# RADIOMETERSONDE TECHNICAL MANUAL

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## 1. Introduction

The net radiation normal to the earth's surface is the difference between the total upward radiation flux and the total downward radiation flux. Net radiation is important to many meteorological problems because it is a measure of the energy available at the earth-atmosphere interface. The energy exchange at the earth's surface represents the major input to the giant heat engine which circulates the atmosphere.

A number of instruments which measure net radiation are already available (Albrecht[1], Gier and Dunkle[2], Suomi, Fransilla and Islitzer[3]). Most of them, however, are fairly expensive. As a result there are only a few stations which make net radiation observations, and it is not possible to study the effects of a variable heat input on subsequent weather from these isolated measurements. There are far too few to give anything approaching a representative sample. The purpose of this paper is to describe a net radiometer of moderate accuracy but very low cost. The low cost and simple construction will make it possible to obtain more observations of net radiation over land and ocean both at the surface and in the atmosphere.

If one uses thermistors to measure the temperature of the upper and lower blackened surfaces of such a radiometer, it is possible to telemeter this information in a manner similar to that used to transmit air temperatures in the ordinary radiosonde. By employing very light-weight material for insulation and framework, the net radiometer can be made light enough to be carried aloft by a radiosonde balloon. Figure 1 shows such an instrument which weighs only 90 grams. In order to telemeter air temperature, humidity, and upper and lower surface temperatures a sequencing switch is added, and this is driven by a mechanical clock, or a suitable driving mechanism.

## Operation of Instrument

Figure 2 shows a schematic diagram of the radiometer in vertical cross-section. Briefly, it is a double-faced hemispheric bolometer with broad response blackened sensing surfaces shielded by thin membrans of polyethylene film. Flux evaluations are made for one-half micron spectral intervals, taking into account the "non-flatness" of the black surfaces. Its two sigma absolute error is seven watts per square meter. The thermal resistor sensors modulate the carrier frequency of a U. S. type radiosonde through a pulsing circuit. The mechanical or solid state sequencer provides observations every 100 meters. The instrument is attached to the side of a U. S. Weather Bureau type radiosonde or held a short distance out from the radiosonde. The side of the radiosonde to which the radiometer is attached and facing the radiometer is covered with reflecting aluminum foil.

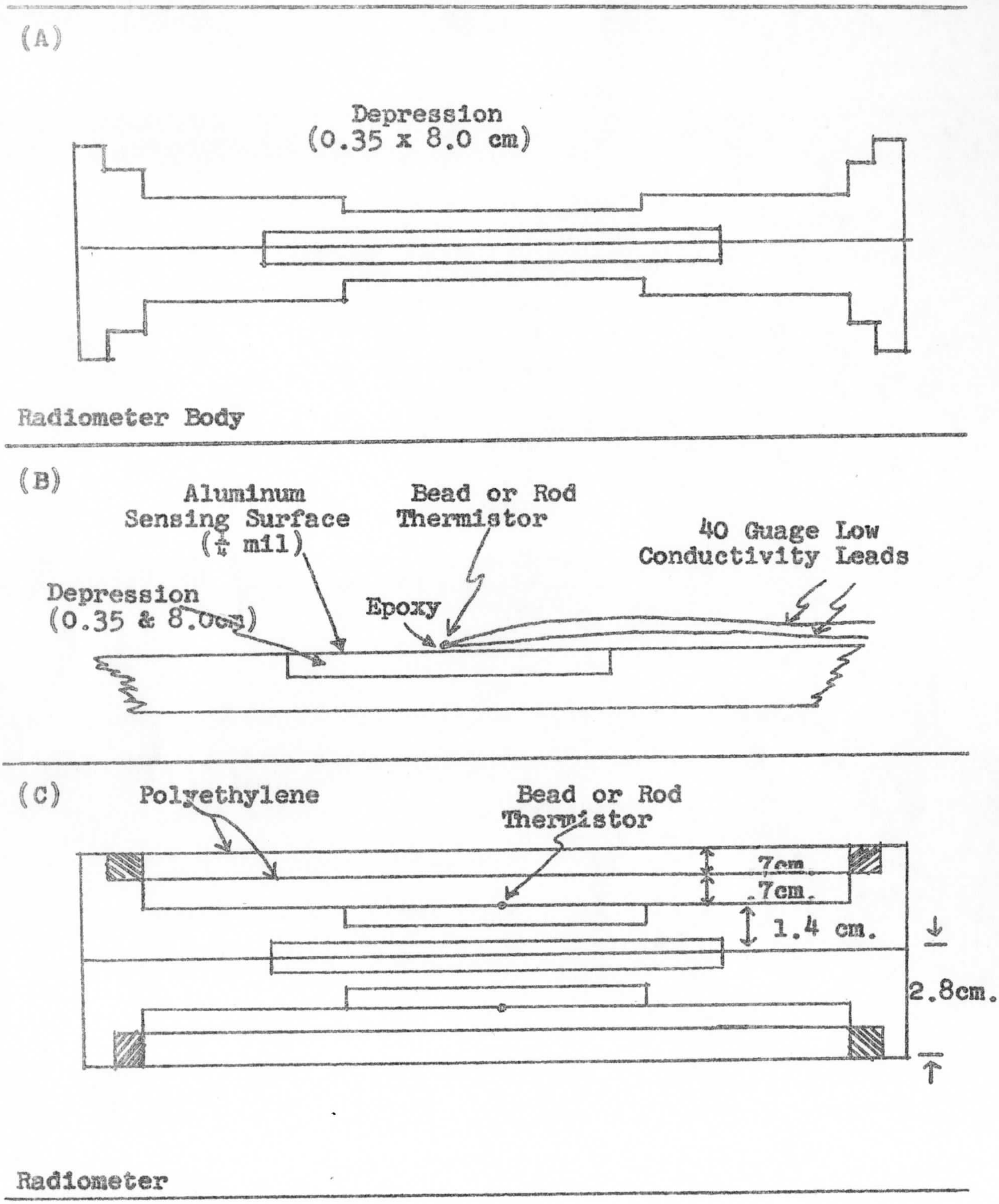

(A)
Depression
(0.35 x 8.0 cm)
Radiometer Body
(B)
Aluminum
Sensing Surface
(¼ mil)
Bead or Rod
Thermistor
40 Guage Low
Conductivity Leads
Depression
(0.35 & 8.0cm)
Epoxy
(C)
Polyethylene
Bead or Rod
Thermistor
.7cm.
.7cm.
1.4 cm.
2.8cm.
Radiometer

FIGURE 2

## 2. Physical Description of Radiometer

The original design of the radiometersonde (Suomi and Kuhn)[4] was changed in 1963 to improve the quality of the measurements. The improved instrument performance over its predecessor has been verified by flight tests.

The new radiometer unit, which is shown in Figure 1 with a modified radiosonde and switching device, is circular in design and is symmetrical about a tiny bead thermistor at its center. In Figure 1, the bead is too small to be seen. Details of the construction of the radiometer can be seen in Figure 2 which shows (A) the radiometer body which is composed of back-to-back identical "trays" made of expanded polystyrene (B) details of how the sensing surface and bead thermistor are attached to the upper and lower surfaces of the radiometer, and (C) the complete radiometer with double polyethylene windows on top and bottom of the sensor.

### A. Modifications

There is no change in the vertical dimensions between the thermistor and polyethylene shields because these are optimum dimensions which are important in suppressing convection (De Graff and Van der Held)[5]. However, beneath the level of the thermistor or air cavity, just below the sensor surface (Fig. 2-A and 2-B) the depression is 0.35 cm deep and 8.0 cm in diameter and is effective in decreasing both vertical conduction, heat capacity and of the sensing surface in the area of the thermistor bead. The other air cavity, the one in the center of the radiometer body, is continued as in the previous model and is divided by a thin, rigid aluminum film.

To further reduce lateral conduction low conductivity, 40 guage leads are used for the thermistors. The thermistors have also been reduced in size in an attempt to shorten the time constant of the sensor; bead thermistors of the type 31CB1 and 41 CB1 are being used. As shown in Figure 2 (B), the beads are cemented with a high conductivity epoxy resin to a thin aluminum sensing surface, 1/4 mil thick, which has its outer surface painted with a high quality flat black paint with an average absorptivity of 90 percent.

The effect of these modifications has been to shorten the time constant considerably. On the previous model the constant was approximately 2.0 minutes, whereas the new model has a constant of 1.0 minute. As a result, we have been able to detect multi-layered clouds on a large number of flights. In addition, it appears that lateral conduction has been overcome on the present model as the downward flux or irradiance approaches zero as ascents reach three to five millibar levels.

B. Thermistor Calibration

The overall accuracy of the measurements has been improved by individual calibration of all of the bead thermistors that are used in the sensors. For the radiometers which are assembled at the University, each thermistor is calibrated in a cold chamber every 10° C over the range from -90° to +30° C.

When a set of resistance and temperature values are obtained for each thermistor by this method, the data is used to determine the best materials constants, β and S, for each thermistor by a Gauss-Jordan least squares regression from the thermistor expression,

$$\frac{R}{R} = \frac{e^{\beta/T}\, T^{-s}}{e^{\beta/T_o}\, T_o^{-s}} \qquad 1$$

The β and S values are used to compute a table of resistance, R, versus temperature, T, at 0.1° C intervals for each thermistor. The tables are also converted to values of radiosonde frequency, F, versus Temperature, T. This has a much more direct application in evaluating the radiometersonde data which are recorded on the radiosonde recorder chart scale from 0 to 100 ordinates. The expression for conversion from Resistance to Frequency values, based on the expression for the frequency versus resistance of the radiosonde modulator circuit, is:

$$f = \frac{F_{ref} \times R_{ref}}{R_{thermistor} + R_{ref}} \qquad 2$$

The resistance of the modulator ($R_{ref}$) is 44.9 kilohms, and the frequency of the modulator ($F_{ref}$) at this resistance is 190 cps (or 95.0 ordinates on the radiosonde record).

The thermistor calibration results in an accuracy of the radiometer temperature data, through the entire system, including processing by machine method, of $\pm$ 0.2$^{\circ}$ C at the 95% level. The random error in flux or irradiance measured by the radiometersonde system is 7 watts per meter squared.

C. Availability of Instruments

The Department of Meteorology, University of Wisconsin, and I.A.S., Environmental Science Services Administration, can furnish a list of commercial suppliers.

## 3. The Radiometer as Part of the Sounding System - Radiometersonde

### A. Assembly of the Radiometersonde

(1) The radiometersonde for the IQSY program consists of a bisic Weather Bureau 1680 MC type radiosonde to which is added a Radiometer. Within the radiosonde is a clock-work-driven switching device that controls the elements to be reported. This sequencer switch is divided into 6 segments consisting of top radiometer temperature, bottom radiometer temperature, meteorology, top radiometer temp., etc. The clock turns the sweeper arm over the segments at 1 revolution per minute. This gives dwell times on the various segments of 3 sec., 3 sec., 24 sec., 3 sec., etc., respectively. When the sweeper arm is on meteorology, the baroswitch controls the elements to be reported; that is, pressure reference contacts, air temperature and humidity report as on a regular radiosonde. However, when the sweeper arm of the sequencer rests on top or bottom radiometer temperature, these elements interrupt what normally is reporting from the baroswitch. At times this will result in interrupted reference contacts or the masking of the start or ending of a reference contact. Particular care must be exercised when evaluating the records to insure proper identification of the reference contacts because of this interruption.

(2) The Radiometer consists of a polyethylene-faced, circular shaped polystyrene frame which is attached to the radiosonde such that the circular faces are horizontal during flight and such that one face is directed upward and the other downward. Each face is covered with transparent polyethylene; if the polyethylene is accidentally punctured, it should be patched, using transparent scotch tape.

(3) The radiometer is attached to the radiosonde with radiosonde or masking tape in a horizontal position with the plate marked T facing upwards. The male plug of the radiometer is inserted into the female plug at the side of the radiosonde.

B. Preparations for Radiometersonde Observations

(1) The tracking, receiving, and recording equipment will be prepared for the observation in a manner similar to that for a radiosonde observation.

(2) The balloon will be conditioned and inflated similarly to one for a radiosonde observation, except that 200 grams of additional lift, over that specified in Circular P, should be provided to offset the weight of the radiometer and clock. The train should be 100 feet in length and assembled in the same manner as for a routine observation. The 100 feet can be attained by using two train regulators.

(3) The radiosonde and radiometer should be carefully removed from their shipping cartons. The radiosonde will be inspected and tested. Carefully remove the cardboard

shielding from the radiometer and inspect it for any visible defect or damage. Check the radiometer for electrical continuity. The blue lead is common to the top and bottom thermistore. The orange lead comes from the bottom thermistor (nominally 10,000 ohms at 25.0° C). The white lead comes from the top thermistor (nominally 1000 ohms at room temperature). Record the following information on the recorder record:

a. Serial number of the radiometer
b. Serial numbers of the thermistors
c. Any other calibration data printed on the radiometer such as resistance versus temperature information.

(4) Carry out the usual baseline check on the radiosonde, including the setting of the pen arm. You will notice a female plug on the right side of the modulator. There may be a piece of red wire across the solder lugs to the terminals. If there is, continue with the baseline check. When completed, cut the red wire across the terminals before inserting the male plug from the plate. If this wire isn't cut, you will not be able to receive radiation data.

(5) However, if you notice that the terminals of the plug at the side of the radiosonde do not have this shunt wire, insert a male shunt plug that has been provided. Continue the baseline check. When completed, remove the shunt plug and insert the male plug from the plate.

(6) Wind the clock and check for continuity of the plate. You should receive TOP PLATE, BOTTOM PLATE, and

METEOROLOGY. Record several sequences to determine the quality of the signal. If the signal is erratic, the cause may be a dirty contact surface in the clock. Clean the surface with tissue used to clean the comutator bar of the radiosonde, or by some other means. The signal should then transmit satisfactorily. If it doesn't, trouble shoot the plate or select another.

(7) Using radiosonde or masking tape, securely fasten the radiometer to the radiosonde box, making sure that the circular faces are horizontal and that no tape adheres to the transparent polyethylene covering the radiometer faces.

(8) When attaching the radiometersonde to the flight train, adjust the length of one of the two leveling strings fastened to the top of the radiosonde box so that the instrument will remain level during flight. Cut off the unused string. The wires leading to the radiometer should be taped to the side of the radiosonde opposite the filament and test leads.

(9) The radiometersonde shall now be placed outside on a 5 foot stand so that the radiometer plate is horizontal. Turn on the radiosonde recorder and obtain a record of the conditioning. This will be a measure of the radiation at the surface. After about 15 minutes the radiometersonde will have been conditioned to the outside temperature and is ready for release.

C. Evaluation of the Recorder Record

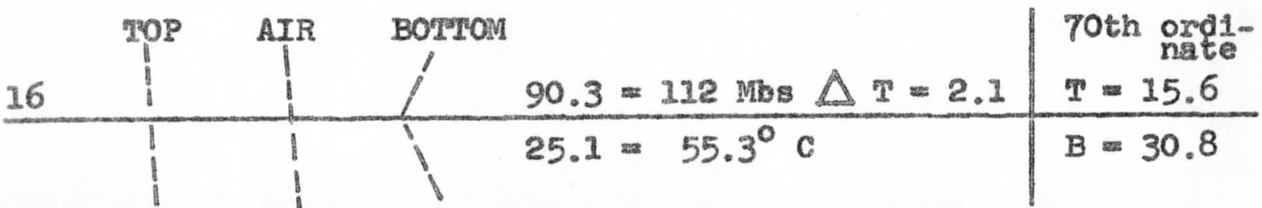
(1) It is not necessary to re-evaluate the humidity

trace for levels selected on the basis of the radiometer temperature.

(2) The TOP, AIR, and BOTTOM temperature traces will be separately evaluated for every minute.

(3) The time between levels selected will be measured to the tenth of a minute.

(4) Entries on the recorder record for each level should be made as indicated:




(5) On a separate sheet of paper, which will be attached to the recorder record, summarize the data for each level selected.

## 4. Radiation Equations

The formulae for evaluating upward, downward and net flux from radiometer temperature observations appear as equations (1) through (6), following. Symbols in the equations are listed below in their order of appearance.

| Symbol | Definition |
|---|---|
| $F\downarrow$ | Downward flux (Irradiance) |
| $T_t$ | Top sensor observed Temperature |
| a | Absorptivity of Block Surface |
| L | Reflectivity of Polyethylene film |
| $k_i$ | Thermal Conductivity internal cells |
| $k_t$ | Thermal Conductivity of top air layer |
| $T_b$ | Bottom sensor observed Temperature |
| D | 2.8 centimeters vertical distance between sensors |
| d | 1.4 centermeters vertical distance between top and sensor |
| $dT_t$ | Incremental temperature change |
| dT | Time increment |
| $F\uparrow$ | Upward flux (Irradiance) |
| $k_b$ | Thermal Conductivity of bottom air layer |
| $\lambda$ | Thermal lag |
| $T_t$ | Equivalent Top Radiation Temperature |
| $T_b$ | Equivalent Bottom Radiation Temperature |
| $F_n$ | Net Radiative FWX (Net Irradiance) |

WEATHER BUREAU RADIOMETER PROGRAM

## Basic Equations

1. $F\downarrow = \sigma T_t^{4} + (^1/(a(1-aL)))(-k_1((T_b-T_t)/D)-k_t((T_a-T_t)/d) + \lambda \frac{d\ T_t}{d_t}) = \sigma T_T^{4}$

2. $F\uparrow = \sigma T_b^{4} + (^1/(a(1-aL)))(+k_1((T_b-T_t)/D)-k_b((T_a-T_b)/d) + \lambda \frac{d\ T_b}{d_t} = \sigma T_B^{4}$

3. $F_n = F\uparrow - F\downarrow = \sigma T_B^{4} - \sigma T_T^{4} = \sigma (T_B^{4} - T_T^{4})$

where $\sigma = .817 \times 10^{-10}$ cal cm$^{-2}$ min$^{-1}$ deg (A)$^{-4}$

TEMPERATURES IN $^{\circ}$ Centigrade

NOTE: .01 cal cm$^{-2}$ min$^{-1}$ 7 watts meter$^{-2}$

## Conduction Terms

. $(^1/a(1-aL)))(k_1 \frac{T_b - T_t}{D} \cong \left(\frac{1.45\ (1.06(\overline{T}\ (^{\circ}C) + 273.) + 59.00)(10^{-5})}{2.8}\right)(T_b-T_t)$

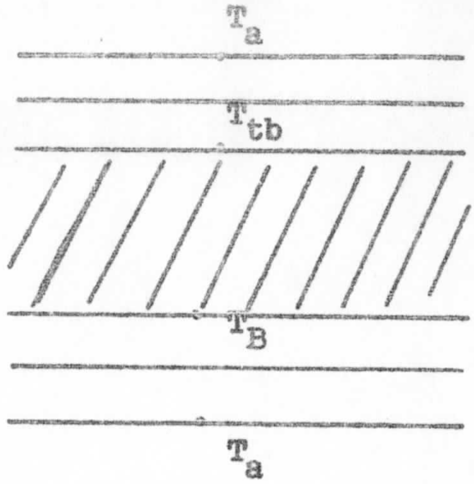
$\cong ((.0000054892853)(\overline{T}) + .0018041107)(T_b-T_t)$ where $\overline{T} = (T_b + T_t)/2$

5. $(^1/(a(1-aL)))(k_t \frac{T_a - T_t}{d}) \cong ((.0000109785706)(\overline{T}) + .0036082214)(T_a-T_t)$

where $\overline{T} \cong (T_a + T_t)/2$

6. $(^1/(a(1-aL)))(k_b \frac{T_a-T_b}{d} \cong ((.0000109785706)(\overline{T}) + .0036082214)(T_a - T_b)$

where $\overline{T} = (T_a + T_b)/2$




and

$$k_{tn + nb} = (1.06\ \bar{\bar{T}}\ (^{o}a) + 59.00)\ (10^{-5})$$

$(\overline{\quad\quad})$ ≡ Average

<u>Lag</u> <u>Terms</u>

$1/(a(1-aL)) = 1.45$

$(1.45)\ (\lambda)\ (dT_{tnb}/dt) = (.01015)(dT_{tnb}/dT)$

<u>Cooling</u>

$$\frac{\sigma T}{\sigma t}\ (^{o}C/day) = ((-g)/Cp))\ ((F_{n_{upper\ SFC}} - F_{n_{Lower\ SFC}})/(\Delta p))^{-1}$$

$$x\ 1440\ min/day = (-4100.4184)((R_{NO} - R_{NL})/\Delta p))$$

For the Record:

a = absorptivity of black sensor = .88

L = absorptivity of ½ mil (.0005 inch) = .22
polyethylene film

Further

Enter with temperatures in $^{o}C$

Exit with Radiation in cal $cm^{-2}$ $min^{-1}$ or watts $meter^{-2}$

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