DESIGN AND EVALUATION OF A PROTOTYPE HIGH PRECISION TEMPERATURE TELEMETRY SYSTEM

by

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LIST OF SYMBOLS

C	temperature in degrees Celsius
Hz	frequency in cycles per second
K	factor of 10^3
M	factor of 10^6
a	current in amperes
cc	volume in cubic centimeter
f	inductance is farad
m	factor of 10^{-3}
mm	distance in millimeters
p	factor of 10^{-12}
v	voltage in volts
Ω	resistance in ohms
μ	factor of 10^{-6}

I. INTRODUCTION

Thermoregulatory models of mature adults have been developed using the well established theory of hypothalmic temperature control about a set point. Experimental investigations have indicated that thermoregulation in newborn infants is different than that of mature adults. Thermoregulatory models require precise repeatable hypothalmic temperature data to which they can be compared and improved. The 0.1C or less oscillations of the hypothalmic temperature about its set point indicates the precision of temperature sensing and control in the human body. Measurement capabilities of 0.02C change in hypothalmic temperature are considered adequate to verify sophisticated adult models and to generate dependable data for development of newborn infant thermoregulatory control models.

The purpose of this thesis is to document the precision of the prototype temperature telemetry system developed. This will be accomplished by exploring the physiological and experimental background of thermoregulation, describing the prototype device which was developed and finally by evaluating its performance as a method of precise physiological temperature measurement.

II. MOTIVATION FOR DEVELOPMENT

Physiological Background

The hypothalmus is a portion of the brain which controls body activities such as maintenance of water balance, sugar and fat metabolism, secretions of endocrine glands and regulation of body temperature (1). The temperature regulating center of the hypothalmus is located in the preoptic and adjacent regions of the anterior hypothalmus and is called the thermostatic center (2). This center controls body temperature by altering both the rate of heat loss from the body and the rate of heat production in the body.

The thermostatic center set point is not a fixed value but may vary from animal to animal and within one animal as different physiologic abnormalities such as fever, dehydration, or underdeveloped hypothalmus occur. Hypothalmic temperature normally will vary no more than 0.1C from the hypothalmic set point temperature (3). Therefore, change in hypothalmic temperature is the critical variable to be measured. When a physiologic abnormality causes a sudden rise in the hypothalmic set point, the hypothalmus senses the temperature difference between the set point and its actual temperature. It then initiates vasoconstriction and increased cell and muscle metabolism to correct the temperature difference. The hypothalmic temperature is now maintained at the new hypothalmic set point temperature. If for some reason the hypothalmic set point temperature suddenly decreases, the hypothalmus senses that it is at a higher temperature than the set point and initiates vasodilation and sweating in order to cool the hypothalmus to the new hypothalmic set point.

A familiar example of the hypothalmic set point phenomenon is in order. A fever infection of the body causes the hypothalmic set point to rise. The victim of the fever feels cold and experiences chills until the temperature of the hypothalmus is increased to that of the set point. The patient then feels normal but his measured temperature is above normal. When the infection is eliminated, the hypothalmic set point drops to its original value and the patient feels hot and begins sweating. This sudden sweating was termed the crisis of the illness because the physician knew that the body temperature would soon return to normal and the patient would return to good health.

Literature Review of Thermoregulation

Mathematical and computer models of hypothalmic thermoregulation in the mature adult are numerous in the literature (4, 5, and 6). However, thermoregulatory models of newborn infants are not available in the literature reviewed. Mestyan and Varga (7) concluded that newborn infant thermoregulation is different from adult thermoregulation. The internal temperature of newborn infants, particularly premature infants, was found to drop 2C immediately after birth and return to a poorly regulated but normal temperature in about eight hours (2). Poor temperature regulation may last from 10 to 12 days after birth. Change in the rectal temperature of 0.2C may result in 100% increases in O_2 consumption in pre-mature infants (7). Such physiological occurences can be better understood through neonatal thermoregulatory modeling. Both mature and immature thermoregulatory models must be verified by repeatable experimental data.

The internal temperatures measured in the above experimental investigations are generally rectal or skin surface temperatures. Hypothalmic temperature measurement is of primary importance as a thermoregulatory control center. Rectal, skin and other body temperatures are followers of hypothalmic thermoregulation (8). In rhesus monkeys, tympanic membrane temperature has been shown to follow 0.5C below actual hypothalmic temperature with a small time lag (9). Tympanic membrane thermometry with a precision of ± 0.02C has successfully been used by Benzinger (8) and others in extensive studies of the mature thermoregulatory system. Precise measurement of all body temperatures is required to verify and compare models and data of other researchers in the literature.

Thermoregulatory Model Verification

For development and verification of newborn infant thermoregulatory models, tympanic membrane temperature data of newborn infants is desired. Unfortunately, newborn infants and newborn infant hypothalmic temperature data are not available for thermoregulatory model verification. Newborn lambs are comparable in size and weight to newborn infants and are available locally.

Personal observation of a newborn lamb being cleaned, fed and cared for by the ewe revealed that hard-wire telemetry would necessitate physically restricting the motion of the lamb in order to avoid entanglement in the wires. Battery powered radio telemetry promised to be the most practical method of data transmission. The 2.5 cc internal volume of a newborn lamb outer ear required that the temperature telemetry device be very small with additional space available on a neck collar. Telemetry distances on the order of 5 meters were required in order to preserve the natural lamb-ewe relationship and lamb freedom of movement in the approximately 2 meter by 1 meter lambing pen. Data gathering periods of approximately one week would be adequate to establish a newborn lamb tympanic membrane temperature history.

Temperature telemetry devices which will meet the thermoregulatory model verification criteria are available through special order commercially (10) and are in the telemetry literature (11, 12, 13, 14). A temperature telemetry device developed by NASA at the Ames Research Center (11) has a precision of ± 0.05C, is totally implantable and can operate for 3600 hours. Because of its very small size and correspondingly small battery power supply, it must be used in a shielded, nonconductive cage of 5 cu ft or less.

III. DESIGN OF THE HIGH PRECISION TEMPERATURE TELEMETRY DEVICE

Introduction

The prototype temperature telemetry system developed is shown in the block diagram representation of Fig. 1. Two 5 megohm @ 25C thermistors exhibit a decrease in resistance for an increase in temperature. A decrease in thermistor resistance causes an increase in the multivibrator frequency. Frequency and amplitude of the multivibrator wave form are frequency modulated onto the carrier frequency of the FM transmitter. The FM receiver demodulates the carrier frequency encoded information to produce the final wave form information of amplitude and frequency. A Hewlett-Packard 5223L timer counter measures the frequency of the received wave form. An oscilloscope is used to tune the receiver to the proper FM band carrier frequency. The telemetry device also incorporates a voltage regulated battery power supply.

Device Specification Goals

The schematic diagram of the temperature telemetry device is shown in Fig. 2. Components of the device were selected with the goal of achieving a device precision of ± 0.02C over a nominal temperature range of 35 to 40C. Selection of components was also limited by the general field application requirements of a device size of 2.5 cc ear space plus minimum collar space, approximately one week operating

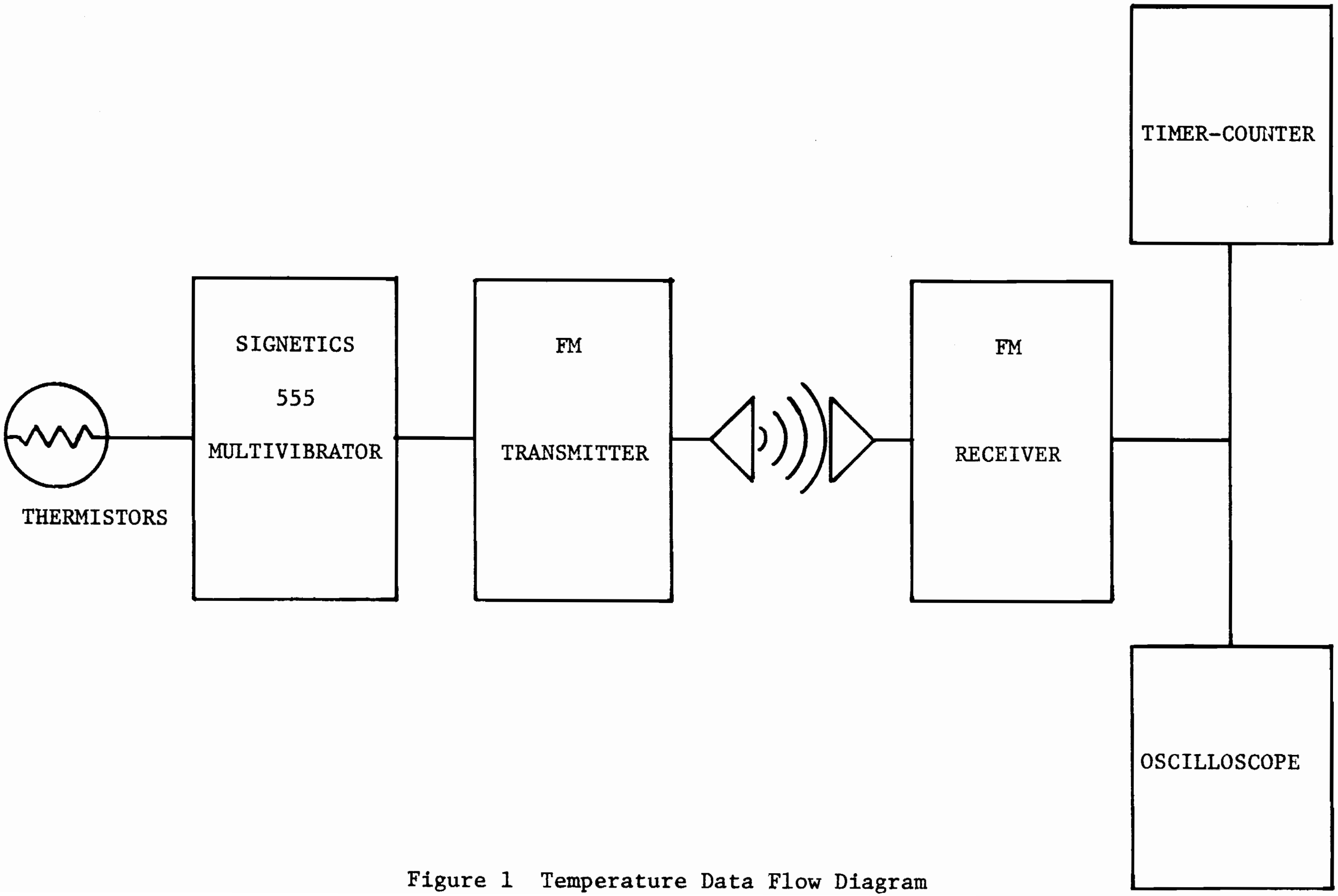
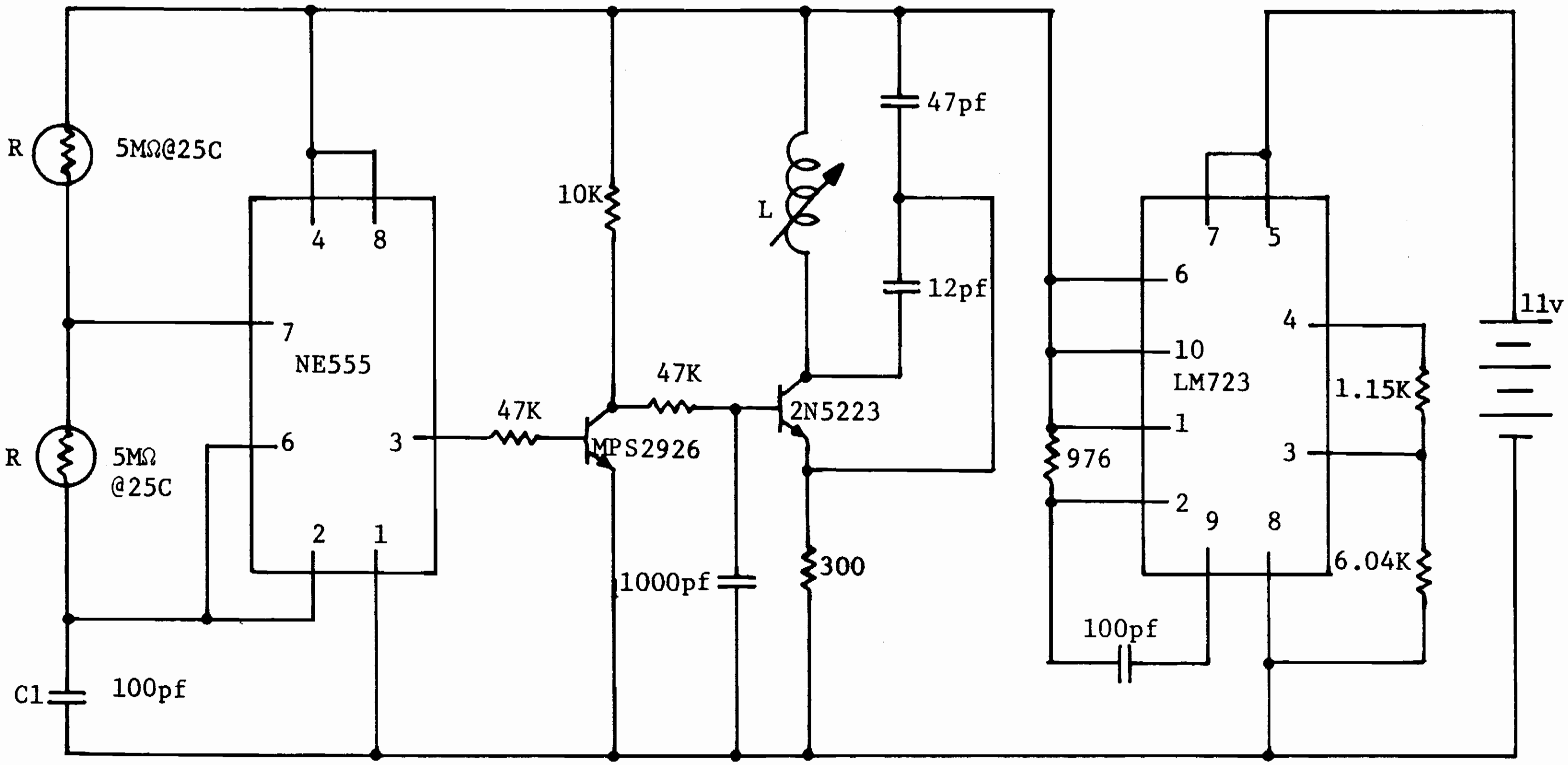


Figure 1 Temperature Data Flow Diagram



L = 4 turns #22 enamel wire 8 mm diameter with variable position ferrous slug core.

Figure 2 Temperature Telemetry Device Schematic time, and data telemetry distances of 5 meters or more.

Component Selection Criteria

Component selection required the interpretation and evaluation of individual component manufacturer's specifications. The precision of poorly specified components was determined by installing them in the circuit and evaluating the overall circuit. Regardless of component specifications or recommendations, the final decision of whether to use a component or not was based on achievement of the device specification goals of ± 0.02C precision and general experimental utility in the field.

The two Fenwall GA65MC1 5 megohm @ 25C thermistors labeled "R" in the schematic of Fig. 2 were chosen for their small size, high sensitivity, high resistance, high precision and long-term stability. The bead thermistor size selected has dimensions of 12.7 mm long by 2.54 mm diameter. Thermistor sensitivity is measured as the ratio of resistance at 50C to resistance at 0C. The manufacturer specified sensitivity ratio of 11.8:1 is the maximum sensitivity available at the time for a 5 megohm @ 25C resistance. This sensitivity is very high in comparison to other thermistor sensitivity ratios. The 5 megohm @ 25C nominal resistance of the thermistor required less than 1 microamp current at the regulated voltage of 6.019 volts. The heat dissipation factor specified by the manufacturer of 1 milliwatt/C insured thermistor self-heating of less than 0.005C. Precision and long-term stability specifications are well documented by the manufacturer (15). A thermistor temperature sensor was chosen over the more precise electrical resistance thermometer because of the expensive readout equipment required for high precision measurement. All other available devices could not meet the tympanic membrane thermometry precision requirements of ± 0.02C (16).

The Signetics NE555 is a monolithic timing circuit which when connected as shown in the schematic of Fig. 2 operates as a multivibrator. The frequency of the device is determined by the equation

$$f = 1.44/(3)(R)(C1) \qquad (1)$$

where, C1 refers to the capacitance of the timing capacitor shown in Fig. 2. An increase in thermistor temperature decreases the thermistor resistance which increases the frequency of the multivibrator. The amplitude of the multivibrator squarewave remains constant.

The method of frequency encoding the thermistor temperature data with the multivibrator was chosen for its inherent digital accuracy over analog bridge circuit voltage amplitude encoding. Once the multivibrator frequency for a particular temperature is physically generated, the information is immune to voltage drifts and attenuations normally associated in signal transmission.

The Signetics 555 was selected for its low timing error drift of 55 ppm/C with change in chip temperature and low timing error drift of 0.01%/V with change in supply voltage. Therefore, measurable error from the integrated circuit of the 555 was not expected. However, the precision of the 555 is limited by the ability of the capacitor C1 to precisely maintain its capacitance with every charge and discharge cycle. The type capacitor used by Signetics was not specified. Tests of several available capacitor types resulted in repeatabilities of 0.3, 0.1, and 0.4% for capacitors of lectrofilm-B, polystyrene, and liquid tantalum respectively. The polystyrene capacitor was selected for use with the multivibrator. Later, a communication with Signetics verified their use of polystyrene capacitors in obtaining manufacturer's specifications. The capacitor value of 100pf was selected to obtain maximum measurable sensitivity from the device without exceeding 2000 Hz. At multivibrator frequencies above 2000 Hz, the square wave transmitted by the FM transmitter and its subsequent frequency measurement deteriorated significantly.

The FM transmitter was designed with considerable aid from Dr. H. R. Skutt, Professor of Electrical Engineering, VPI&SU, and required only minor modification for exceptional performance. Performance of the FM transmitter was determined by measuring the ratio of FM transmitter input frequency to FM receiver output frequency. The ratio was measured by the timer-counter to be 1.0000 resulting in a precision of better than 0.01%. Thus, the FM transmitter section added no error to the multivibrator frequency being transmitted.

The inductor coil of the FM oscillating tank circuit is the only component which required attention. The frequency at which the L-C circuit oscillates is the FM carrier frequency. Inductance of the coil "L" shown in the schematic of Fig. 2, is determined by the number of turns of wire, the geometry of the coiled wire and the inductance properties and position of the core material. Any variation in these parameters will change the inductance of the coil and subsequently the FM carrier frequency. A ferrous slug was used as a core to fine-tune the inductance of the coil thereby avoiding the problem of broadcasting on the same FM carrier frequency as stronger commercial stations.

The voltage regulator shown in the schematic of Fig. 2 is a National Semiconductor LM723C integrated circuit. It was selected for its low quiescent current drain of 1.8ma. Three precision resistors and a capacitor were required to determine the regulated output voltage. The device was able to maintain the output voltage of 6.019 volts over an input voltage range of 10 to 12 volts. Frequency precision tests made with and without the voltage regulator showed that the voltage regulator improved the precision of the temperature telemetry device by a factor of ten.

The use of a voltage regulator meant increase in size, increase in battery power requirements, and increase in heat generated by the temperature telemetry device. Precise temperature measurement requirements and small newborn lamb external ear volume made it necessary to separate the voltage regulator, battery and FM transmitter from the multivibrator by a two conductor shielded cable. The voltage regulator, battery and FM transmitter would be attached to a neck collar for use in newborn lambs.

IV. EVALUATION OF THE DEVICE

A thorough evaluation of the precision of the device must include, first of all, proper calibration instrumentation and a well defined calibration procedure. Concise presentation of the results enable thorough analysis from which firm conclusions can be drawn about the device.

Calibration Instrumentation

Testing and calibration of the prototype temperature telemetry device required a constant temperature bath, an FM receiver, a time-base frequency counter and an oscilloscope. Figure 3 shows the instrumentation interconnections. A list of the calibration equipment is shown in Table 1. The record output of the receiver was used to bypass the amplifier section of the receiver. Good reception was obtained using the power cord FM antenna.

The critical calibration instrument in the system is the digital time-base counter which has an accuracy of ± 1 of the least count. For a ten second frequency sampling period, the counter accuracy is ± 0.1 Hz. Bath temperature precision specified by the manufacturer is ± 0.04C from 20-100C. The Hg-in-glass thermometer used to set the bath temperature has graduations of 0.1C but is calibrated by ASTM at 1.0C increments. Because the accuracy of any device can be improved through calibration only to the degree of its precision, the precision of the temperature telemetry device at any one constant temperature bath setting is the measurement of primary importance. Calibration

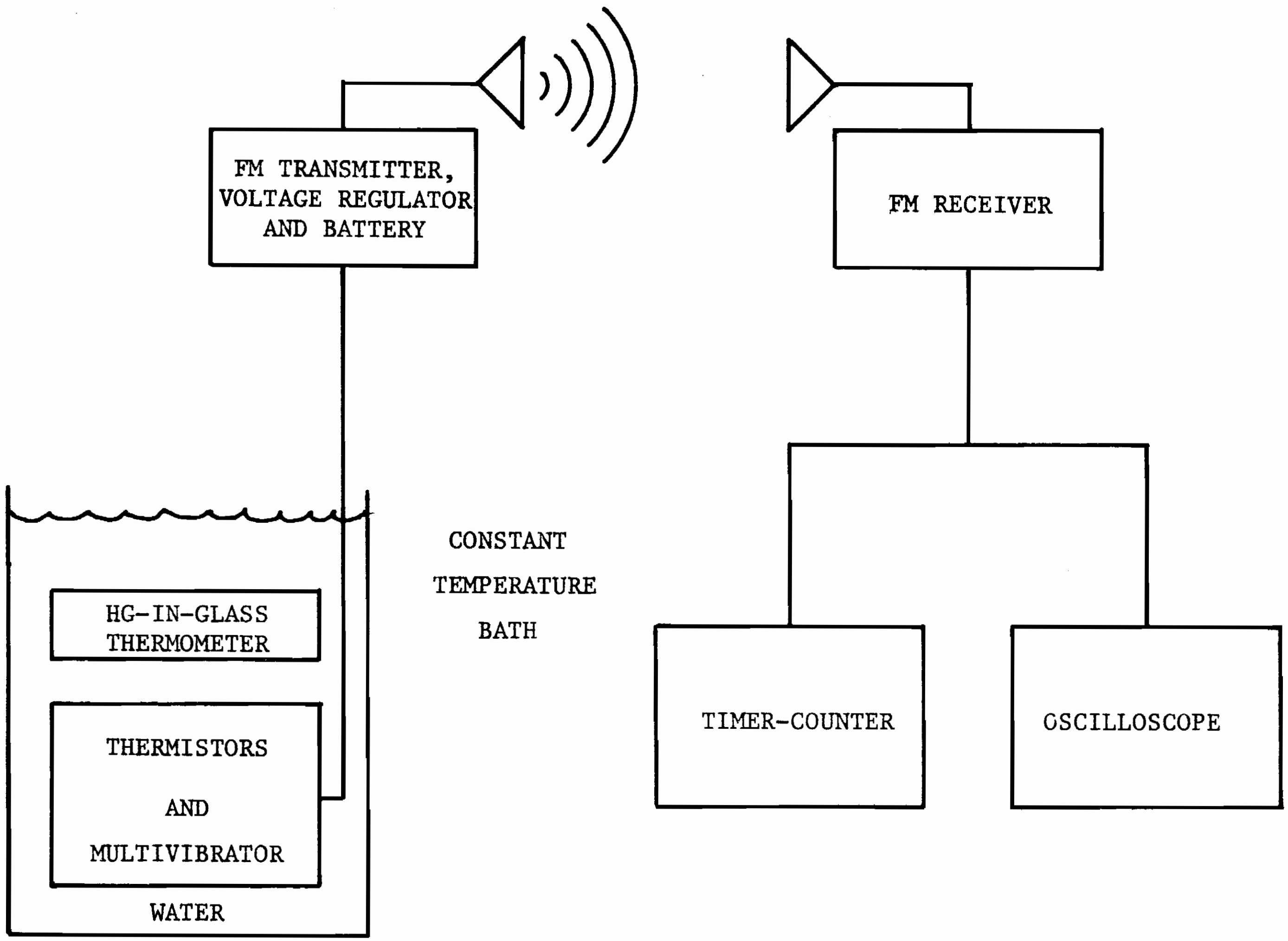


Figure 3 Calibration Instrumentation

TABLE 1

Instrumentation Equipment Specifications

Equipment	Manufacturer	Model Number	Manufacturer's Specification
Constant Temperature Bath	Precision Scientific Corporation	66580	Precision of ± 0.04C from 20–100C
Timer-Counter	Hewlett-Packard	5223L	Accuracy of ± least count
Hg-in-glass Thermometer	Precision Scientific Corporation	121896	ASTM calibrated at 1.0C increments Precision of ± 0.025C

points are useful to determine the temperature telemetry device sensitivity, $\Delta Hz/\Delta C$.

Calibration Procedure

The 555 multivibrator, two 5 megohm @ 25C thermistors and the polystyrene capacitor were placed in a small glass jar. A 2 conductor shielded cable was used as an interconnector to the FM transmitter, voltage regulator and battery approximately 3 ft. away. The glass jar was secured in the bottom of the constant temperature bath a few inches below the Hg-in-glass calibration thermometer. The constant temperature bath was adjusted until the desired Hg-in-glass thermometer reading was obtained.

After a ten minute warm-up period, data samples were taken every ten seconds for ten minutes. The mean and standard deviation of the 60 data samples were recorded. The mean and standard deviation of the next 60 data samples were again taken to verify the repeatability of the previous mean data point. Exceptions to the above procedure occurred where 120 or 180 data samples were taken instead of two sets of 60 and at 39C and 40C where the standard deviation of one set of 60 samples was comparable to previous standard deviations. Long-term precision was determined by comparing the initial mean and standard deviation of the device to the mean and standard deviation of the device eight hours later. The device remained in the constant temperature bath but the device was off during the eight-hour period in order to save battery power.

Results

The calibration curve for the temperature telemetry device is shown in Fig. 4. Only the 1.0C temperatures calibrated by the American Society for Testing and Materials on the Hg-in-glass thermometer are valid for the curve of Fig. 4. The mean and standard deviation of the temperature telemetry system calibration frequency at various nominal temperatures are listed in Table 2. The standard deviation is in all cases less than 0.35 Hz. In the eight-hour long-term drift test, the final mean frequency value returned to within the standard deviation of the initial mean frequency value.

Analysis of Results

There is a 68.3% probability that a single data sample will fall within the standard deviation of the mean value. There is a 95.5% probability (21-1 odds) that a data sample will fall within 2 standard deviations about the mean value. In this thesis, precision is defined as 2 standard deviations. Therefore, the worst case precision of the temperature telemetry system is ± 0.70 Hz.

The curve of Fig. 5 relates the measured system frequency to nominal bath temperature at 0.1C increments from 36.5 to 37.5C. The slope of the curve at any point is the sensitivity expressed as $\Delta Hz/\Delta C$ about that point.

In order to determine the temperature precision of the calibration system, the frequency precision of the system is divided by the system sensitivity. However, uncertainty in sensitivity must also be included

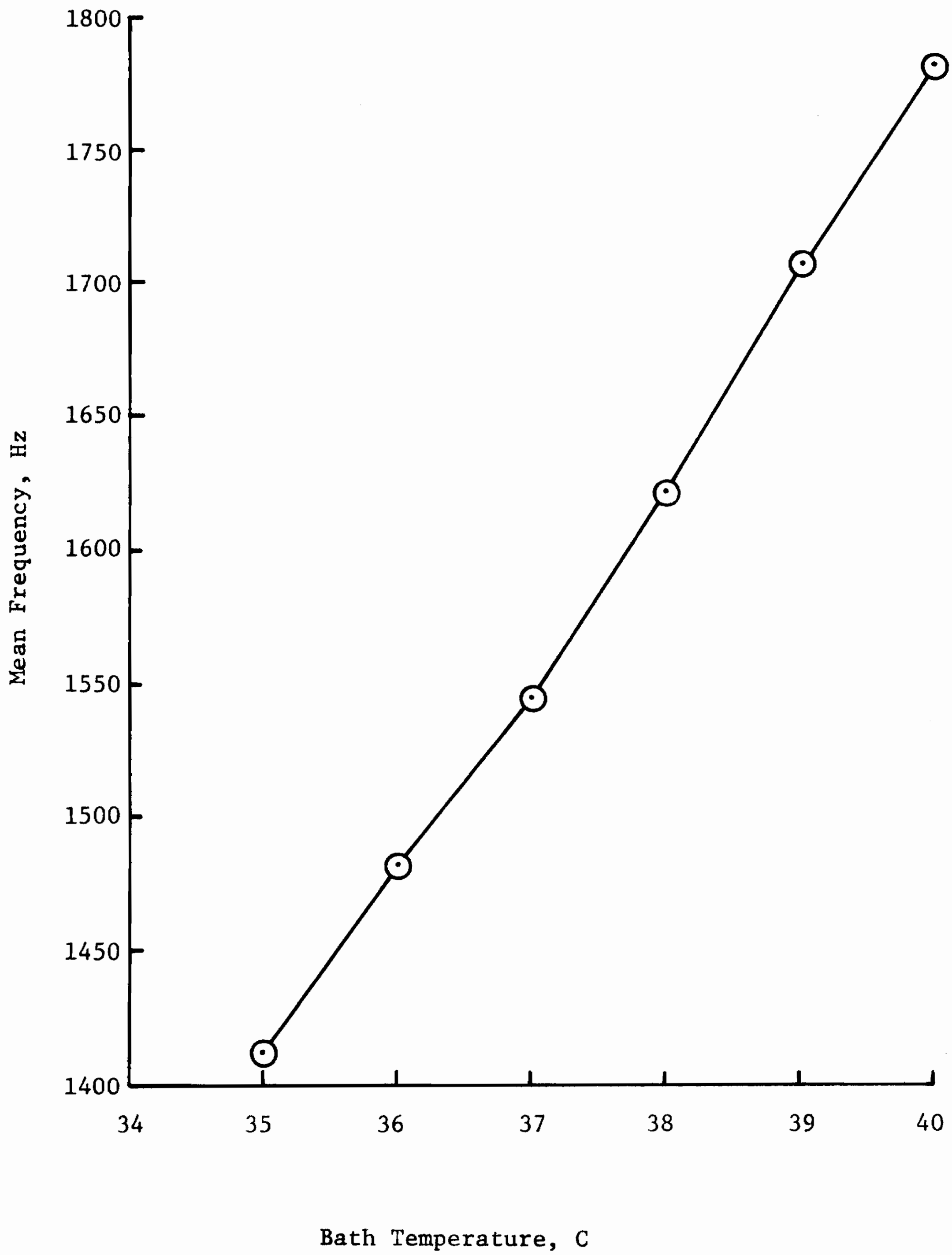


Figure 4. Temperature Telemetry Device Calibration Curve

TABLE 2. Temperature Telemetry Device Calibration Results

Bath Temperature, C	Mean Frequency, Hz	Standard Deviation, Hz	Temperature Precision, C	Uncertainty of Temperature Precision 21-1 odds, %	Worst Case Temperature Precision,
35.0	1413.29	0.19	--	--	--
36.0	1483.05	0.15	.004	33%	.005
36.5	1514.61	0.21	.006	24%	.007
36.6	1521.76	0.22	.008	29%	.010
36.7	1525.28	0.21	.008	30%	.010
36.8	1532.61	0.20	.006	31%	.008
36.9	1538.26	0.14	.004	40%	.006
37.0	1548.41	0.16	.004	36%	.005
37.1	1555.63	0.14	.003	40%	.004
37.2	1563.92	0.13	.006	42%	.009
37.3	1567.83	0.17	.005	34%	.007
37.4	1575.96	0.15	.005	38%	.007
37.5	1584.61	0.22	.006	23%	.007
38.0	1621.66	0.35	.007	14%	.008
39.0	1707.39	0.29	.007	17%	.008
40.0	1781.95	0.25	--	--	--

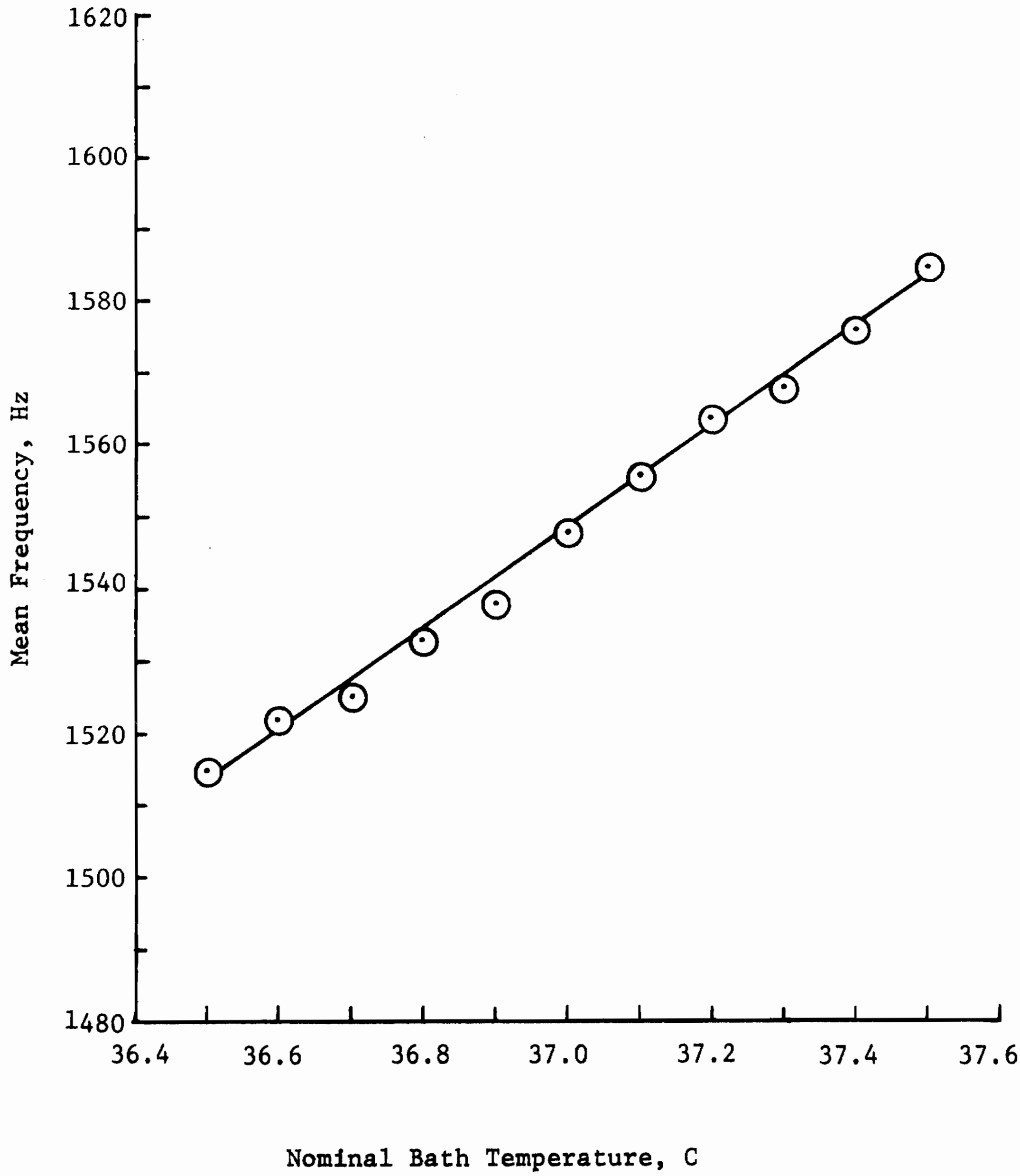


Figure 5. Frequency Profile of 36.5 to 37.5C

in the final temperature precision of the system. Temperature precision is calculated from the equation

$$P_{T_n} = P_{F_n} \left(\frac{T_{n+1} - T_{n-1}}{F_{n+1} - F_{n-1}} \right) \tag{2}$$

where P_T = temperature precision of calibration system

P_F = frequency precision of calibration system

T = temperature of Hg-in-glass thermometer

F = mean frequency at specified temperature.

The subscript n+1 and n-1 refer to the temperature as equal increment above and below the particular temperature n.

Using the uncertainty analysis method of Kline and McClintock (16) on Eq. (2) results in

$$\frac{W_{P_T}}{P_T} = \left[\left(\frac{W_{P_F}}{P_F} \right)^2 + 2\left(\frac{W_T}{\Delta T} \right)^2 + \left(\frac{W_{F_{n+1}}}{\Delta F} \right)^2 + \left(\frac{W_{F_{n-1}}}{\Delta F} \right)^2 \right]^{1/2} \tag{3}$$

where W_{P_T} = uncertainty of temperature precision

W_{P_F} = uncertainty of frequency precision = 2 standard deviations

W_T = uncertainty of bath temperature = 0.025C

W_F = uncertainty of mean frequency = 0.1 Hz

ΔT = $T_{n+1} - T_{n-1}$

Δ = $F_{n+1} - F_{n-1}$.

The percent uncertainties of the temperature precisions and the resulting worst case temperature precisions are shown in Table 2. The largest worst case temperature precision is ± 0.01C.

The long term stability test of eight hours was conducted at a nominal temperature of 37.3C at an initial measured frequency of 1567.69 ± 0.16 Hz. The system measured frequency returned to within .14 Hz of the initial mean frequency which is well within the precision of the total system.

Conclusions

The total temperature calibration system minimum precision is ± 0.01C. Changes in temperature of 0.02C can be precisely measured. The precision of the system is limited by the constant temperature bath and not be the thermistors, multivibrator, FM telemetry or power supply components. The long term precision of the device is as good as the short term precision.

The device draws approximately 5ma current at 11v. Mallory TR-431 batteries of 1000ma-hr will operate the device well over a week. The batteries can be easily replaced without disturbing the critical thermistor placement against the tympanic membrane. The battery is by far the largest component in the device. However, the device is small enough to be used on newborn lambs without compromising the normal post-natal activities of lamb and ewe.

The temperature telemetry system developed by NASA at Ames Research Center is totally implantable, can operate for 150 days and has a precision of ± 0.05C. This means only temperature variations of 0.1C or more can be measured. The prototype device reported herein can measure temperature variations of less than 0.02C. That is five times the usable sensitivity of the NASA device.

The field utility of a temperature telemetry device is also important in gathering precise data. The prototype device can easily transmit its precise data 5 meters or more with battery life of seven days. The NASA device is restricted to shielded, non-conductive cages 5 cubic ft. or less. Cage restrictions of this order clearly defeat the need for radio telemetry in thermometry investigations in animals approaching the size of newborn infants.

V. RECOMMENDATIONS

Future refinements, calibration and utilization of the device is fully anticipated. Refinements in physical strength and ruggedness with appropriate miniaturization will transform the device from a prototype to a useful experimental tool. More precise calibration instruments are needed to establish the absolute maximum precision of the device. Establishment of proper statistical data gathering procedures are necessary. Long-term field testing will determine the actual usefulness of the device in gathering definitive data by which veracity of computer models can be measured.

Present thermistors in use have 0.001 in. lead diameters and break frequently. Thermistors of 5 megaohm @ 25C thermistors with equal or greater temperature sensitivity and larger lead diameters are manufactured but were not available from commercial distributors at time of calibration. Miniaturization and potting can then be completed.

Although absolute temperature calibration is not needed to measure change in temperature, the absolute precision of the device should be determined. Facilities at NBS are available for such testing.

Utilization of the device in the field is straightforward. Frequency data points at intervals of ten seconds are easily related to their temperatures by the well defined standard deviation and mean. Microprocessor technology could be applied to make data acquisition completely automatic.

LIST OF REFERENCES

1. Taber, Clarence Wilbur, Taber's Cyclopedic Medical Dictionary, F. A. Davis Company, Philadelphia, 9th ed., 1963, p. H-64.

2. Guyton, Arthur C., Textbook of Medical Physiology, W. B. Saunders Company, Philadelphia, 4th ed., 1971, p. 837-8.

3. Huckaba, C. E., and J. A. Downey, and R. C. Darling, "A Feedforward-Feedback Mechanism For Human Thermoregulation", Chemical Engineering Progress - Symposium Series, No. 114, 1971, pp. 1-7.

4. Winton, Henry J., and R. N. Linebarger, "Computer Simulation of Human Temperature Control", Simulation, November 1970, p. 213-21.

5. Wissler, E. H., "A Mathematical Model of the Human Thermal System", Bulletin of Mathematical Biophysics, Vol. 2, 1964, p. 147-66.

6. Crosbie, R. J., J. D. Hardy, and E. Fessenden, "Electrical Analog Simulation of Temperature Regulation in Man", Temperature - Its Measurement and Control in Science and Industry, Vol. 3, Part 3, 1963, p. 62.

7. Mestyan, G. Y., and F. Varga, "Chemical Thermoregulation of Full-Term and Premature Newborn Infants", Journal of Pediatrics, Vol. 56, No. 5, May 1960, pp. 623-629.

8. Benzinger, T. H., "Heat Regulation: Homeostasis of Central Temperature in Man", Physiological Reviews, Vol. 49, No. 4, October 1969, pp. 671-759.

9. Rawson, R. O., and H. T. Hammel, "Hypothalmic and Tympanic Membrane Temperatures in Rhesus Monkey", Federation Proc. Vol. 22, 1963, p. 283.

10. Emergency Beacon Corp., 13 River St., New Rochelle, N.Y., 10801.

11. Fryer, T. B., G. J. Deboo, and C. M. Winget, "Miniature Long-life Temperature Telemetry System", Journal of Applied Physiology, Vol. 21, 1966, p. 295-8.

12. Hertzler, Emanuel C., "Tympanic Temperature Telemetry", Biomedical Instrumentation, Vol. 13, 1966, p. 44-6.

13. Hund, August, Frequency Modulation, McGraw-Hill, New York, 1st ed., 1942, p. 375.

14. Gruenberg, E. L., Handbook of Telemetry and Remote Control, McGraw-Hill, N.Y., 1967.

15. Fenwall Electronics, "Thermistor Technical Data Notes-Stability and Reliability Characteristics", Fenwall Electronics, Framingham, Mass., 01701.

16. Holman, J. P., "Experimental Methods for Engineers", McGraw-Hill, N.Y., 2nd ed., 1971.

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(ABSTRACT)

A prototype temperature telemetry system was designed and evaluated for measuring the change in tympanic membrane temperature of newborn lambs. The tympanic membrane temperature closely follows the hypothalmic temperature. The precise measurement of the change in this temperature is essential in development and verification of infant and mature thermoregulatory models. The precision of the temperature telemetry device was measured to be within ± 0.01C in the 35 to 40C nominal temperature range. Telemetry transmission distances of 5 meters will allow undisturbed tympanic membrane temperature monitoring of the lamb in its natural post-natal environment.