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CIRCUITRY FOR A
HUMIDITY-LEVEL DETECTOR

PDO 6984703, Topical Report

W. B. Abel, Project Leader

Project Team:
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Prepared for the
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**Kansas City
Division**

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Department 142**

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**PDO 6984703
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Technical Communications

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CIRCUITRY FOR A HUMIDITY-LEVEL DETECTOR

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Prepared by J. W. Hill, D/142, under PDO 6984703

A prototype humidity-level detector utilizing a lithium chloride humidity sensor has been designed and built. A dry-to-wet humidity-level indication is obtained through the deactivation of a calendar watch as the humidity reaches a preset limit. Technical considerations in the design and utilization of the electronic circuitry are given. Measured accuracy and drift characteristics of the prototype are provided together with recommendations for improving these characteristics, if necessary.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

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SUMMARY

The resistance humidity sensor is a humidity-variable resistor with a nonlinear characteristic showing high resistance at low humidity and low resistance at high humidity. The sensor is slow-acting and must be ac-driven to prevent its polarization and destruction.

In the maximum humidity indicator, the sensor is driven with a micropower oscillator and serves as one part of a voltage divider. A comparator is used to compare the peak value of the ac signal to a low-voltage reference. When the signal exceeds the reference, the comparator latches and fires an SCR. The SCR discharges through a 2-mA fuse which is also common to an electronic calendar watch. When the fuse blows, the watch is nondestructively turned off, thus recording the date and time.

The prototype exhibited a short-term repeatability of approximately ± 0.2 percent relative humidity, an estimated long-term drift of approximately 1 percent rh/24 days, and a temperature coefficient of 0.063 percent rh/ $^{\circ}\text{C}$. These parameters can be improved only by increasing the minimum power consumption of 196 microwatts.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was to prove the feasibility of an electronic maximum humidity indicator and to develop a prototype of a practical unit. The work was done under PDO 6984703.

ACTIVITY

Resistance Humidity Sensor

The resistance humidity sensor is a humidity-variable resistor with a nonlinear characteristic showing high resistance at low humidity and low resistance at high humidity. The sensor used for this application has a humidity-dependent resistance which is a function of the surface conductivity of a film of lithium chloride. The conductivity is a function of the quantity of water absorbed in the hygroscopic salt film.

The important parameters in the operation of the sensor are resistance and humidity. A curve showing their relationship is presented in Figure 1. The drastic difference in the resistance for a dry condition and a 10-percent rh level is readily apparent.

Experience has indicated that the response time for the sensor is extremely long. The experimental setup was arranged so that a stream of air of known humidity was directed directly across the sensor. In its dry state, the air had a relative humidity of approximately 4 percent. When the mixture was mechanically changed to a relative humidity of 10 percent, the sensor typically required six minutes to catch up to within 10 percent of the humidity setting. Experiments made by the metrology laboratory indicate about 24 hours are required for the sensor to stabilize after an abrupt change in humidity.

Any ac power supply that provides less than 10 volts rms at a frequency greater than 10 hertz is satisfactory for use with the sensor. The emphasis must be made, however, that no dc voltage can be allowed. Even the biasing currents of an operational amplifier (less than 1 nanoampere, in this case) can polarize the sensor and develop a substantial offset voltage. A blocking capacitor in series with the sensor is a necessity.

Circuit Design Considerations

The photographs and the block diagram shown in Figures 2 and 3 outline the basic configuration chosen for the humidity-level

Figure 1. Relationship of Resistance and Relative Humidity for Lithium Chloride Sensor

detection system. An oscillator is necessary to power the sensor, and a simple comparator can be used to sense when the humidity has reached the set-point. An electronic calendar watch is used for the one-shot indicator. When the comparator latches positive, the watch is nondestructively turned off by the firing of the SCR and the blowing of a fuse that is common to the watch circuit. The watch indicates the day and time that the humidity exceeded its maximum allowable limit.

The basic parameters considered in this system are the power drain, the repeatability of the trigger point, and the stability.

Power Drain

This type of circuit is inherently a low-drain type because the driving of a passive, high-resistance sensing element does not dissipate a significant amount of power. Several types of solid state, low-bias circuits can be used. For this application, two programmable, micropower operational amplifiers were used. The RCA CA 3078AT appeared to have the best specifications of all the micropower operational amplifiers made by the major semiconductor manufacturing companies.

Figure 2. Front and Rear Views of Prototype Humidity-Level Detector With Sensor Mounted at Top

Figure 3. Block Diagram of Humidity-Level Detector

In its quiescent state, the CA 3078AT can be biased down to a drain of 700 nanowatts. The specifications indicate a bias current of 0.45 nanoamperes, an open-loop gain of 65 dB, a common mode rejection ratio (CMRR) of 90 dB, and an input impedance in excess of 4 megohms. These characteristics make the device a natural choice for this type of application.

The power consumption of the overall circuit can be attributed largely to the drain of the oscillator. The drain is a function of the amplitude of oscillation, which is an inverse function of the set-current of the programmable operational amplifier. The set-current is, in turn, a direct function of the battery voltage. When optimized for low drain, this circuit can be operated at a quiescent drain of 35 microamperes with a ± 2.8 -volt supply. Optimizing the circuit for such a low drain, however, causes undesirable effects on temperature stability and long-term drift.

Stability

The set-point of an operational-amplifier comparator depends on the offset voltage, the voltage drop that results from the offset current, the voltage caused by the bias current flowing through the input resistor, the offset developed from power supply variations, and the signal values. All of these parameters are subject to drift with changes in temperature or in the supply voltage. In addition, the random noise generated in the operational amplifiers, combined with the environmental noise picked up by inductive coupling, generate some uncertainty in the set-point. Problems also occur with changes in reference potential and oscillator voltage as the terminal voltage of the battery decays.

Operational amplifiers are subject to long-term drift and, with industrial-grade components, to shot noise. Shot noise is characterized by short pulses of two or more times the magnitude of the normal noise. Shot noise normally is not present, but sometimes it is found to exist in units from certain production lots.

When the power drain is optimized, the signal voltages become small and the various offset voltages and noise signals become comparatively large. Here exists the dilemma of an acceptable balance between low power drain and immunity to drift.

For optimized power-drain conditions, the oscillator runs at a level of 200 millivolts, peak-to-peak. With the 100-kilohm sense resistor and the 500-kilohm resistance of the humidity sensor, the set-point should be 16.6 millivolts at 10 percent rh. In this region of the resistance-versus-humidity curve of the sensor, the resistance coefficient is approximately 10 k Ω /percent rh. This indicates that a 1-percent rh change is equivalent to a signal change of 0.283 millivolts at the operational-amplifier input. This amount of change can also be caused by a 10.2-percent change in oscillator voltage, an equivalent offset voltage, or an equivalent amount of noise pickup.

Offset Voltages

Direct-current offset voltages can be developed from the offset voltage of the operational amplifiers and the voltage drop caused by the offset current. While fixed values can be easily compensated for in the calibration of the set-point, the fluctuation of these values causes problems. Both offset voltages and currents have a temperature coefficient, a long-term drift, and a drift coefficient due to power supply variations.

For the CA 3078 operational amplifier, typical static values are 1.5 millivolts of offset voltage and 0.05 nanoamperes of offset current at low bias. The gain at low bias is typically 65 dB, and the quiescent power dissipation can be as low as 700 nanowatts. The offset drifts are typically 100 μ V/V, 10 μ V/ $^{\circ}$ C, and 10 pA/ $^{\circ}$ C. At this rate, a change of 25.7 $^{\circ}$ C is equivalent to a humidity change of 1 percent rh near the 10-percent point. With the measured coefficient of 0.063 percent rh/ $^{\circ}$ C, a 15.8 $^{\circ}$ C change is equivalent to a 1-percent change in rh. This additional drift probably can be attributed to drift of the oscillator.

A 1-volt change in the power supply voltage can result in as much as 100 microvolts of offset voltage at the comparator input. This is equivalent to a drift of 1 percent rh for a power supply drift of 2.83 volts. The effect is not significant because this amount of drift is greater than the power supply voltage, and the oscillator accuracy is much more sensitive to power supply variations.

In addition to the characteristics already described, an operational amplifier of this type may exhibit a typical input offset voltage drift of 500 microvolts over the first 1000-hour burn-in period. This is equivalent to a 1-percent-rh drift in 24 days, but the drift slows down significantly after the initial burn-in.

The drift of the operational-amplifier comparator can be greatly reduced by using one of the recently introduced chopper-stabilized integrated circuit amplifiers.

Noise Considerations

Two types of noise exist in this circuit: noise generated in the circuit, and noise picked up from outside sources. The noise generated in the comparator can be modeled as an equivalent voltage and current source at the input. The typical equivalent input voltage is 1.265 microvolts, and the equivalent noise generated from the input current source and input resistance is also, typically, 1.265 microvolts. This yields a total input noise of 2.53 microvolts which is equivalent to an uncertainty of 0.01 percent rh.

Although the noise generated in the circuit is almost insignificant, the noise picked up inductively is substantial. The 60-Hz pick-up is difficult to prevent. The best defensive tactic is to employ careful design in the layout. The sensor and the circuit must be mounted as close as possible, and the wiring should be kept as compact as possible. A shield enclosure should be provided around all components, including the humidity sensor. In the prototype, copper screen was used to form the ground plane. This was reasonably effective under laboratory conditions, but additional control measures may be necessary in noisy environments.

Even with care in layout, wiring, and shielding, erroneous triggering occurred when the comparator was set within 2 or 3 percent of its trigger-point and certain types of electrical equipment close to the circuit were switched on. In an environment where electrical noise is extremely bad, better shielding should be used.

Except for providing a good ground plane, a nonmagnetic metal is not an effective shield at low frequencies. To obtain good shielding, a high-permeability magnetic material is needed. At low frequencies, the magnetic hysteresis causes energy losses to signals trying to penetrate the material far in excess of the eddy-current losses.

If careful layout and good shielding do not adequately control the noise, a micropower active bandpass filter can be incorporated

as a buffer to the comparator. The need for this, however, would occur as an extreme case which normally would not be encountered under laboratory conditions.

Oscillator Stability

The oscillator voltage can change as a function of the supply voltage, the temperature coefficient of the RC components, and the level of the set-current controlling the operational amplifier. An effective stabilization of oscillator voltage can be achieved if the current-setting resistor is replaced by a junction field-effect transistor (JFET) biased to operate as a constant-current regulator. This feature was included in the prototype. The variation was reduced to the equivalent of approximately 1 percent rh in the set-point, in the 10-percent-rh region of the curve, over the useful life span of the batteries. A current regulator should also be used to set the reference voltage that adjusts the set-point.

For best results, the current regulators should be temperature-compensated. The temperature coefficient of the source resistance can be selected as the inverse of the temperature coefficient of the JFET. While this was not done in the prototype, it should improve the performance.

The selection of RC components having smaller temperature coefficients will improve the thermal stability of the oscillator amplitude. To obtain really good performance, however, a feedback-stabilization scheme must be used. One such scheme claims an amplitude drift of less than 6 percent in the range from $+10^{\circ}\text{C}$ to $+65^{\circ}\text{C}$.¹ This is equivalent to a 0.6 percent rh drift in the trigger-point. The oscillator in the prototype would require only slight modifications to incorporate this scheme.

Power Supply Selection

Two important factors should be considered in the selection of a power supply: the noise introduced through the supply, and the regulation of the supply. Both of these affect the accuracy and repeatability of the humidity-level detector.

The noise present in the output of most power supplies contains voltage spikes which can find their way into the circuit and trigger the comparator. If a line-driven power supply is used, special consideration must be given to filtering.

Because of the noise problem in coupling to a line (as well as for fulfilling the portability requirement), batteries were employed in the prototype. Batteries, however, have the disadvantage of providing poor regulation. The regulation of a

typical alkaline cell is shown in Figure 4, the regulation of a nickel-cadmium cell is shown in Figure 5, and that of a silver oxide cell is shown in Figure 6. Although the silver oxide cell is clearly the best for this application, it was not available at the time. Nickel-cadmium batteries therefore were used in the prototype. The use of silver oxide batteries should improve the small voltage instabilities in the circuit and may eliminate the need for JFET current regulators.

Figure 4. Alkaline Cell Voltage Regulation

The recently introduced lithium primary cells have regulation comparable to that of the silver oxide cell, and they have a much higher energy density. Their announcement came after the development of the humidity-level detector, but they should be considered for any future development.

Circuit Operation

A schematic of the circuit for the humidity-level detector is shown in Figure 7. The following sequence of events describes the operation of the instrument.

As the humidity increases, the sensor resistance decreases and the voltage drop across the sensing resistor increases. When the peak value of this voltage drop exceeds that of the reference

Figure 5. Nickel-Cadmium Cell Voltage Regulation

Figure 6. Silver Oxide Cell Voltage Regulation

voltage, the comparator latches positive and turns on the SCR. The SCR draws enough current to blow the fuse and turn off the watch. The watch indicates the time at which the humidity exceeded the set-point.

Figure 7. Humidity-Level Detector Schematic

The comparator consists of a single operational amplifier used in an open-loop configuration. The reference voltage is supplied by the drop across a resistor. The current for the reference resistor is set by a JFET connected in a constant-current diode configuration. The constant-current source is used to minimize the reference voltage drift as a function of the battery voltage decay. A constant-current diode is used also to stabilize the set-current of the oscillator. These measures provide a great improvement in stability with respect to battery decay. The four diodes in the inverse-feedback loop provide nonlinear negative feedback to stabilize the oscillator voltage.

The output from the comparator is used to excite an SCR which is connected across the power supply through a 2-milliampere fuse. The drive circuit for the electronic watch is also common to the fuse. A diode is placed in series with the SCR gate to protect the SCR, and another diode is placed in series with the watch circuit to protect it from being reverse-biased by the main supply voltage.

When the CA 3078 line of operational amplifiers is driven at low bias, some crossover distortion is apparent in the output. This is not a problem, however, for this circuit application.

Experimental Results

Short-Term Repeatability

A histogram showing the trigger-point accuracy of the humidity-level detector is presented in Figure 8. This data represents 120 consecutive trials under identical conditions. As can be seen, the total spread was within ± 0.2 percent rh. These experiments were made with a variable resistance substituted for the humidity sensor. Repeatability tests made with the humidity sensor will provide equally good results if the measurements are carefully timed to allow for the response time and hysteresis of the sensor. Because the response time is long and the hysteresis is large, making measurements using the sensor is a very tedious process.

Temperature Stability

Two repeatability studies similar to the one previously described were made at temperatures close to room temperature but a few degrees apart. The results were similar to those already shown, except that the histograms were slightly offset. The offset drift was 0.063 percent rh/ $^{\circ}$ C.

Figure 8. Histogram Showing Trigger-Point Accuracy of Humidity-Level Detector

Power Consumption

When a ± 2.8 -volt supply is used, the current drain is 60 microamperes or less during quiescent operation. This figure can be adjusted downward to 35 microamperes without affecting performance figures. The repeatability and drift measurements previously described were made at this lower level of power consumption.

Increasing the oscillator voltage increases the immunity of the humidity-level detector to drift, but the power consumption is substantially increased. Improvement in drift can be made only with an increase in power consumption.

ACCOMPLISHMENTS

A prototype has been designed and built to demonstrate the feasibility of an electronic humidity-level detector.

The experimental results indicate a short-term accuracy of ± 0.2 percent rh, a temperature-drift coefficient of 0.063 percent rh/ $^{\circ}$ C, and an estimated long-term drift of 1 percent rh/24 days. These figures apply only when the sensor resistance corresponds to the portion of the resistance-versus-humidity curve near 10 percent rh. Decreasing the humidity-level of the trigger-point increases the sensitivity of the instrument to a change in humidity.

Provided the long response time and hysteresis of the humidity sensor can be tolerated, this system should be adequate for use as a dry-to-wet transition detector. Added precision at higher humidity levels can be developed only with an increase in power consumption and a more complex circuit.

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