The ANL 403 MHz Radiosonde System[1]

R. L. HART, F. R. GEORGE, L. S. VANLOON, B. B. HICKS AND F. C. KULHANEK

Argonne National Laboratory, Argonne, Ill. 60439

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ABSTRACT

A new radiosonde system considerably improves the detection of fine temperature structure in the lower atmosphere. Special features of the system include a simple, inexpensive radiosonde which uses a monolithic timer in a rapid-response, temperature sensing audio oscillator circuit, a receiver which uses an integrated-circuit phase-lock-loop to track the audio-frequency pulses, and a simple, barometric release mechanism. The system has been used extensively in recent field investigations of the planetary boundary layer.

1. Introduction

Recent emphasis on problems concerning atmospheric pollutant transport over distances of the order of 1000 km in the United States, Canada, and Europe has resulted in increased interest in the fine structure of the lower atmosphere, particularly in the diurnal cycle of the planetary boundary layer (PBL). The rates of transport, dispersion, and chemical transformation of certain pollutants are affected considerably by

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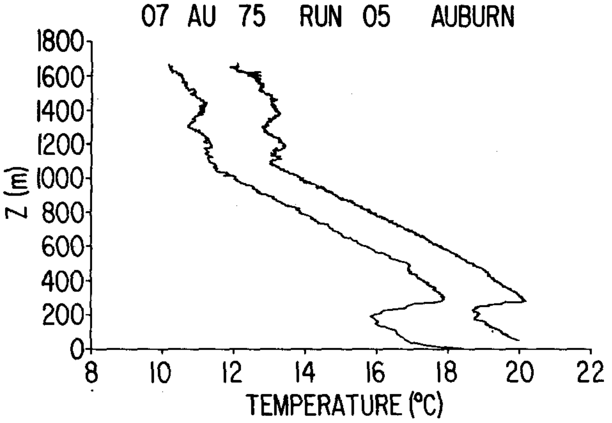

FIG. 1. An example of an ascent and descent temperature profile obtained from a single radiosonde run. The descent profile has been offset +2.0°C to prevent obfuscation. Erosion of the inversion due to surface heating occurred during the 20 min flight time.

the fine structure, especially the type and extent of vertical stratification of flow in the lower atmosphere. Programs such as the U. S. Energy Research and Development Administration's Multistate Atmospheric Power Production Pollution Study (MAP3S) and the U. S. Environmental Protection Agency's Midwest Interstate Sulfur Transformation and Transport (MISTT) study include experimental investigations to document the properties of the PBL that affect the transport and dispersion of pollutants.

To complement more conventional monitoring techniques of the PBL, new radiosonde instrumentation has been developed for obtaining temperature measurements with an accuracy better than 0.4°C, a resolution of better than 0.05°C and a time constant of 2.7 s. When used in conjunction with the automatic, double-theodolite, balloon-tracking system (i.e., the WHAT system, for wind, height, and temperature, as reported by Frenzen *et al.*, 1973) which records the data digitally on computer-compatible magnetic tape at one second intervals, the new radiosondes have yielded temperature profiles with 3 m height increments for a 3 m s^{-1} rise rate.

When the radiosondes reach a predetermined altitude, they are released from the balloon by the mechanism (described in Section 4) and allowed to descend back to earth by parachute. In this manner two consecutive profiles may be obtained using a single radiosonde. Typical temperature ascent and descent profiles obtained using the radiosonde and WHAT systems are shown in Fig. 1. These profiles are considerably more detailed than those obtained with conventional radiosondes, which typically transmit a temperature signal intermittantly at 100 to 150 m intervals below 2 km. While standard radiosondes have similar accuracy, resolution, and time constant to the type being presented here, the Argonne National Laboratory (ANL) type are smaller, considerably less expensive, and transmit the temperature information continuously.

The new instruments have been used in two recent field studies of the PBL as a part of the MAP3S and MISTT programs. In this paper some aspects of the new radiosonde system are described.

2. Radiosonde design

The ANL radiosonde, a variation of a simple 403 MHz transmitter originally designed by workers of the Atmospheric Environment Service of Canada (AESC), utilizes printed circuit boards which allow mass production by nontechnical personnel. The original design has been modified to reduce the temperature sensitivity of the audio oscillator circuitry and to extend the useful range of the transmitter.

Fig. 2 shows a diagram of the circuit. The audio-frequency generator consists of a monolithic timer of the 555 type, a 4.7 kΩ metal film resistor, a 0.0047 μfd polycarbonate capacitor, and the temperature sensor. The use of an integrated circuit timer, which exhibits reduced temperature sensitivity when compared to the unijunction transistor used in the original design, and a metal film resistor and polycarbonate capacitor, both of which have approximately 50 ppm per °C temperature coefficients, results in a frequency error in the audio output due to temperature of about 0.04% per °C. This frequency error corresponds to about 0.01°C apparent temperature error per °C. Since the radiosondes are normally exposed to temperature variations of up to 20°C, they are packaged in light-weight polystyrene insulating containers to minimize these errors. To obtain rapid response and to minimize self-heating errors in the sensors, 1 mm diameter, 100 kΩ bead thermistors are used. The thermistors, which are exposed to direct sunlight, are coated with white acrylic paint to reduce solar heating errors. Depending upon the amount of solar radiation, these errors may still be as large as 0.2°C. A 3 m s^{-1} ascent rate provides sufficient ventilation for the sensor to exhibit a 2.7 s time constant.

The frequency output of the timer, typically 1.5 kHz at 25°C, is inversely proportional to the RC time constant of the thermistor and the polycarbonate capacitor. Since components with 15–20% tolerance are used, the calibration of each circuit is different. A one-point calibration of frequency f_0 (Hz) versus temperature T_0 (K) obtained just prior to launch allows computa-

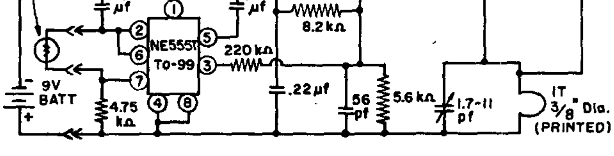

FIG. 2. The circuit diagram of the miniature radiosonde currently in use at Argonne.

tion of the temperature T from the frequency reading f by use of the formula

$$\frac{1}{T}=\frac{1}{T_0}+\frac{1}{\beta}\ln(f_0/f).$$

The constant β, typically 3890 for the Fenwall GA51J1 sensors being used, enters through the thermistor-resistance relation

$$R_T=R_0\exp\{\beta[(T^{-1}-T_0^{-1}]\},$$

where R_T is the resistance at temperature T, and R_0 the resistance at temperature T_0.

The output of the audio-frequency generator is, to some extent, a function of voltage supplied by the battery. As the current drawn by the radiosonde is at the rather high value of about 40 mA, a battery suitably small and lightweight will decrease in voltage once activated. Alkaline cells exhibit a lower rate of battery voltage drop under this type of load than do conventional carbon-zinc batteries. Use of a 9 V alkaline transistor radio battery of the MN1604 type results in a predictable drift in the audio frequency with time, a 1.1% decrease per hour.

To keep the design simple and inexpensive, the radiosonde has a single-transistor radio-frequency oscillator/transmitter which radiates only a few hundred milliwatts of power. The transmitter is modulated by the pulse output of the audio-frequency generator. The only modification of the original AESC design of the transmitter portion of the radiosonde has been in the tank circuit. Replacement of a two-turn, hand-wired coil and a trim inductor with a one-turn coil printed on the circuit board not only simplified construction, but also increased the range of the transmitter by improving the impedance match to the end-fed, half-wave antenna (see Fig. 3). The tank tuning capacitor is of the air-variable type. Although this combination results in some difficulty in tuning the transmitter to the proper frequency because of the coarseness of the adjustment, the capacitor is an inexpensive, commercially available component which performs satisfactorily in the present application.

3. Receiver system

As the transmitter utilizes a "whip" antenna and emits a weak signal, a high-gain directional receiving antenna such as a vertically-mounted yagi should be used. Orientation of the receiving antenna with a television rotor eases the task of tracking the transmitter package. Although the transmitter is subject to drift in carrier frequency, which is a function of both battery voltage and temperature, no difficulties are encountered in reception using a wideband receiver such as the Metrodata MR17B. However, this receiver is not designed to handle the type of modulation that is used by the ANL radiosonde; therefore, a signal conditioner, which utilizes a "phase-lock-loop" to track the audio frequency output from the FM detector, has been added.

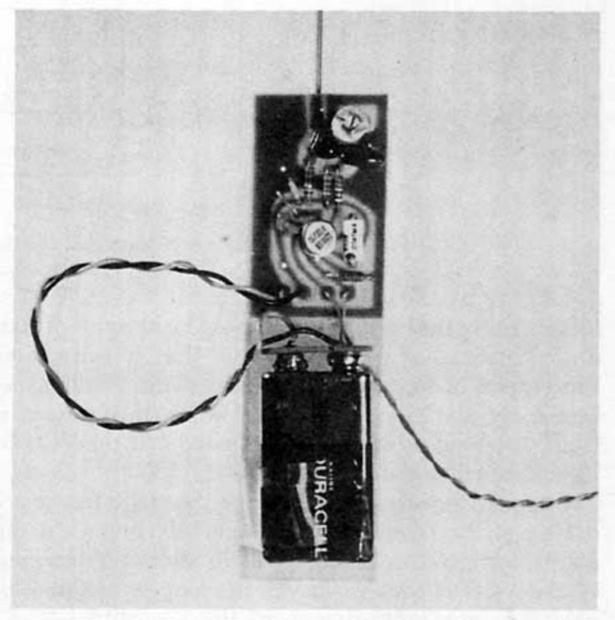

FIG. 3. The ANL miniature radiosonde in ready-to-fly form. The one-turn, printed coil located in the upper-right corner of the circuit board is partially obscured by the air-variable capacitor. The lower portion of the antenna can be seen extending from the top of the circuit board. The other end of the antenna, which is not shown, has a small loop for attaching to the parachute and balloon.

A block diagram of the signal conditioner is shown in Fig. 4. The signal from the FM detector is first amplified and limited, the latter removing any large noise spikes. The phase-lock-loop contains a voltage-controlled oscillator (VCO), a phase detector, and a low-pass amplifier. The phase detector compares the frequency of the input signal with that produced by the VCO. The resultant error signal, which is amplified and filtered to remove any high frequency components, is used to drive the VCO frequency towards that of the input signal. An additional error signal amplifier is used to control the VCO's center frequency, the frequency range over which the circuit will be able to lock onto the signal (the capture range), and the time required to achieve lock. A front panel control allows manual adjustment of the VCO's center frequency to a value near the input frequency.

The circuit described above will lock onto the frequency of a strong input signal and reject any high-frequency noise. As the signal gets weaker, however, the circuit may drop out of lock and, if the input is outside of the loop's inherently narrow capture range, not be able to re-establish lock. A sweep generator will then drive the VCO above and below its natural frequency until the singal is within the circuit's capture range. This provision reduces the need for readjustment of the VCO's center frequency. When the loop is

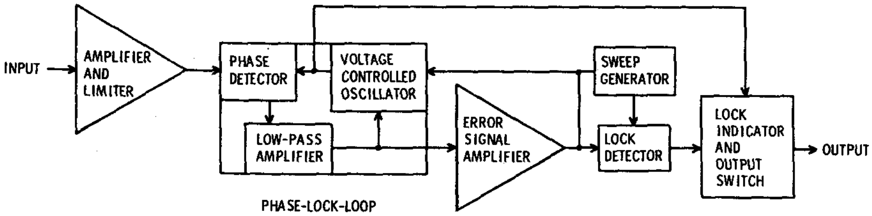

FIG. 4. A block diagram of the signal conditioner used with the Metrodata MR17B receiver. The input is taken from the receiver's FM detector.

locked onto the input frequency, the output of the error signal amplifier will be such that it will cancel the output of the sweep generator. This "nulling" is sensed by the "lock detector," which then causes a front panel indicator to be illuminated and the VCO to be connected to the system output.

Using a phase-lock-loop to track the audio-frequency output of the receiver has substantially improved the ability to recover a weak signal. In addition, disabling of the VCO output whenever the loop is not in lock gives a reliable indication of the signal quality.

4. Release mechanism

For routine operation in the PBL, the radiosondes have been used in a "structure-sonde" mode, i.e., they are released automatically from a rising balloon at some predetermined altitude in order to obtain two profiles consecutively through nearly the same layer of the lower atmosphere. The release mechanism (Kulhanek, 1975) consists of a sealed, one-ounce polyethylene bottle with a plastic tube extending from the bottom to approximately 15 cm above the cap. A special water-soluble paper[2] is fastened to the top of the tubing with a pin or paper clip and to the balloon string with a small battery clip. As the radiosonde package ascends, the lowering atmospheric pressure causes the air in the bottle to expand. This forces the water up the tubing to wet and dissolve the paper, which results in a disconnection of the balloon from the parachute and radiosonde, releasing them to slowly descend to the surface. By use of different lengths of tubing or different initial volumes of air in the bottle, the mechanism can be made to release at various altitudes. Calibration of the release altitude can be performed in a partially evacuated chamber.

5. Conclusions

The circuits described above have been used at ranges up to 20 km in several experiments in recent years (e.g., see Hess *et al.*, 1975). The data recorded on magnetic tape in the field has been analyzed with the use of a computer to produce considerably higher-resolution vertical profiles of wind components and temperature than can be obtained using conventional radiosonde techniques.

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[2] Such as that which can be obtained from Edmond Scientific Company, 300 Edscorp Building, Barrington, N. J.