# A Simple Psychrometric Apparatus for Bowen Ratio Determinations

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## ABSTRACT

A simple apparatus has been devised which automatically reverses the vertical positions of two pairs of shielded and aspirated wet- and dry-bulb diodes. Analog voltage signals proportional to the dry and wet bulb temperatures $T$ and $T_w$ and to the differences $\Delta T$ and $\Delta T_w$ are provided. The diodes present a low source impedance, a linear response over normal ranges, a sensitivity of about 2.3 mV(°C)$^{-1}$, and as used here, a time constant of about one minute. From these measurements the Bowen ratio can be determined conveniently.

## 1. Introduction

The Bowen ratio technique often is used to determine the partitioning of sensible and latent heat fluxes (Lettau, 1957). The argument relating the vertical fluxes is outlined as follows:

$$\text{Sensible flux/latent flux} = B \approx (K_h/K_v)\gamma(\Delta T/\Delta e), \quad (1)$$

where $\gamma$ is the psychrometer constant, $T$ the dry-bulb temperature, $e$ the vapor pressure, and $K_h$ and $K_v$ are the eddy diffusivities of heat and water vapor. Then, it follows directly from the standard psychrometric equation that

$$B = \left[\left(\frac{s}{\gamma}+1\right)\frac{\Delta T_w}{\Delta T}-1\right]^{-1}, \quad (2)$$

where $T_w$ is the wet-bulb temperature, $s = de_s/dT_w$ at $T_w$ is a known function of $T_w$, and where the similarity hypothesis $K_h = K_v$ is made (Suomi, 1957; Tanner, 1960; Fritschen and Van Bavel, 1963).

The critical measurement is then $\Delta T_w/\Delta T$, as $s$ varies only about 5 per cent (°C)$^{-1}$.

## 2. Sensors

The sensors employ the temperature sensitivity of the junction voltage of a forward biased 1N2326 diode, operating at nearly constant current. Principles, characteristics and circuits have been discussed by Sargeant (1965). It is sufficient to note here that appropriate diodes have a very linear voltage-temperature characteristic, with a sensitivity of about 2.3 mV(°C)$^{-1}$ which is quite uniform among diodes. The linearity and uniformity make temperature difference measurements convenient by direct voltage difference. See Fig. 5 for typical circuitry.

The sensor and shield assembly is shown in Figs. 1a and 1b. The diodes are mounted in double radiation shields, the innovation here being the use of the polyurethane insulation itself as the structural member supporting the elements. The air ducts were cored using a one-half inch, thin wall tube which had been sharpened on its inner surface. The duct surfaces were hardened with a thin epoxy coating and lined with aluminum foil to form the inner radiation shield. The outer shield surface is covered with aluminized mylar tape.

The wet bulb is fed by a wick made from tubular, white cotton shoelace that has been boiled in laundry detergent containing a small amount of NaOH and then rinsed well by boiling several times in distilled water. Two concentric pieces of wick extend from the diode base into the reservoir, where they branch to either end of the reservior. A small third piece of wick is stretched over the diode, overlapping the reservoir wicks to allow easy replacement and cleaning. Later tests showed that the diode could be covered more conveniently with facial tissue as described by Collins (1965). Wetted facial tissue extending over the wicking from the reservoir remains wet under severe drying conditions and is easily replaced when dirtied.

The reservoir, less than half filled, automatically provides tension on the wick in either position as the water runs to the lower end. Access to the diodes and reservoir is via three springs, and refilling is done easily using a plastic wash bottle.

## 3. Reversing mechanism

Systematic sensor differences produce a zero offset, and slight differences in diode-pair temperature sensitivities produce a slow zero point drift in the difference measurements as $T$ and $T_w$ change. These errors can be removed by sensor reversal.

The reversing mechanism is shown in Figs. 2 and 3. A mast supports a sleeve bearing, the reversing motor and a sunshade. This assembly is held to the mast with

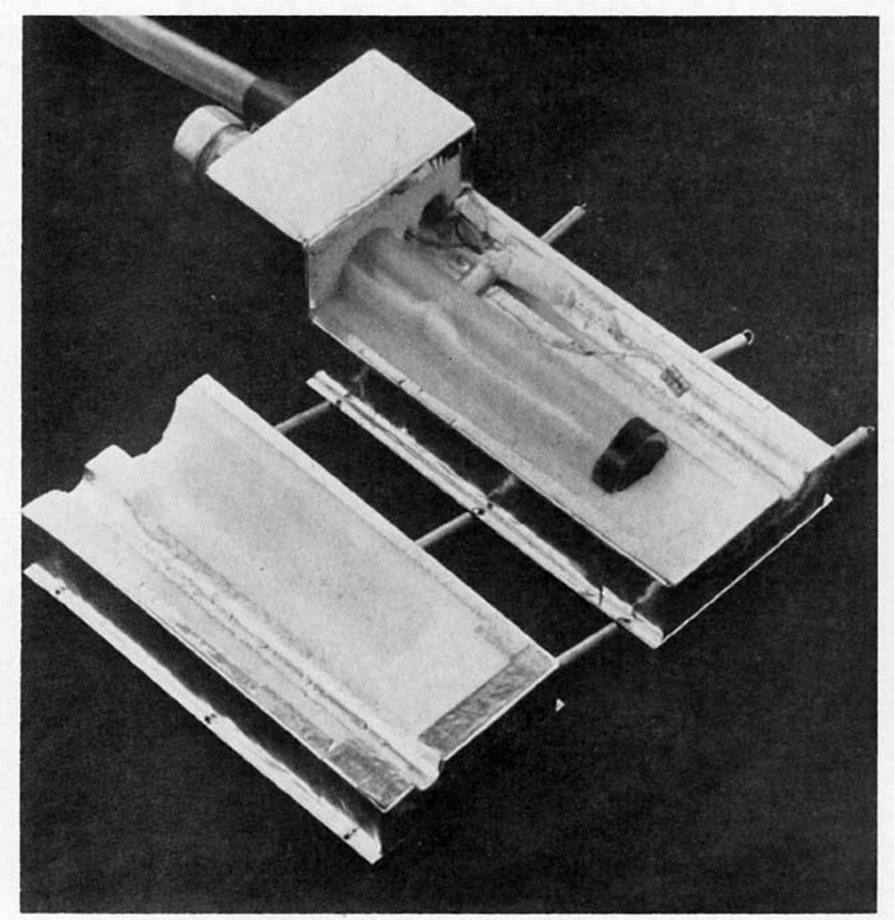

Fig. 1a. Sensor and shield assembly.

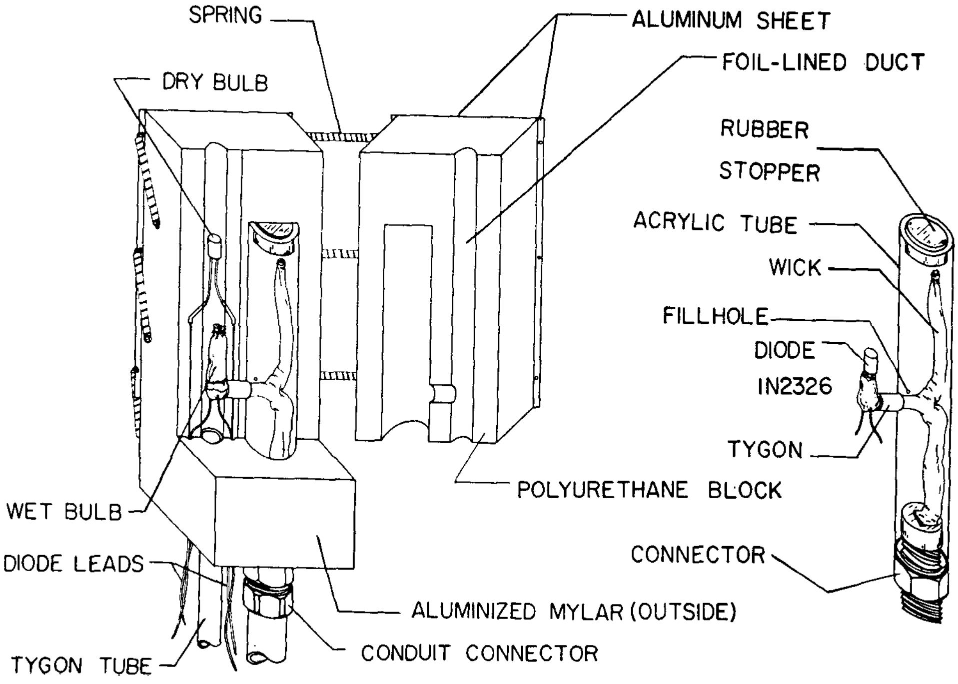

Fig. 1b. Sensor and shield assembly detail.

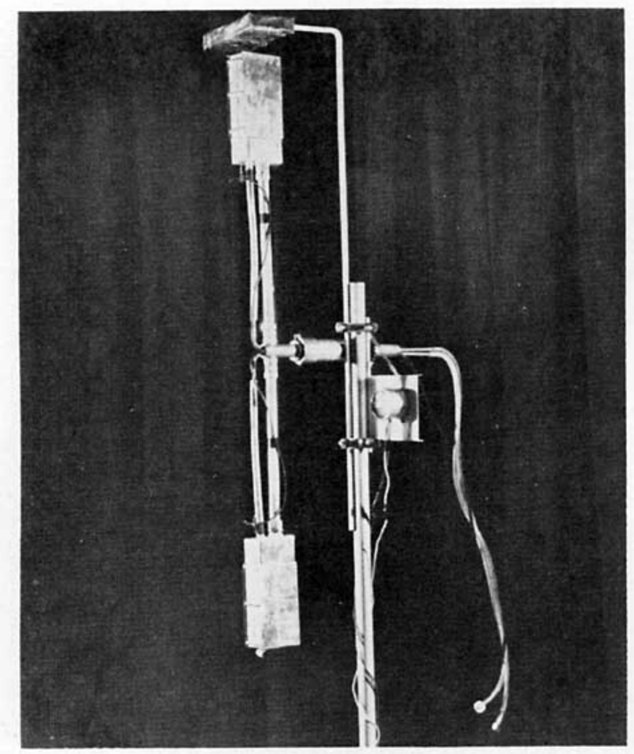

FIG. 2. Bowen ratio apparatus.

U-bolts and may be moved up and down easily. The sensor assembly rotates rigidly back and forth as a "propellor." The assembly is driven against mechanical stops by a reversible motor that can be stalled continuously without damage. This arrangement is much simpler than those used by Suomi (1957) and Tanner (1960), which were designed to keep the sensor ducts pointed toward the ground in order to prevent strong radiation entrance. In our arrangement, radiation entrance into the upper shield is prevented by a fixed sunshade. The sunshade is covered with aluminized mylar on the upper surface and with aluminum foil on the bottom so that the upper sensor also "sees" the ground.

Tygon tubing from the sensor shields connects to copper tubes which feed through the hollow rotation shaft, along with the leads. Aspiration is provided by positive-displacement vane or diaphragm pumps with an aspiration rate of 5 liters $\mathrm{min}^{-1}$ which exceeds that required for maximum wet-bulb depressions. Other drive arrangements have been used successfully, with O-ring belts and other reversible, stallable motors besides the configurations shown. The distance between sensors is varied by changing the length of the conduit arms in the assembly and the tygon tubing. The

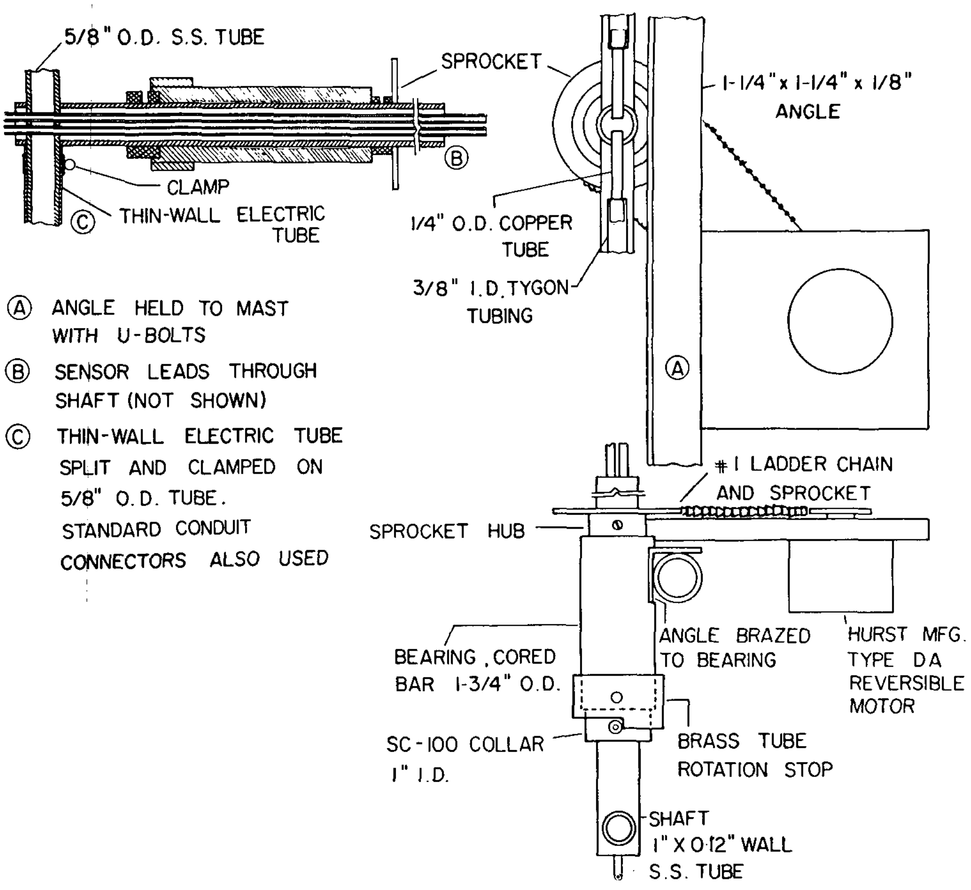

FIG. 3. Reversing mechanism detail.

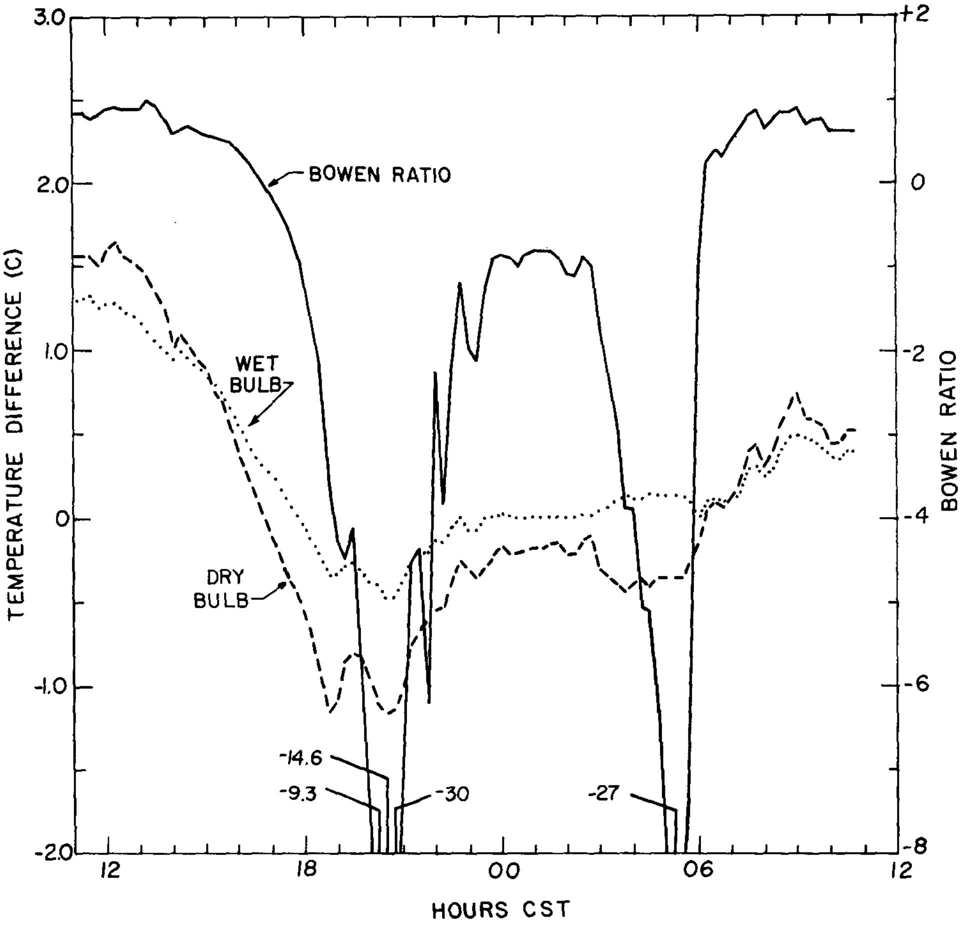

Fig. 4. Typical data plotted as 15-min averages of measurements sampled two times per minute.

vertical duct configuration is useful for all wind directions. The ratio $(\Delta T/\Delta T_w)$ is meaningful despite any ambiguity concerning the exact levels sampled; however, the arrangement is not designed for precise profile measurements.

## 4. Results

Temperature difference measurements have been made at the maximum sensitivity of 2.3 mV(°C)$^{-1}$ and ambient temperature measurements at 0.2 mV(°C)$^{-1}$ to provide sufficient range. The diode measurements

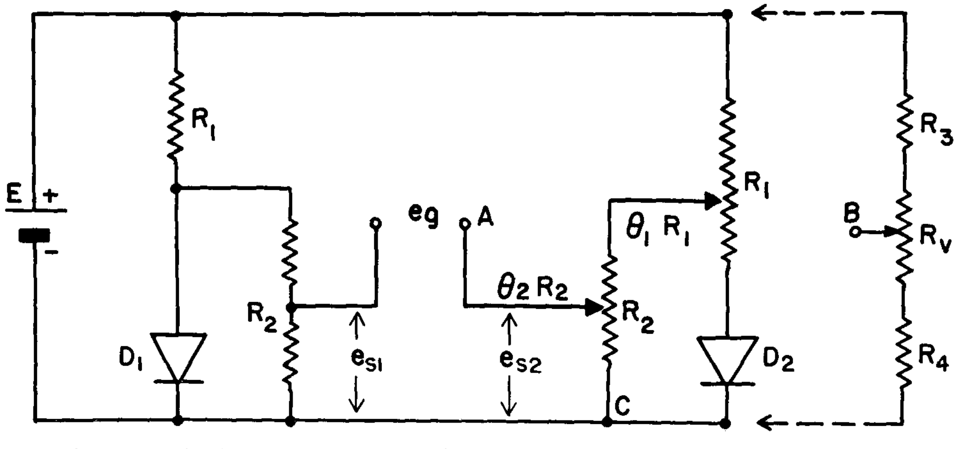

Fig. 5. Typical circuitry. Fine adjustments in gradient zero and zero drift can be made using $\theta_1$ and $\theta_2$, respectively. Appropriate diode selection eliminates $\theta_2$. Temperature signal available between A and B, with range and zero adjustable. Practical values: $E=1.4$ V, $R_1=1\text{k}\Omega$, $R_2=20$ kΩ, $\theta_1 R_1<5\Omega$.

of temperature difference were compared in the field with measurements using a 10-junction thermopile; excellent agreement was obtained. The reservoirs shown require attention at perhaps 6–8 hr intervals during summer conditions. Some typical data are shown in Fig. 4 (26 and 27 August plotted with $\Delta T$, $\Delta T_w$, $B$) in which $\Delta T$ and $\Delta T_w$ were averaged over 15-min periods, the interval of reversal. Relatively smooth and consistent trends of $B$ were found for most periods, even under calm nighttime conditions.

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## REFERENCES

Collins, B. G., 1965: An integrating temperature and humidity gradient recorder. *Principles and Methods of Measuring Humidity in Gases*, Vol. 1, New York, Reinhold Pub. Corp., 83–94.

Fritschen, L. J., and C. H. M. Van Bavel, 1963: Experimental evaluation of models of latent and sensible heat transport over irrigated surfaces. Intern. Assoc. Sci. Hydrology, Berkeley Committee for Evaporation, Pub. 62, 159–171.

Lettau, H. H., 1957: Computation of heat budget constituents of the earth/air interface. *Exploring the Atmosphere's First Mile*, Vol. 1, New York, Pergamon Press, 305–327.

Sargeant, D. H., 1965: Note on use of junction diodes as temperature sensors. *J. Appl. Meteor.*, 4, 644–646.

Suomi, V. E., 1957: Double-psychrometer lift apparatus. *Exploring the Atmosphere's First Mile*, Vol. 1, New York, Pergamon Press, 183–187.

Tanner, C. B., 1960: Energy balance approach to evapotranspiration from crops. *Soil Sci. Soc. Amer. Proc.*, **24**, 1–9.