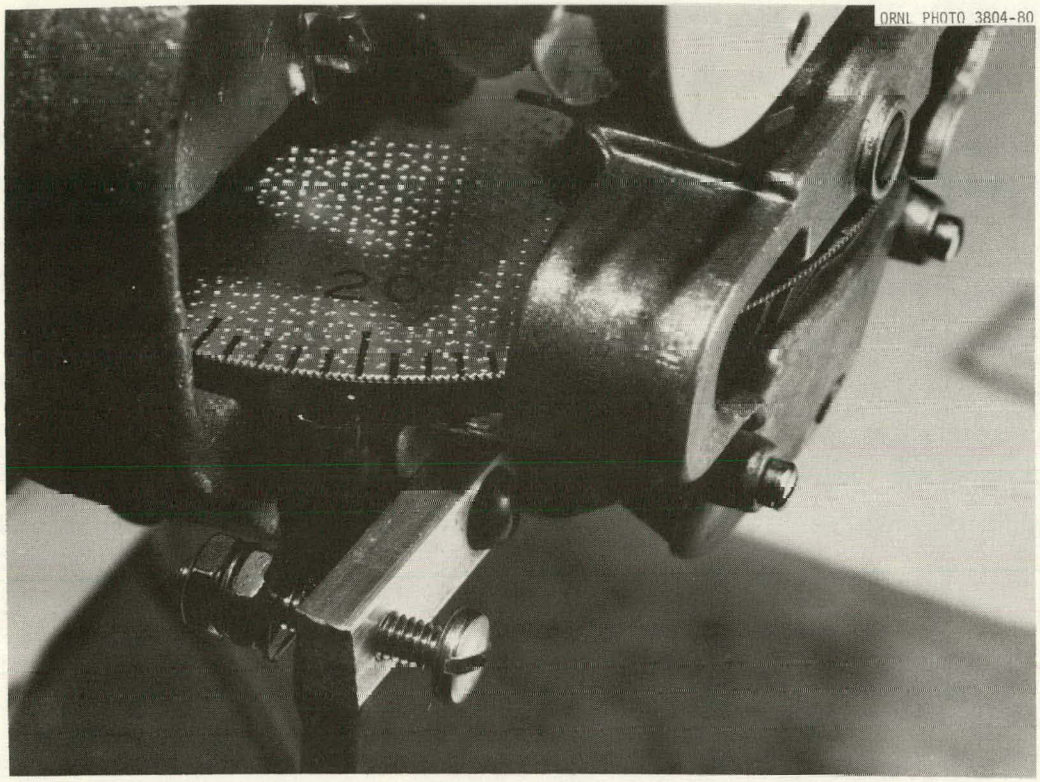


Fig. 1. Installation of Sensor on Meter.

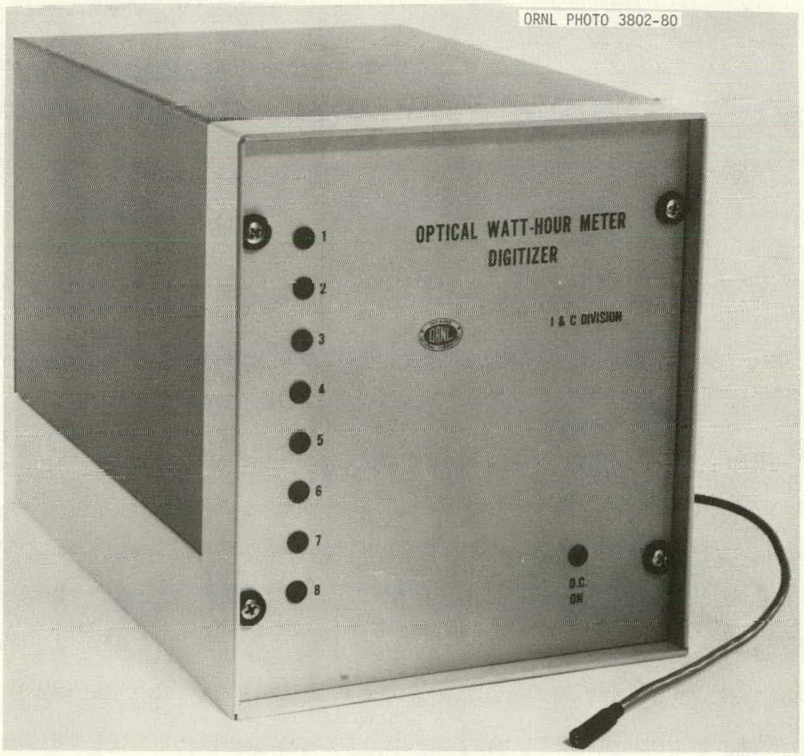


Fig. 2. Electronics Package.

allow installation of sensors on their revenue meters; however, we see no objection to a customer installing his own meter between the revenue meter and the device to be monitored as long as the installation meets applicable codes.

The circuit for the optical digitizer is designed around a solid-state reflectivity sensor. Two different sensor models have been used successfully: Fairchild Semiconductor FP104A, consisting of an infrared, gallium arsenide, light-emitting diode (LED) source and a silicon phototransistor detector (Fig. 3a); and Optron OPB707A, which differs only in its use of a photo-Darlington detector (Fig. 3b). A minor circuit modification is required to adapt from one sensor to the other.

The sensor optically detects the passing of one or more nonreflective areas painted on the perimeter of the aluminum disc that rotates in the meter. Each passing initiates a uniform, RRL-compatible output pulse that tells the data acquisition system that another fixed amount of energy has been delivered, the amount being equal to the meter constant K_h, divided by the number of nonreflective areas on the disc. Light-emitting diodes on the front panel of the electronics package visually indicate the presence of a pulse.

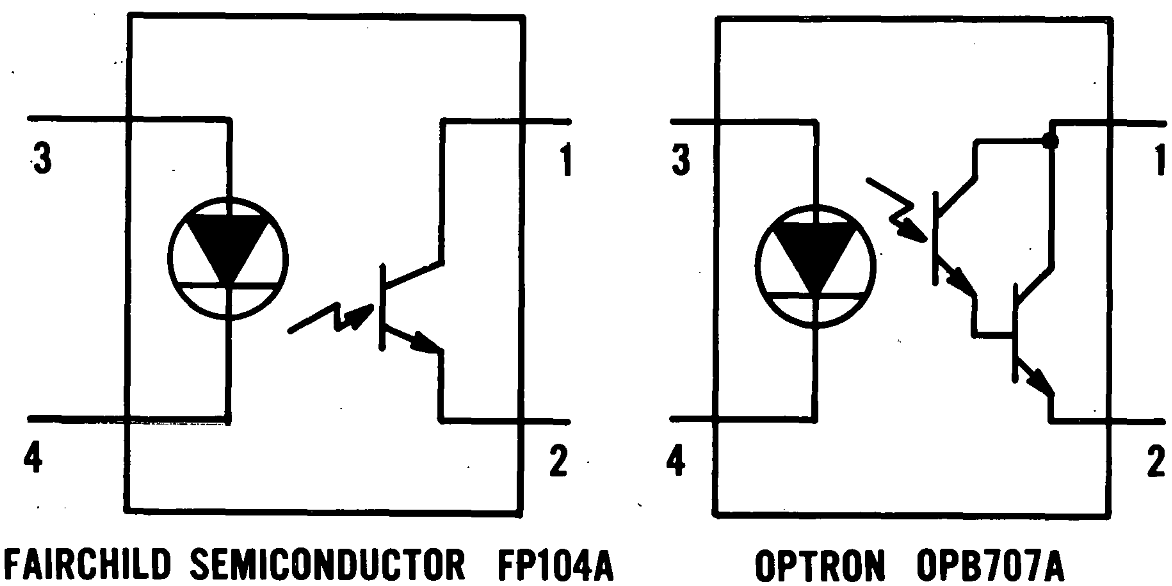


Fig. 3. Optical Reflectivity Sensors.

The output pulses can be used in two different ways: (1) a pulse can increment a counter, giving a cumulative record of energy use; or (2) the time between two pulses can be measured and used to calculate power usage. With appropriate scaling constants, a variety of engineering units, including joule, \$/h, and Btu, can be derived.

Since the digitizer is an interface device, it does not affect the accuracy of the measuring instrument, the watthour meter. It can, however, increase the resolution of a typical meter by a factor of a 1000 or more.

3. CIRCUIT DESCRIPTION

The LED in each sensor is continuously forward biased so that when the face of the sensor is close to the reflective area(s) of the rotating disc in the watthour meter, light from the LED is reflected into the base of the phototransistor and turns it *on*, if the transistor is wired into the circuit shown in Fig. 4. This low collector-emitter impedance decreases the voltage at the input (V_{in} in Fig. 4). When the flat black area on the rotor disc passes over the sensor, the phototransistor turns *off*, increasing V_{in} almost to the power supply level. As the input voltage rises above the comparator's threshold voltage V_t, the output of the comparator increases. Resistors R_2, R_4, and R_6 provide positive feedback hysteresis for noise immunity and protect against oscillation if the rotor should stop just as the input voltage reaches the threshold voltage.

Resistor R_2 is divided into R_{2A} and R_{2B} to allow the introduction of C_1 for rf filtering of the input signal. V_t is adjusted by setting the wiper of R_5 to a desired level.

A positive transition at the output of the comparator initiates a 0.3-s pulse from the one-shot. This duration was selected to allow a visual verification of the pulse on the front-panel display, without permitting overlapping of pulses when the rotor is spinning at its maximum rate. The width of the pulse is easily tailored to the specific application by optimizing the values of R_T and C_T.

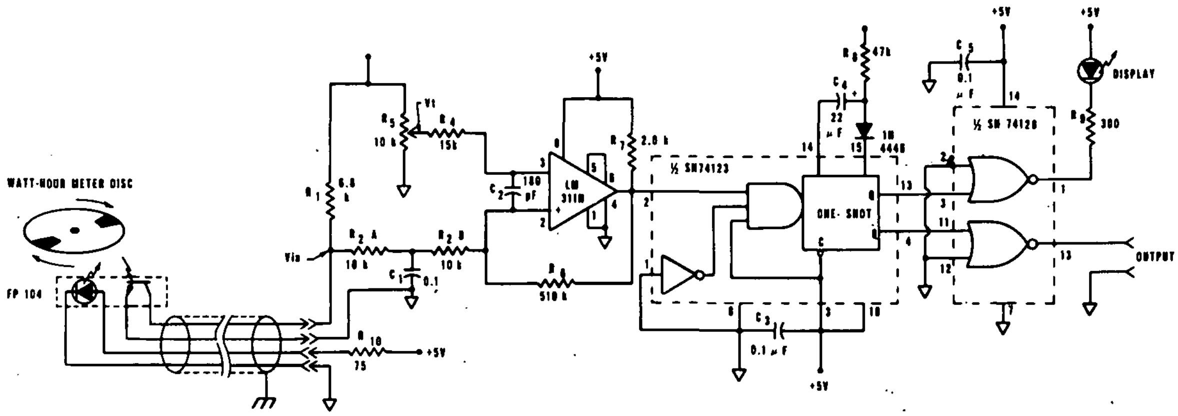


Fig. 4. Digitizer Electronics.

The one-shot is wired in its retriggerable mode; that is, any positive input transition that occurs during its timing cycle restarts the timer, and the output remains true. Since the input signal is more susceptible to noise when the sensor transistor is in its *off* state, the retriggerable mode feature was employed to help mask noise for the duration of the input pulse.

The complementary outputs of the one-shot control two NOR gate line drivers wired as simple inverters. The output of gate A drives the front panel display, and that of gate B is the well-buffered 50-Ω data output.

Data are delivered to the data acquisition system by a shielded, twisted pair cable or a 50-Ω coaxial cable. Both the sensor and output cable can be up to several hundred feet long if high-quality instrumentation cable is used. Since the devices often will be used in hostile electrical environments, the circuit requires proper grounding, shielding and bypassing techniques.

4. RESULTS

4.1 Bench-Top Tests

Typical input and output waveforms are shown in Fig. 5. In Fig. 5a, the upper trace shows V_{in}, the voltage at the collector of the sensor's photo-transistor. The shape of this waveform depends on many factors, including the finish of the rotor's surface, the shape and size of the nonreflective area, and the distance between the face of the sensor and the surface of the rotor disc. The middle trace is the output of the comparator. The lower trace shows the output voltage with no load on the line driver. This waveform is identical, within component tolerances, for each nonreflective area on the rotor disc and for each channel in the electronics package. In Fig. 5b, the leading and trailing edges of the output pulse are expanded to show the short rise and fall times (<20 ns) of the output signal.

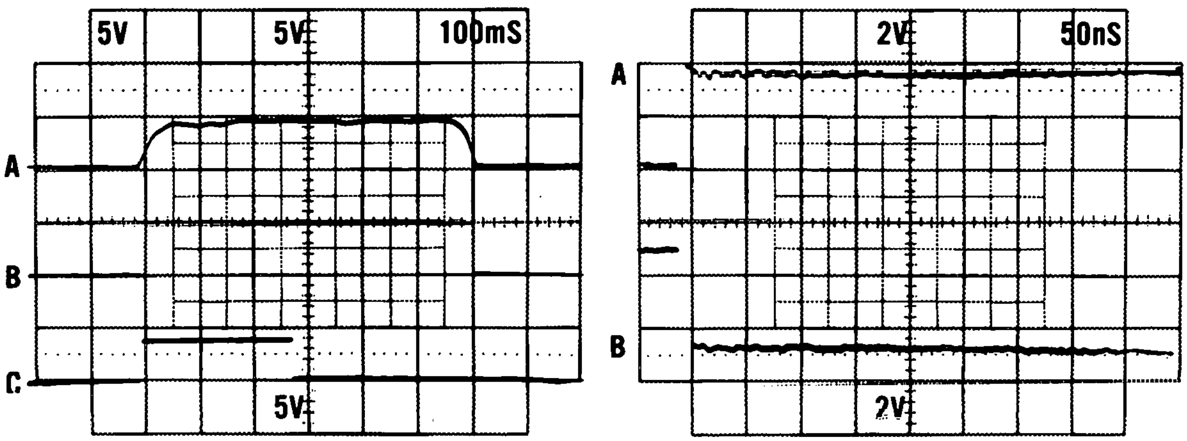


Fig. 5. Typical Input and Output Waveforms.

a. Oscillograph of voltages (A is V_{in}; B, comparator output; and C, output pulse)

b. Output Pulse Waveform with time scale expanded (A is the leading edge, and B is the trailing edge)

A prototype was initially tested for 23 h with a 2-kW heater bank load, using a Duncan MF-S watthour meter and a Fluke 1911A digital pulse counter on the output of the electronics. Agreement between the counter and the register on the face of the meter for this period was within the resolution with which the register can be read (~0.1 kW•h).

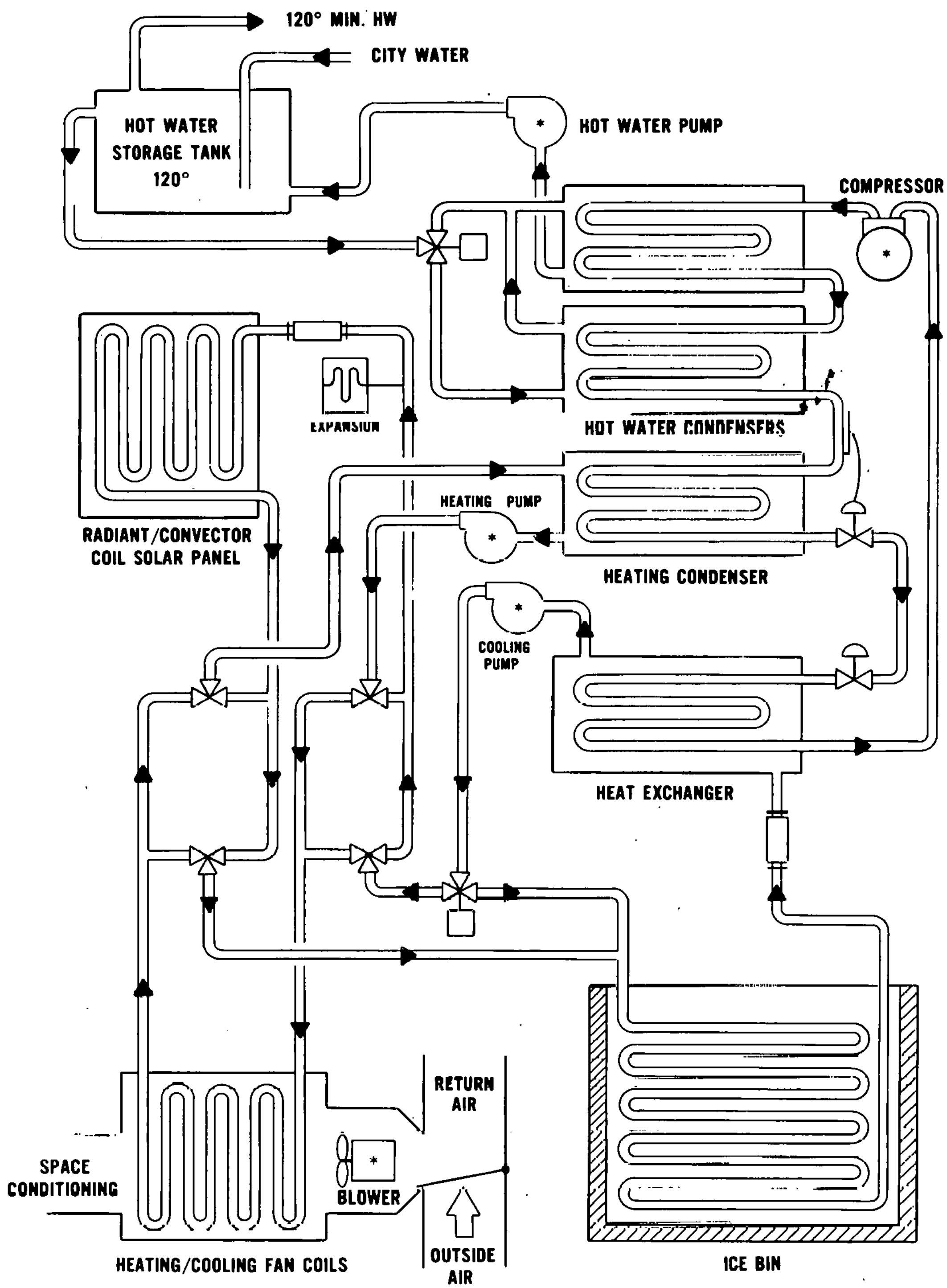
4.2 Field Tests

Three eight-channel units have been in use at the Tennessee Energy Conservation in Housing facility near Knoxville, Tennessee, for several months and have performed satisfactorily since their installation. The facility, which is operated jointly for the Department of Energy by the University of Tennessee and the Oak Ridge National Laboratory, consists of three experiments, each to test a unique way of energy storage or utilization. One experiment, the Annual Cycle Energy System (ACES), will be discussed here to illustrate a typical application of the optical watthour meter digitizer.

The ACES experiment uses the large latent heat of the water-ice phase transition to store energy for winter heating of the living space in a house. During the winter heating season, a heat pump removes heat from a large insulated reservoir of water, causing ice to form on immersed heat-exchanger coils. The ice is melted during the following summer cooling season when the ice-water mixture absorbs heat from the living space. The heat pump network also includes a water heater loop for residential hot water needs. A flow diagram of the system is shown in Fig. 6.

The system is managed by a programmable logic controller which accepts such inputs as indoor temperature, outdoor dry- and wet-bulb temperatures, hot water tank temperatures, and the amount of ice in the bin. The controller operates the compressor, blower, valves, and pumps as the input parameters demand.

To monitor the energy consumption of the various components of the heat pump system, each electrical device has a watthour meter installed in its power line, and each of the meters has a channel of digitizer electronics attached (Figs. 7 and 8 and Table 1). Each channel of electronics feeds a counter card in an input channel of a Hewlett-Packard



* THE COMPRESSOR, HOT WATER PUMP, HEATING PUMP, COOLING PUMP, AND BLOWER ARE EACH MONITORED WITH WATT-HOUR METER DIGITIZERS.

Fig. 6. Flowsheet of ACES Experiment.

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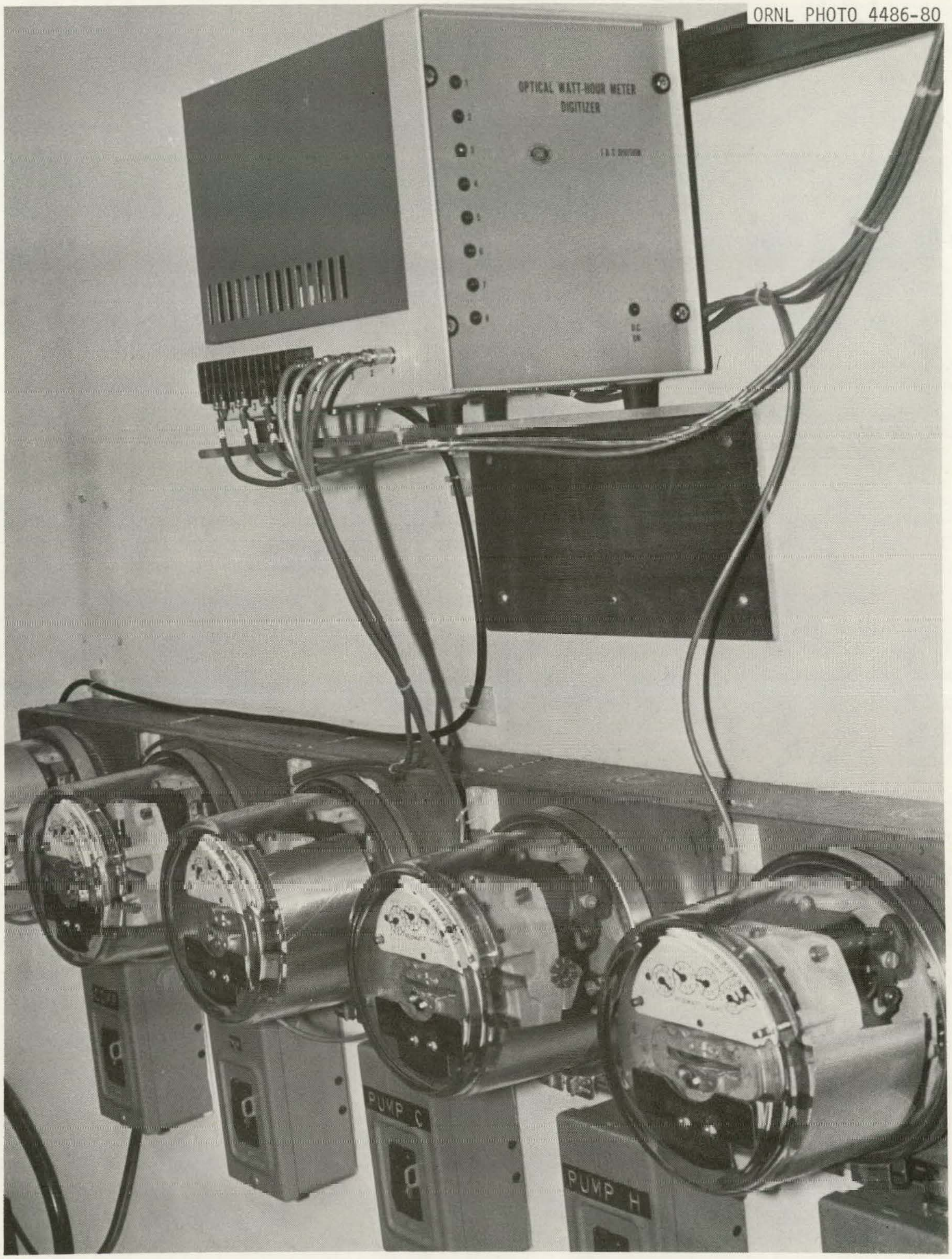

Fig. 7. Aces Digitizer Installation.

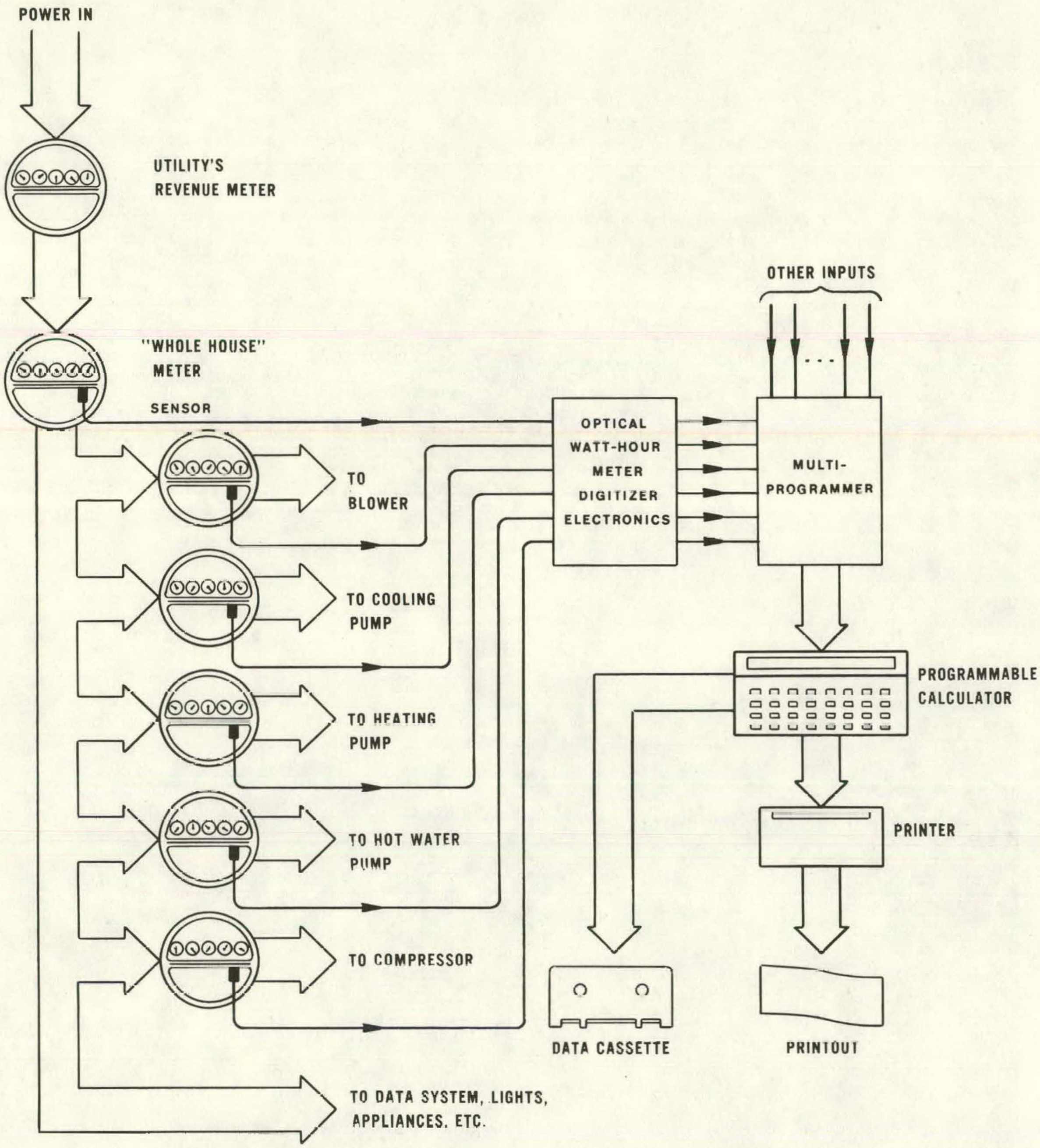

Fig. 8. Application of Watthour Meter Digitizer to ACES Equipment.

6940A multiprogrammer. Every hour, the counters are scanned and reset by a Hewlett-Packard 9325A programmable calculator. The calculator scales the data into appropriate engineering units, and this information is included in an hourly data summary. The energy performance of the system can be compared to the performance of the other experiments and of a conventional heat pump system at the facility. To check the validity of the data, they are periodically compared with the readings on the meter registers. Well over 50,000 meter-hours of data have been logged, and, with the exception of one easily correctable sensor failure, the devices performed as desired for that period.

Table 1. Details of individual stations in the ACES house

Monitored Device	Digitizer Channel	Load Demand	No. of Nonreflective Areas	Minimum Period of Rotation (s/rev)	Watthours Per Pulse
Heat-pump compressor[a]	1	3000 W, fixed	2	4.3	1.8
Heat-pump blower[a]	2	400 W, fixed	2	32.4	1.8
Cooling pump[a]	3	200 W, fixed	2	65	1.8
Heating pump[a]	4	200 W, fixed	2	65	1.8
Hot water pump[a]	5	100 W, fixed	2	130	1.8
Whole house[b]	6	15 kW max, variable	2	1.7	3.6

[a]Monitored by a Sangamo JS, 15-A watthour meter, with K_h = 3.6.

[b]Monitored by a GE I-60-S, CL 200 watthour meter, with K_n = 7.2.

5. CONCLUSIONS

An effective electrical energy consumption monitor was developed for use in typical automatic data acquisition systems. Several units were fabricated, tested, and used in the field. The instrument has proved to be reliable, cost-effective approach to making energy and power usage measurements.

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