

A SOLID-LIQUID PHASE PRECIPITATION METERING DEVICE

A Thesis

Presented in Partial Fulfillment of the Requirements for the

DEGREE OF MASTER OF SCIENCE

Major in Electrical Engineering

in the

UNIVERSITY OF IDAHO GRADUATE SCHOOL

by

JOHN CARLTON READ

May, 1966

QC  
926  
R4

This thesis of John Carlton Read for the Master of Science degree, "A Solid-Liquid Phase Precipitation Metering Device,"

A. has been reviewed in rough draft form and preparation of the final draft is recommended; permission is granted to proceed with the final examination upon submission of two final draft copies to the Graduate School:

Major Professor JAM Yeun Date 4/22/66  
Committee Members MR Parish Date 4/24/66  
John C. Moore Date 4/25/66

B. is approved in final draft form:

Head of Department H. E. Hattrup Date 12 May 1966  
Dean of College Allen Janssen Date 13 May 1966

C. has been granted final acceptance after review by the Graduate Council and after successful completion of the final oral examination:

Dean of the Graduate School Edward H. Thuh Date June 10, 1966

## BIOGRAPHICAL SKETCH OF THE AUTHOR

John Carlton Read was born in Twin Falls, Idaho, on March 3, 1942. He received a diploma from Twin Falls High School in May, 1960. In September, 1960, he enrolled in the University of Idaho. He completed the requirements for a Bachelor of Science degree in Electrical Engineering in February, 1965, and was graduated with that degree in June, 1965. During his last semester as an undergraduate, he entered, in partial enrollment, the Graduate School of the University of Idaho. The following semester he entered in regular enrollment, and in June, 1966, completed the requirements for the Master of Science degree, of which this thesis is a part.

## ACKNOWLEDGEMENTS

The author would like to express appreciation to the Intermountain Forest and Range Experiment Station, Moscow, Idaho and the Engineering Experiment Station of the University of Idaho for their joint financial support of this research project. Also, acknowledgement is due to Professors G. A. McKean and W. R. Parish of the Department of Electrical Engineering and Professor J. C. Moore of the Department of Civil Engineering for suggestions and guidance during the execution of this project and for time spent in review and evaluation of the rough draft of this thesis.

# TABLE OF CONTENTS

v

CHAPTER	PAGE
I. INTRODUCTION . . . . .	1
1. Nature of the Problem . . . . .	1
2. Research Objective . . . . .	2
3. Conditions of Operations . . . . .	4
II. INITIAL RESEARCH . . . . .	5
1. Literature Search . . . . .	5
2. Evaluation of Ideas . . . . .	7
III. DEVELOPMENT OF OPTICAL SCHEME . . . . .	12
1. Initial Optical Experiments . . . . .	12
2. Optical System Functional Scheme . . . . .	16
IV. COMPONENT CIRCUITS . . . . .	22
1. General . . . . .	22
2. The Amplifier . . . . .	24
3. Multivibrators . . . . .	26
4. OR Circuit . . . . .	28
V. OPERATIONAL CHARACTERISTICS . . . . .	30
1. System Layout . . . . .	30
2. Geometric Characteristics . . . . .	32
3. Nature of Recorded Outputs . . . . .	35
4. Photodiode Supply Voltage Effect . . . . .	38
VI. CONCLUSION AND RECOMMENDATIONS . . . . .	40
1. Conclusion . . . . .	40
2. Recommendations . . . . .	40
LIST OF REFERENCES . . . . .	45
APPENDIX . . . . .	46

## LIST OF FIGURES

vi

FIGURE		PAGE
1	Layout of Initial Experiments . . . . .	14
2	Optical System Functional Diagram . . . . .	19
3	Amplifier Circuit Diagram . . . . .	25
4	Multivibrator and OR Circuit Diagrams . . . . .	27
5	Operational System Configuration . . . . .	30
6	Operational Configuration Illustrating Geometric Parameters . . . . .	31
7	Snow Sensitive Beam Length, $S$ , Versus Alpha . . . . .	34
8	Illustration of Recorded Outputs . . . . .	37

# LIST OF TABLES

vii

TABLE		PAGE
1	Optical Scheme Logic . . . . .	17
2	Card Positions and Connections of Component Circuits . . . . .	23
3	Geometric Characteristics of Optical System Performance . . . . .	33
4	Saturation Effect of Lowering Photodiode Supply Voltage . . . . .	39

ABSTRACT

A need for a precipitation metering device capable of discriminating between solid and liquid phases of precipitation initiated this research project. A literature search revealed no existing instrument capable of performing this function; however, references were found to certain schemes which, with modifications, could possibly be adapted as a solution to this problem.

An optical scheme was selected for further research because this type of system requires no mechanical motion, thus avoiding icing problems likely to be encountered in the operational environment, and because luminous radiation and electricity are energy forms which are easily transducible from one form to the other. A photosensitive device was used to determine the relative light attenuant and reflective effects of the precipitation particle types. With certain geometric restrictions it was found that the reflective properties of snow are of a sufficient degree of magnitude greater than those of rain to enable the development of a system sensitive to the presence of snow and not rain. Optical attenuant characteristics of the snow and rain particles were found to be similar in degree of magnitude of photosensitive device response.

A prototype system employing both reflective and attenuant effects of the particles was developed and shown to be capable of detection and identification of both precipitation phases. This system is recommended as a solution to this problem.



## INTRODUCTION

1. The Nature of the Problem

With existing catch-type precipitation gages it is possible to record both the period (time and duration) and amount (in terms of water equivalent) of precipitation which falls. It is possible to determine not only the total water equivalent accumulation during a given period; but also, the rate of water accumulation at specific times during the precipitation period may be determined. This is done by employing a slope analysis technique on a graphical recording of total water accumulation as functionally dependent on time.

As was mentioned previously, however, such instruments measure water equivalent only, and are not capable of distinguishing the phase of precipitation (solid or liquid). In certain hydrological studies it is necessary to obtain data on the time and amount of precipitation, and also a record of the time distribution of the phase of the precipitation. In this case, an instrument capable of distinguishing another hydrologic parameter, namely phase of precipitation, becomes necessary.

A need for such an instrument has been pointed out by the Intermountain Forest and Range Experiment Station for use in watershed management research. The Engineering Experiment Station of the University of Idaho is interested in determining the effect of precipitation phase upon snow pack measuring devices that are being developed. The possibility also exists that data on time distribution of precipitation phase, used in conjunction with other types of hydrologic data, would

be extremely useful in predicting the flood potential of certain drainage systems.

One possible method of obtaining such data is through human observation. The remoteness and inaccessibility of sites where it is often desirable to gather such information however, necessitates the development of a method of continuously distinguishing and metering the phase of precipitation as it falls at an unmanned site.

## 2. Research Objective

The purpose of this research is to find suitable properties of rain or snow in the falling state that can be used in the development of a suitable means of identifying and metering the time distribution of the phase of precipitation.

Although it is realized that several types of precipitation in the solid phase exist such as snow, hail and sleet, the scope of this research is aimed solely at distinguishing between snow (solid phase of precipitation) and rain (liquid phase of precipitation). It is assumed that precipitation will exist as either rain or snow, and that the occurrence of other precipitation forms will be comparatively rare such that errors they may induce in such a metering device will have negligible effect on the accuracy of hydrologic data obtained for one season. For this reason, throughout the rest of this thesis the phrase "solid phase of precipitation" is used to imply snow, and "liquid phase of precipitation" implies rain.

It should be noted that such a metering system need not be capable of detecting and recording both solid and liquid phases of

precipitation when used in conjunction with a precipitation accumulation type of recording device. This is because precipitation is assumed to occur in one of two possible phases. If a detection system is sensitive to only one particular phase, and if the system indicates that precipitation of this phase did not occur during a period during which, coincidentally, the precipitation accumulation device indicates that precipitation has fallen, the other phase of precipitation may be assumed to have occurred during that period. Any property which is unique to either snow or rain would be a suitable one provided that a system could be devised which is sensitive to that property.

### 3. Conditions of Operation

Although general engineering objectives such as efficiency, low power consumption, reliability, and low cost are assumed desirable for such a proposed metering system, conditions under which the device must operate should be examined because they impose severe limitations on the system design and tend to enhance the usage of certain detection types while detracting from the usage of others. The system will ultimately be expected to perform reliably while unattended for the duration of a winter season. Temperatures can be expected to fluctuate erratically, and temperatures well below 0° F. may be expected. Frequently snow and rain will be wind blown and in general, will not fall in an entirely vertical manner.

The detection system must be expected to function reliably under cold temperatures, and it must also withstand the effect of numerous and frequent temperature cyclings. The effect of icing is also a problem which must be considered in the selection of a reliable detection method.

## INITIAL RESEARCH

1. Literature Search

This project was started with a literature search in order to ascertain if devices presently exist which have potential for use in conjunction with this project. No reference to any device which was capable of making the distinction between snow and rain was found; however, three references were found which did suggest at least possible means of attaining the desired functioning provided that necessary modifications were made.

One such device which is a modification of what is known as the Barnothy and Bell method, is basically an alarm system which is activated whenever a water droplet strikes a blotter paper which encloses a heated metal cylinder. <sup>1/</sup> The droplet wets the blotter and thereby increases the electrical conductivity between the cylinder and an outer wire winding. This increase in conductance is used to increase the grid bias on a thyatron, causing it to fire. A recorder relay coupled to the plate circuit of the thyatron is then used to furnish the output information. Because the interior cylinder of the detector is heated, the moisture absorbed by the blotter will eventually evaporate. The thyatron bias is then lowered to a value at which the tube ceases to conduct, and the system is then ready to detect another water droplet.

Although this system is not designed to discriminate between phases of precipitation, it does present a possible method of achieving this especially if a trap could be devised which would allow only one of the phase types to reach the detecting element.

Another possible means of snow detection is suggested by various literary sources concerning the measurement of the static electric charges contained by various snowflakes. Data on such measurements are erratic and various experimenters working at different locations and times have produced markedly different results. Polarity, magnitude and statistical distribution of the charges carried by snowflakes apparently vary with the size of flakes, temperature, rate of snowfall and other characteristics of the storm. 2,3/

In one experiment to measure the charge of falling snowflakes in Japan, an electrostatic deflection system was devised. 2/ A snowflake passing through an electric field between parallel charged plates would be deflected in accordance with its charge magnitude and polarity. Although rain also is known to have a charge distribution among droplets, data do not show charge magnitudes for rain droplets to be significantly greater than for snowflakes. 3/ The possibility arises that if precipitation particles were made to pass between charged plates, the electrostatic deflection would be greater for snow than for rain due to its inherently slower velocity. Mass and air resistance are also phase characteristics which would affect the amount of particle deflection. Catch containers could then be placed in a position that is sufficiently offset to allow only deflected snow particles to collect there.

A third precipitation detection technique, a minor variation of which is the subject of the primary consideration of this

thesis, is an optical method employed by E. Bollay Associates, Incorporated, of Boulder, Colorado, in their snow-rate detection scheme. <sup>4/</sup> Although specific details of the "snow-rate sensor" are not known, it is basically described as an optical attenuation device. A parallel light beam is produced by a flashlight-type reflector and is directed to a photosensitive surface of the detection system. The system functions basically from the attenuation of light incident upon the detector due to the presence of falling precipitation particles in the light beam. A personal communication from E. Bollay Associates, Incorporated, indicates that as of June 22, 1965 the rain detection capabilities of the device had not been assessed. <sup>5/</sup>

## 2. Evaluation of Ideas

In addition to the approaches suggested in the literature search, certain other ideas were investigated. All of these involved a measurement of different physical properties of snow and rain in the falling state. These methods included measurement of impact momentum, dielectric properties, acoustic energies transmitted through fluid in a receiving receptacle upon impact of a precipitation particle, and optical reflectivity as opposed to optical transmission attenuation suggested in the literature search.

Information concerning the dielectric constants of snow packs for different types of snow crystals and various conditions is available. <sup>6/</sup> The data show the dielectric constant to vary widely

for different types of crystals, density, temperature, degree of purity, and frequency at which the measurement is made. Other problems discourage consideration of development of this method. In order to obtain an indication of the dielectric properties of precipitation, either a measurement must be made as the particles fall in near proximity to the detector, or a sample of the precipitation must be collected. Assuming that samples would be collected, the system would then have to dispose of each sample before system readiness to perform another interrogation of precipitation could be attained. This is a mechanical task made awkward in view of the fact that icing conditions at the site imperil the reliability of mechanical systems. Measurement of the dielectric effects of precipitation particles passing near the detector would require a great system sensitivity because of the small ratio of particle volume to surrounding air volume. The presence of a particle in the vicinity of the detector would produce a negligible effect on the equivalent dielectric constant of the surrounding medium.

The acoustical method was given only minor considerations. A microphone capable of transducing a usable electric signal from energy transmitted as a result of particle impact on a fluid surface would also be subject to interference from vibrations caused by wind against the mounting structure.

The possibility of measurement of impact momentum does not appear feasible. Rain droplet diameters may vary from 0.275 inch for heavy rain to 0.020 inch for what is considered "drizzle."



Corresponding velocities for the respective droplet diameters are 2080 feet per minute and 555 feet per minute. <sup>7/</sup> Assuming the droplets to be spherical and the mass density of rain to be about one gram per cubic centimeter, the range of momentum per particle for the droplet sizes mentioned is 189 gm-cm/sec to 0.0183 gm-cm/sec. Snow velocities vary from about 180 cm/sec for a graupel-type crystal of 0.8 milligram mass to about 30 cm/sec for a plane dendrite-type crystal of 0.04 milligram mass. <sup>8/</sup> Snow momentum then varies in the range of from 0.144 gm-cm/sec down to 0.0012 gm-cm/sec. A comparison of snow and rain particle momentum shows an overlap among the lighter rain droplets and heavier snow crystals. Use of this principle would be limited to the detection of heavier rain droplets because light droplets could be mistaken for snow. Also if this method were used, icing of the impact head could render the system non-functional.

In an experiment to measure the electrostatic deflection of snowflakes, a field strength of 1300 volts per centimeter was found adequate to produce what was termed "moderate" deflection to the paths of sufficiently charged snow particles. <sup>2/</sup> Although the term "moderate" is vague, it appears from a photograph that sufficient deflection was produced in more highly charged particles to cause them to strike one of the deflection plates within a 65 centimeter vertical fall when entering approximately midway between parallel plates spaced 30 centimeters apart. Although it does appear possible to separate rain from snow in this manner, the high field strength required is a disadvantage. For the physical

dimensions described the potential differences of the plates would have to be 39,000 volts to produce the field strength of 1300 volts/cm. A plate separation of 30 centimeters might not be required, but any reasonable plate separation would require the use of voltages higher than would be desirable in a field instrument. Also snow and rain particles must fall vertically between the plates to produce accurate results. During windy periods the use of chimney catches or shields would be required which add awkward physical dimensions to the size of the instrument. The chimney used in the experiment described was 420 cm long and 54 cm in diameter.

The Barnothy and Bell type of detector <sup>1/</sup> does not appear to be useful for the purpose of phase discrimination. This is because of difficulties involved in designing a trap that would allow only one of the two precipitation phases to reach the detector element. A shielding system is recommended in the mentioned report that aids in the detection of snow; however, whether the detector is shielded or not, it is still capable of intercepting a particle of either precipitation phase.

As was mentioned in the literature search, an optical system has been developed for use as a snow-rate sensor. <sup>4/</sup> An optical system has the advantages that it involves no mechanical movement of system parts, thus minimizing icing problems, and also, luminous radiation and electricity are energy forms that are easily transducible from one form to the other. The problem is to find an optical characteristic of rain or snow which distinguishes itself from the other phase, and from which a detection system can be devised.

Two possibilities for such a distinction are differences in reflective characteristics of the phases, and also difference in optical attenuation. The general opaqueness of snow and transparency of rain are indicators that differences in these characteristics exist. For these reasons, optical experiments were performed to determine these characteristics. The results and their consequences are the subject of the next chapter.

## DEVELOPMENT OF OPTICAL SCHEME

1. Initial Optical Experiments

The reflectance of fresh snow varies as a function of wavelength; however, for the visible wavelengths of from 0.4 to 0.7 micron, the reflectance varies only in the range of from 92 to 95 per cent.<sup>2/</sup> Although these data were obtained from tests using settled snow, the high percentage of luminous energy which is reflected for these wavelengths does enhance the possibility of distinguishing snow reflectivity from that of rain.

Experiments were performed to measure the effects of light reflection and attenuation on a photosensitive device for rain and snow. Because these tests were not made during a snow season, one-quarter inch squares of white paper were used to simulate snow. It was assumed that the reflectivity of natural snow could not be significantly less than that of the paper particles.

A 1N2175 type photodiode made by Texas Instruments, Incorporated was used as a light detector. The 1N2175 is a subminiature, solid state silicon unit. It is cylindrical in shape and is approximately 0.6 inch long and  $0.082 \pm 0.003$  inch in diameter. A focusing lens is self-contained in the head of the unit. Typical illumination sensitivity is about 0.6 microampere per foot-candle of light intensity. Peak sensitivity occurs at about 0.97 micron; however, the response is above 50 per cent at 0.60 micron. Characteristic curves and other pertinent data are contained in the Appendix of this thesis.

---

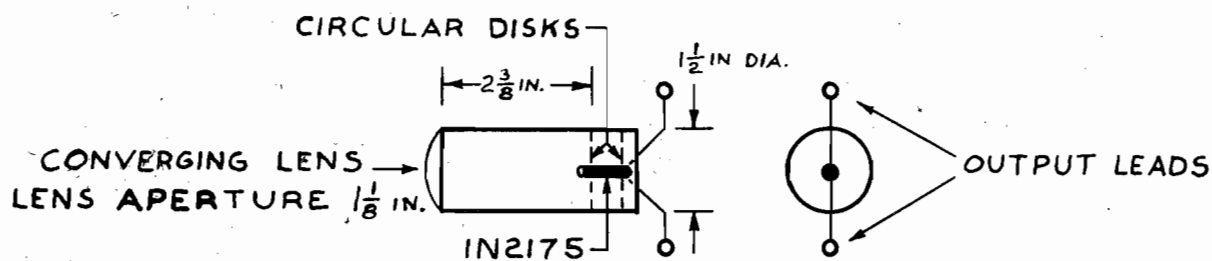
A housing for the 1N2175 was constructed of a cardboard tube 1 1/2 inches in diameter. A focusing lens was mounted 2 3/8 inches ahead of the light sensor so as to focus a parallel light beam, incident upon the lens aperture, onto the lens head of the 1N2175. The lens opening was 1 1/8 inches. A diagram of this mounting system is given in Figure 1a, page 14.

The light source for this experiment was an ordinary flashlight using a General Electric type PR-2 bulb, powered by two D size flashlight batteries.

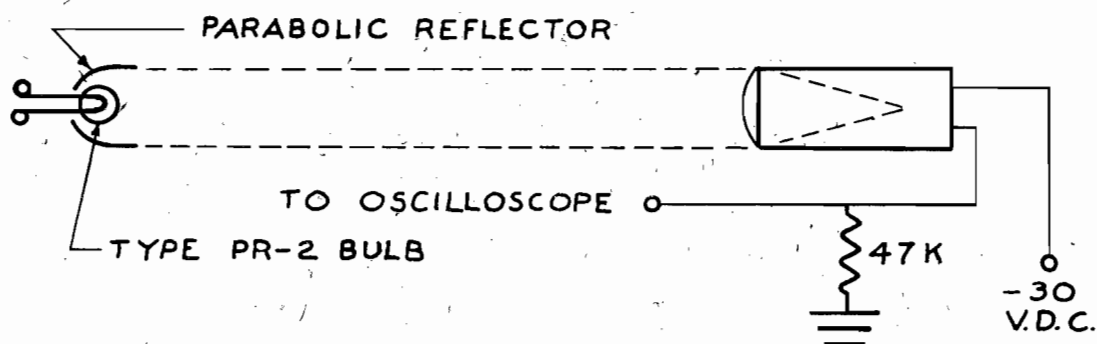
In order to measure the optical attenuation effects of water droplets and simulated snow on the diode, the apparatus was arranged as indicated in Figure 1b, page 14. Water droplets supplied through a pipette dropper and the white paper particles were made to pass through the light beam, and the effect was observed on the oscilloscope.

It was noted that both the paper particles and the water droplets produced output pulses varying in the range of from 0.2 volt to 4.0 volts. No basic differences in the output voltage magnitudes were noted. Both the water droplets and the paper particles produced high and low voltages in the range indicated, and in a random manner. A probable cause of the fluctuations in output magnitude is differences in the amount of light attenuation caused by particles passing through different portions of the beam.

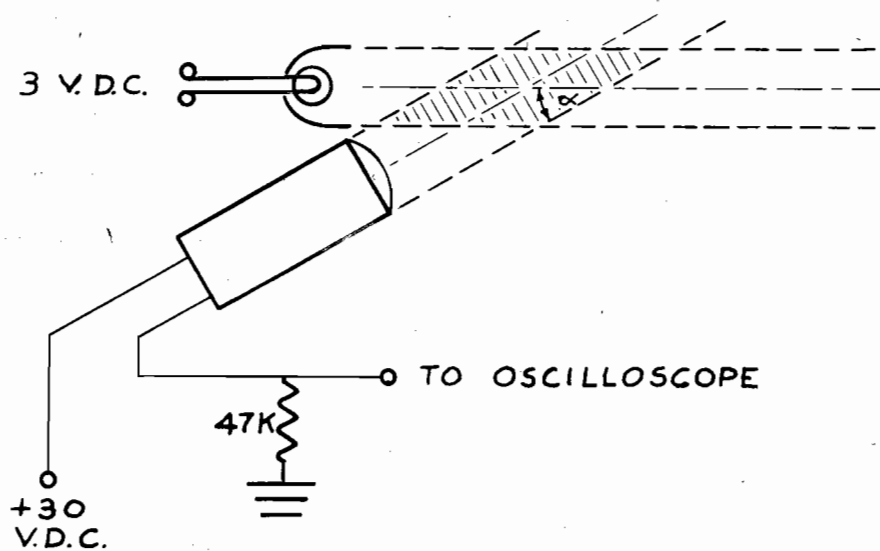
From this portion of the experiment it was concluded that optical attenuation offered no means of discrimination of precipitation phase.



(a) IN2175 Photodiode Housing



(b) Attenuation Studies



(c) Reflection Studies

Figure 1. Layout of Initial Experiments

Selective effects were observed by positioning the detector in a position so as to scan the light beam as is indicated in Figure 1c on the previous page. It should be noted that as " $\alpha$ ", the included angle between the detector and light beam axes, is made smaller, the portion of the light beam which the detector scans becomes larger. As the paper particles were passed through portions of the beam indicated by the shaded area in the figure, random outputs were observed varying from 0.5 millivolt to 4 millivolts. The orientation of the plane surface of the paper particle with respect to both the light source and the detector determines, to a large degree, the amount of reflected light which is received at the detector.

No observable output was noted as water droplets were passed through the beam during these initial experiments. As is later explained, water droplets do produce significant voltages when passed through a certain critical area of the beam. The critical area indicated, however, is considerably smaller than the area for which the detector is sensitive to the paper particles. A more precise definition of this critical area is contained in the section entitled "Geometric Characteristics" of Chapter V.

## 2. Optical System Functional Scheme

Although a system based on optical attenuation in itself does not appear capable of solving the problem, its use in conjunction with a reflected light detector in detecting and distinguishing both rain and snow can be shown. If a detection system is assumed to consist of a diode to sense light attenuation, a diode to sense reflected light, and a unit to perform an analysis of the two sensor outputs, a form of logic may be derived which enables the distinction of precipitation phase. The reflected light sensor is referred to as "source A", and the attenuated light sensor is referred to as "source B".

In accordance with the experiment previously explained, an output is obtained from source B for the presence of either rain or snow. With proper geometric arrangements, source A can be made sensitive to snow only, and therefore an output from this source dictates the presence of snow regardless of the presence or absence of an output from source B. Table I on the following page presents the logic necessary for a proper decision to be made by the analyzer unit.

One inherent source of error is the possibility that a snow particle may fall with such an orientation that it is sensed by the B diode, but not by the A diode. In this case it would appear that a rain droplet were present instead of snow. It is possible to mistake snow for rain with this system; however, the possibility of mistaking rain for snow is made remote with proper geometric arrangements.



Since system errors of only one type occur, this system is compatible for the desired phase discrimination functioning because the intermixed appearance of snow and rain characteristic outputs would indicate snow. Rain could be distinguished by the repeated appearance of its characteristic output without the appearance of a snow detection error.

Table 1  
OPTICAL SCHEME LOGIC

Outputs Present		Conclusion (Phase Present)
Source A	Source B	
Yes	No	Snow
Yes	Yes	Snow
No	Yes	Rain
No	No	None

One other factor further complicates the usage of this logic system. Assuming that, in the event of the presence of a snow flake, both A and B outputs are obtained, there is no assurance that both outputs will occur simultaneously. The phasing of the outputs is entirely arbitrary and must be considered when utilizing this logic method. Should the B output occur first, it would appear for a short time that the particle were a rain droplet.

From the logic presented in Table 1, a functional system was

devised and built which is capable of performing the desired logic and is also inherently free from the problems presented by phase differences between the timings of the sensor outputs. The system is shown in block diagram form in Figure 2 on the following page.

Because of the low level of the outputs from source A, an amplifier is first employed to raise these outputs to a usable level. The amplifier gain is approximately 1000. Because outputs from the B diode are considerably higher than those of one A diode, it was not found necessary to amplify these signals. Actual circuit diagrams for the amplifier and other circuits are found in the next chapter.

The system utilizes the monostable multivibrator. The advantage of this device is that it is permanently stable in only one of two possible states. When it is properly triggered by an input signal the multivibrator regenerates into its astable state and exists in that condition for a controllable length of time, and then returns to its permanently stable state until it is again triggered. The resulting output is a single square shaped pulse for each trigger that is applied to its input. The period of the output pulse is controlled by an RC discharge circuit within the multivibrator itself.

The signals from source B and the amplified signals from source A are used to trigger multivibrator B and A respectively. When triggered, multivibrator A produces a 7.3 volt output for a period of 45 milliseconds. Multivibrator B produces a 7.3 volt output of

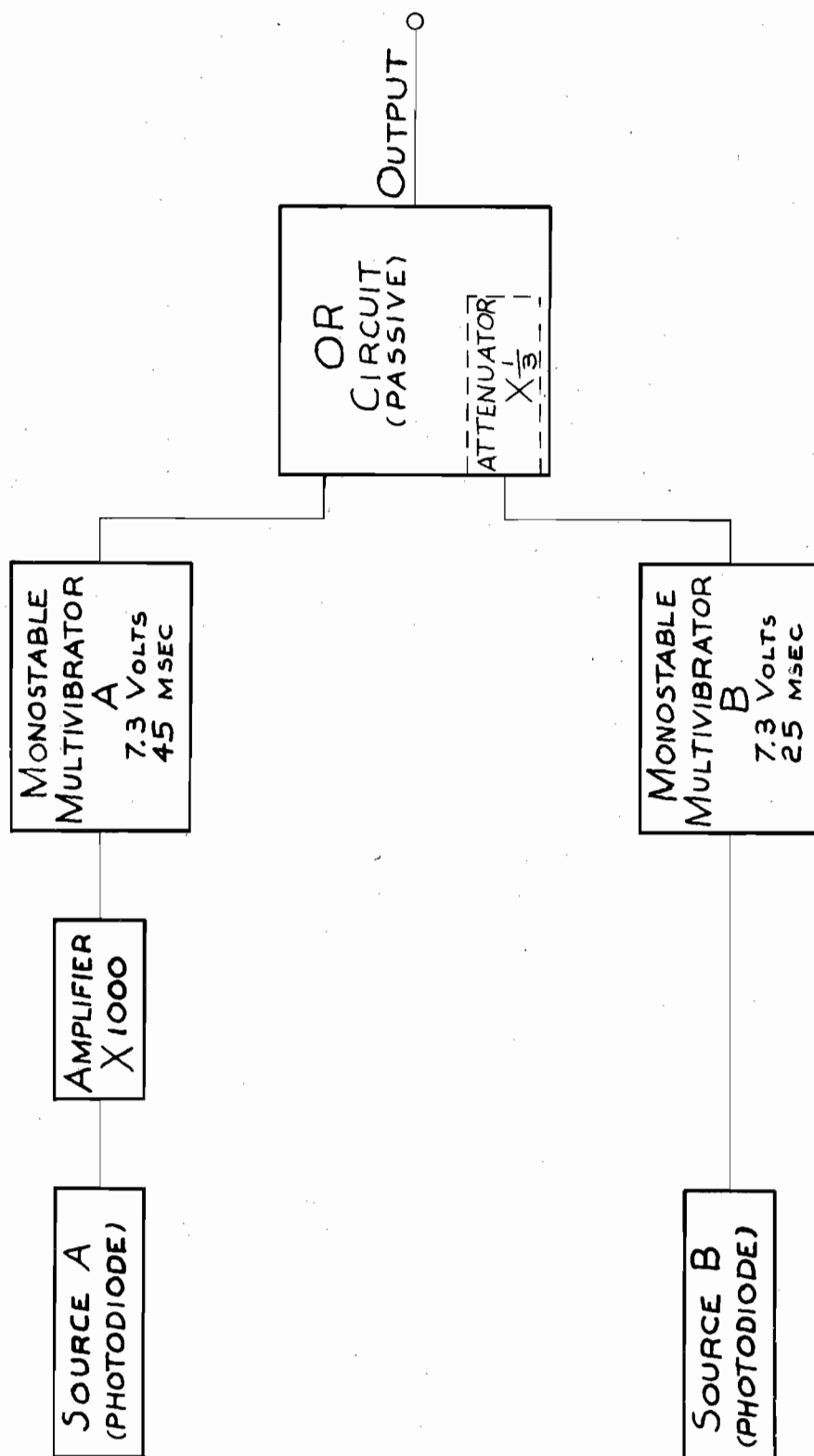


Figure 2. Optical System Functional Diagram

25 milliseconds duration. The outputs of both multivibrators are fed into a passive OR circuit. An OR circuit gives an output whenever an input of the proper polarity is present at any of its inputs. Also, this output magnitude will be the same as the largest voltage present at any of its input terminals.

Because of the commanding influence of a signal from the A source (an input from source A represents snow regardless of the state of source B), a resistive attenuation circuit is employed within the OR circuit which reduces the level of the OR circuit output when stimulated only by the B multivibrator to a value which is approximately  $1/3$  of the original B multivibrator output magnitude. The result is that when multivibrator A is triggered the OR circuit output is a 7.2 volt pulse of 45 milliseconds duration. This is the characteristic output obtained when snow is sensed by the A diode. The slight attenuation of the multivibrator output from 7.3 to 7.2 volts is due to the conduction resistance of the diode used in the OR circuit. When multivibrator B alone is triggered, a 2.3 volt output of 25 milliseconds duration is obtained at the OR circuit. This output is characteristic of the sensing of rain. Should both multivibrators be triggered simultaneously, the result is the same as though only multivibrator A were triggered. This is because of the commanding influence multivibrator A has on the output of the OR circuit.

In this manner, problems caused by the time phasing of the triggering of the two multivibrators are overcome. It is

inconsequential if the B output is received at the OR circuit slightly before or after the A output since the 7.2 volts output due to the sensing of snow is easily distinguishable once it does occur.

It should be noted that source A, the amplifier, and multivibrator A compose a completely functional scheme since this portion of the system can be rendered sensitive to snow only. As was mentioned previously, only one of the two possible phases needs to be detected when used in conjunction with a precipitation accumulation recording device.

## COMPONENT CIRCUITS

1. General

Each of the circuits indicated in Figure 2, with the exception of the photodiodes was constructed on a 3 inch by 5 inch vector-board card. There are four such cards. Input and output connections are made through 6-pin, Amphenol-type connectors. The receptacle sections of the connectors are wired into a harness. In this manner, each of the circuits of the system can be removed for individual inspection and testing. The cards are placed parallel to each other with approximately 1 1/4 inches between cards. The card order and terminal connections of the different circuits are indicated in Table 2 on the following page.

In order to minimize stability problems, multivibrator A and the amplifier were purposely spaced at opposite ends of the configuration, thus maintaining maximum separation between the multivibrator output and the amplifier input. Multivibrator A was originally positioned adjacent to the amplifier in the number 2 position. This positioning was found to produce circuit instability, and oscillations could not be stopped. At times short periods of stability were attained; however, switching on the laboratory lights would usually produce sustained oscillations. With these circuits placed as shown in Table 2, the system is stable except when the multivibrator output lead is brought near the amplifier input.

The transistor used in all of the circuits is the n-p-n, 2N1302 type made by Texas Instruments, Incorporated. This is an

alloy-junction germanium transistor used primarily for computer and switching applications.

Table 2

CARD POSITIONS AND CONNECTIONS OF COMPONENT CIRCUITS

Circuit	Card Position Number	Terminal	Amphenol Connection Terminal
Amplifier	1	+12 V. D. C.	D
		Ground	A
		Input	F
		Output	B
Multivibrator B	2	+12 V. D. C.	D
		Ground	A
		Input	B
		Output	C
OR Circuit	3	Ground	A
		A Input	B
		B Input	C
		Output	E
Multivibrator A	4	+ 12 V. D. C.	D
		Ground	A
		Input	B
		Output	E

With the exception of the photodiodes, the system is designed for 12 volts operation. A total input current of 7.7 milliamperes is required. The total power consumption is then 92.4 milliwatts. The FR-2 bulb used as a light source in these experiments draws 0.5 ampere at 3 volts and therefore consumes 1.5 watts. A bias current

of from 0.4 to 0.7 milliamperes was used for the operation of photodiode B. Different diode supply voltages up to 30 volts were used for this diode. Better results were obtained as the supply voltage was increased. With a 30 volt supply, the photodiode B input circuit consumes from 12 to 21 milliwatts of power. Since source light is not incident upon photodiode A, bias current and power consumption of this circuit are completely negligible in comparison with that used by the other system components.

A picture of the system in operational configuration is shown in Figure 5.

## 2. The Amplifier

The circuit diagram of the amplifier is shown in Figure 3 on the following page. It is a four-stage amplifier, however, the first and last stages are emitter followers and actual voltage amplification is accomplished in the second and third stages. Resistive-capacitive decoupling is provided between the second and third stages to reduce the possibility of instability due to feedback. The amplifier uses 3.3 milliamperes of supply current.

In experiments previously described, a 47K load was used for the photodiodes. The emitter follower was used for the initial stage of this amplifier to keep the signal load impedance seen by photodiode A at this same level. The emitter follower impedance is approximately 100K. This impedance in parallel with the bias load produces a signal load of about 50 K.



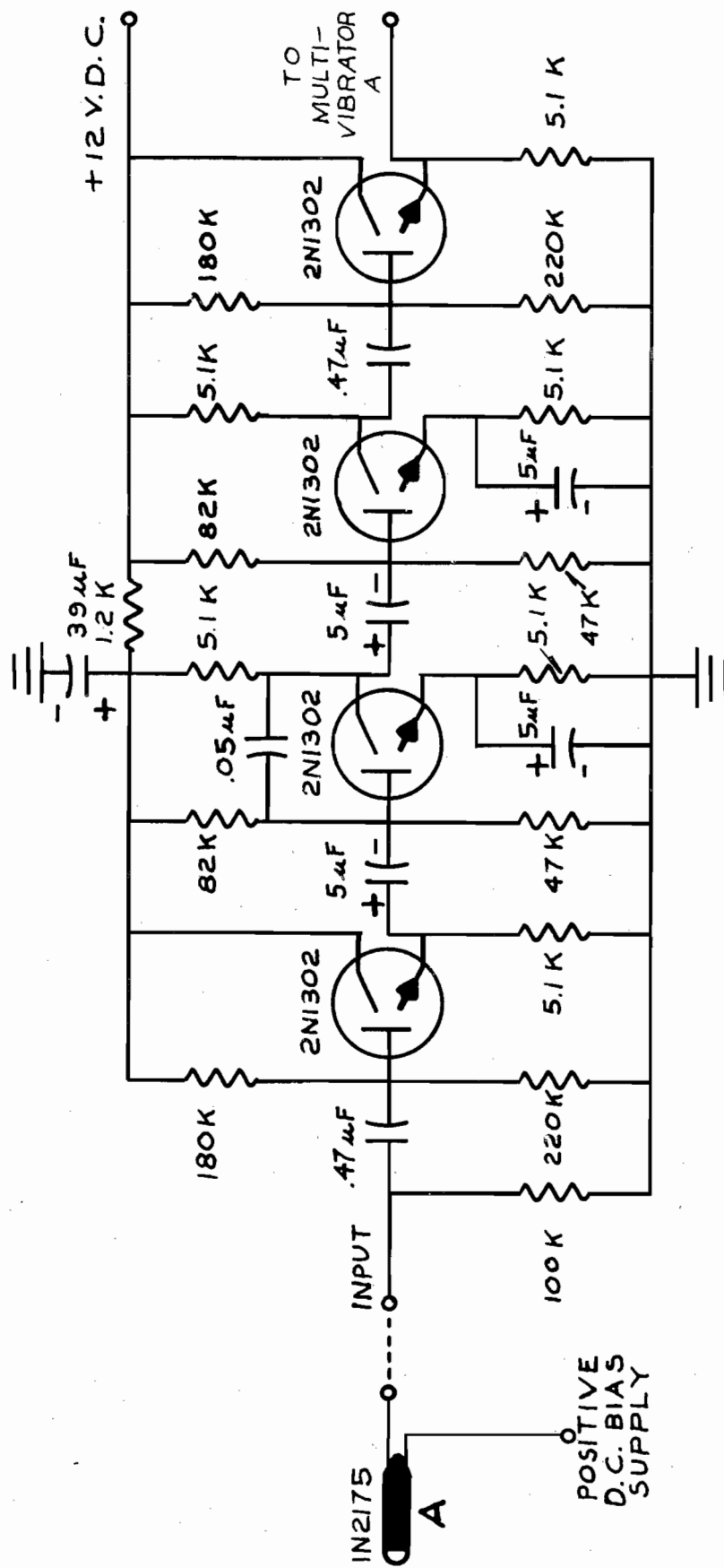


Figure 3. Amplifier Circuit Diagram

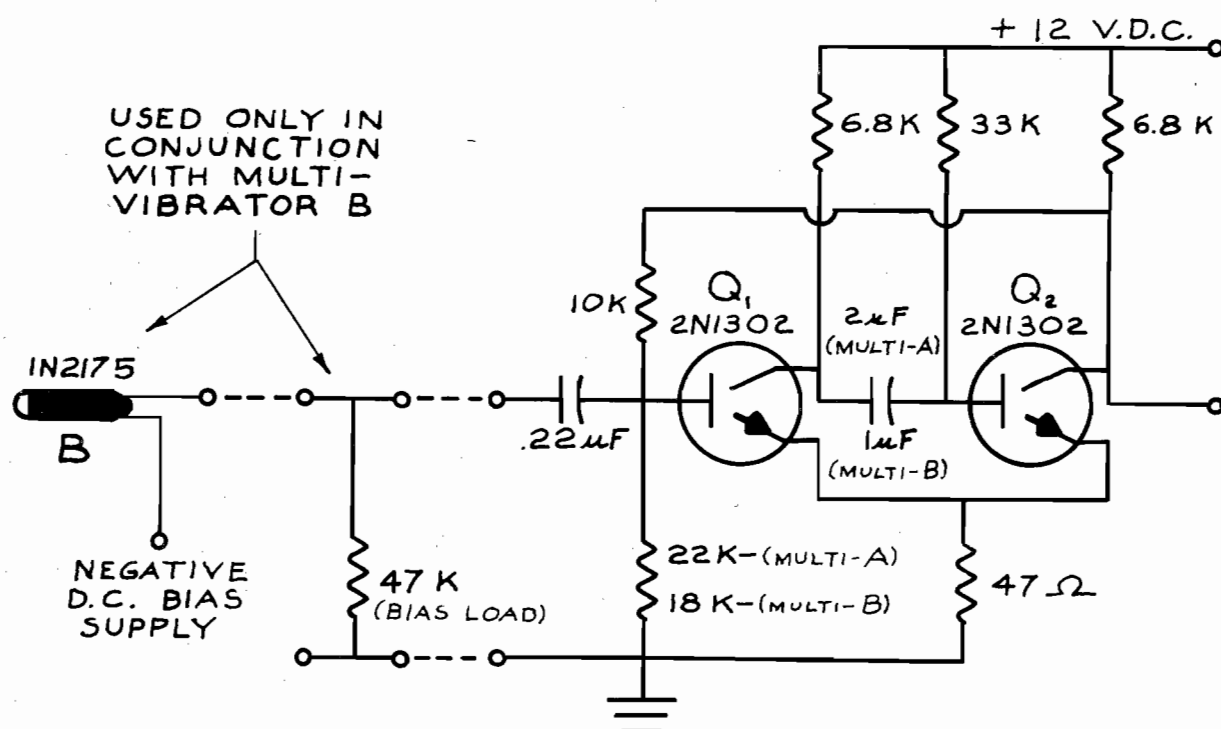
The overall pulse amplification of the amplifier is about 1000. This was measured by applying a 1 millivolt square wave at the input and observing the output. Output spikes of 1.0 volt magnitude were observed which decayed with a time constant of about 0.2 millisecond. The gain was measured with the amplifier loaded by multivibrator A.

A 0.05 microfarad feedback capacitor was included from the collector to the base of the second stage transistor. The amplifier is unstable without applying feedback in some manner. Initially a 0.005 microfarad capacitor was used for this purpose. With this configuration, the amplifier gain was found to be about 1600. The increased gain, however, was found great enough to cause triggering of multivibrator A whenever multivibrator B was triggered.

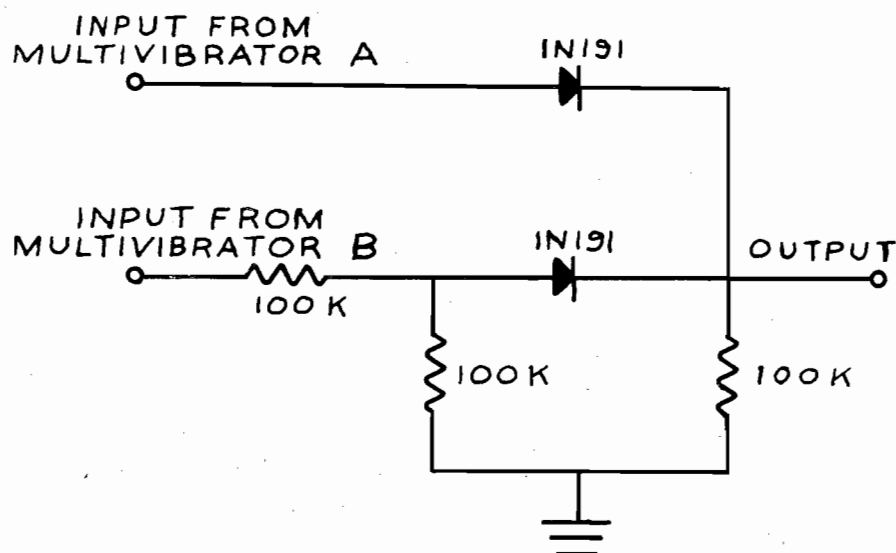
### 3. Multivibrators

The circuit diagram for the monostable multivibrators is shown in Figure 4a on the following page. The circuits for both multivibrators are identical with the exception of the base resistors of the respective input transistors and also the timing capacitors. In the steady-state, the input transistor,  $Q_1$ , is cutoff (OFF), and the output transistor,  $Q_2$ , is saturated (ON). Slight characteristic differences among transistors make it necessary to use a slightly lower input base resistance for multivibrator B in order to assure cutoff.

If an input trigger of sufficient magnitude is received, regeneration will occur and the multivibrator will exist in its astable



(a) Monostable Multivibrator Diagram



(b) OR Circuit Diagram

Figure 4. Multivibrator and OR Circuit Diagrams

condition ( $Q_1$  ON,  $Q_2$  OFF) until the timing capacitor (charging through the 33K resistor) charges sufficiently to allow  $Q_2$  to turn ON. The amount of time in which the astable state exists is approximately equal to 0.7 times the RC product of the timing capacitor and its charging resistor. <sup>10/</sup> In this case the charging resistor is 33K.

A 47K resistor is included with the multivibrator B circuit to serve as a biasing load for photodiode B.

Multivibrator A requires 2.2 milliamperes of supply current. The base voltage of  $Q_1$  is 0.085 volt. This voltage must be raised to 0.38 volt in order to trigger the circuit; however, this base circuit is decoupled from the input with a capacitor, and therefore an input pulse of about 0.29 volt will trigger the multivibrator. When loaded by the OR circuit, its output is a 7.3 volt pulse of 45 milliseconds duration. When unloaded, the output magnitude is 7.6 volts.

Multivibrator B also uses 2.2 milliamperes of supply current. Its input base bias voltage is 0.080 volt which must be raised to 0.35 volt to accomplish triggering of the circuit. A 0.27 volt pulse at the input is sufficient for this purpose. The loaded output is a 7.3 volts, 25 milliseconds pulse. The unloaded output is also 7.6 volts.

### 3. OR Circuit

The OR circuit is illustrated in Figure 4b on the previous page. A 1N191 general purpose, germanium diode is used in this circuit. The forward conducting resistance of the 1N191 is about 450 ohms.

The output of multivibrator A passes through the OR circuit only slightly attenuated. When an input from multivibrator A is present, the OR circuit output is a 7.2 volts, 45 milliseconds pulse. This is the characteristic output of snow detection.

The resistive attenuation network seen at the B input reduces the output of multivibrator B from 7.3 volts to 2.3 volts. A 2.3 volts, 25 milliseconds pulse is the characteristic output of rain detection.

Should inputs from multivibrators A and B exist simultaneously, the OR circuit output is the same as the characteristic snow output. This is because the output resulting from the A input back biases the diode in the B input. The OR circuit output when neither multivibrator output exists is about 0.075 volt which is slightly less than the steady-state output collector voltage of multivibrator A.

The OR circuit is passive, and the characteristics given apply only when high impedance loads are applied at the output terminals. Should this system be used to drive a recorder load which requires a significant amount of power from the circuit, an active type OR circuit would have to be designed which is capable of delivering the required power.

## OPERATIONAL CHARACTERISTICS

1. System Layout

The system was arranged in operational configuration as is shown in Figure 5 below, in order to obtain some of the operational characteristics of the instrument. Figure 6 on the following page illustrates the geometric arrangement of the photodiode housings and the light source. The plane of illustration of the figure is horizontal as viewed from above.

The photodiode housings and light source were mounted on ring-stands to permit easy manipulation of the geometric parameters involved.

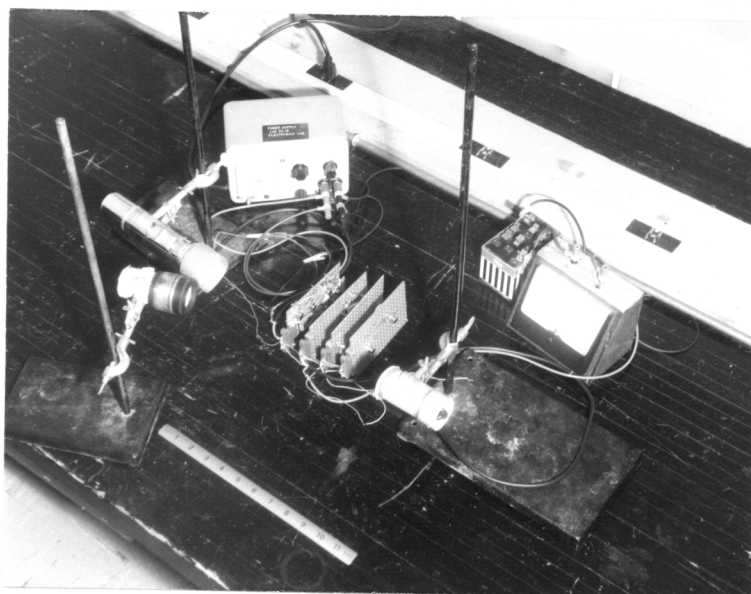


Figure 5. Operational System Configuration

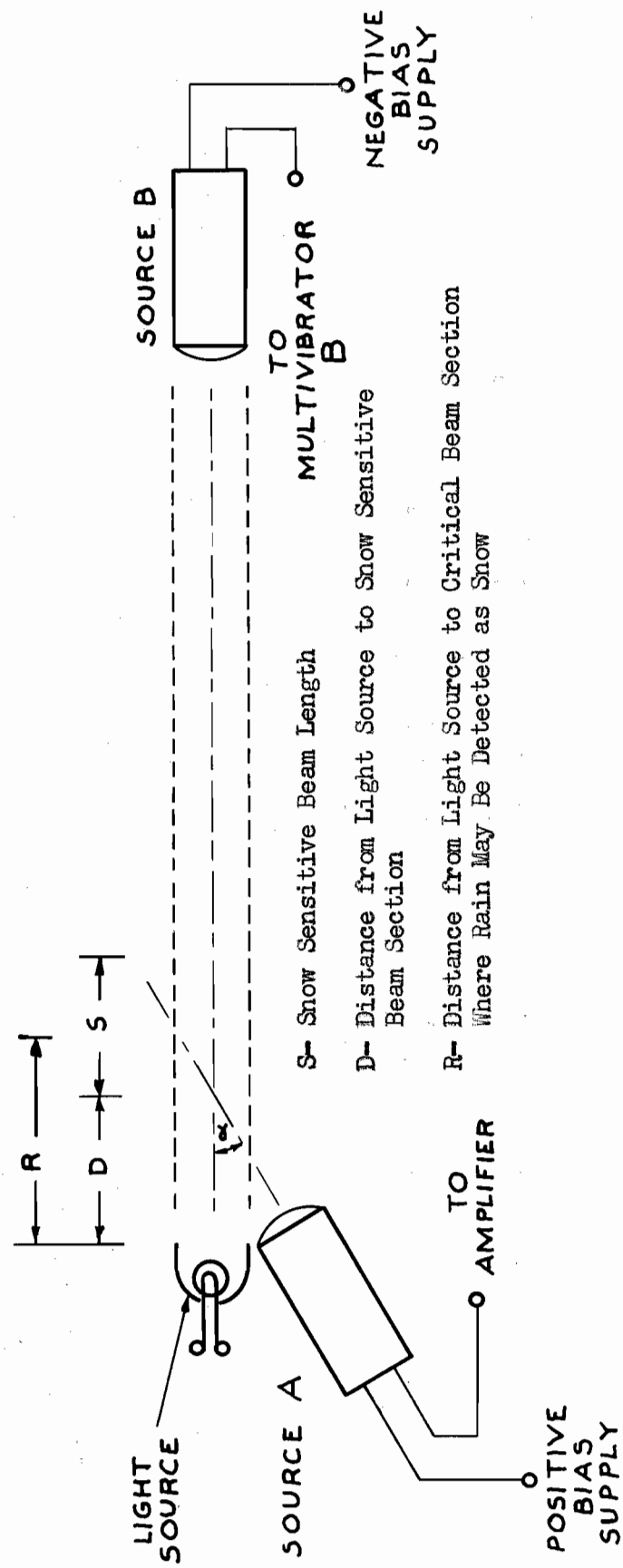


Figure 6. Operational Configuration Illustrating Geometric Parameters

## 2. Geometric Characteristics

As was mentioned previously, water droplets passing through certain sections of the light beam produce outputs from source A which are of the order of magnitude of those outputs produced by simulated snow particles. Experiments with the developed circuitry demonstrated that these outputs were sufficient to cause triggering of multivibrator A when the water droplets were passed through a certain critical section of the beam. The beam length for which multivibrator A is sensitive to triggering resulting from water droplets was found to be difficult to measure. This is because not every droplet passed through this critical section produced an output pulse. In some cases as many as ten droplets were required to produce one output from multivibrator A. The distance from the light source to a point at which the system is initially subject to erroneous detections of rain for snow is designated "R" in Figure 6.

As the angle between the axes of photodiode A and the light source is lessened, the beam length for which the system is sensitive to simulated snow is increased. This angle is referred to as "alpha", and is illustrated in Figure 6. The distance from the light source to a point at which source A becomes sensitive to snow particles is designated "D" in the figure. The section "S" is the beam length for which source A is snow sensitive.

An experiment was arranged to determine the functional relationship between R, D, S, and alpha. System outputs were observed on a



Tektronix 503-type oscilloscope. Since all of the variable measured in this experiment are defined with respect to effects observed at multivibrator A, photodiode B was not used for this portion of the experiment. A  $1/4$  by  $1/4$  inch slice of styrafoam-type plastic was used to simulate snow instead of the paper particles previously used. The styrafoam particle was attached to the end of a long black wire, thus enabling good control of the location of the particle as it was manually passed through the beam. Water droplets were issued from a medicine dropper.

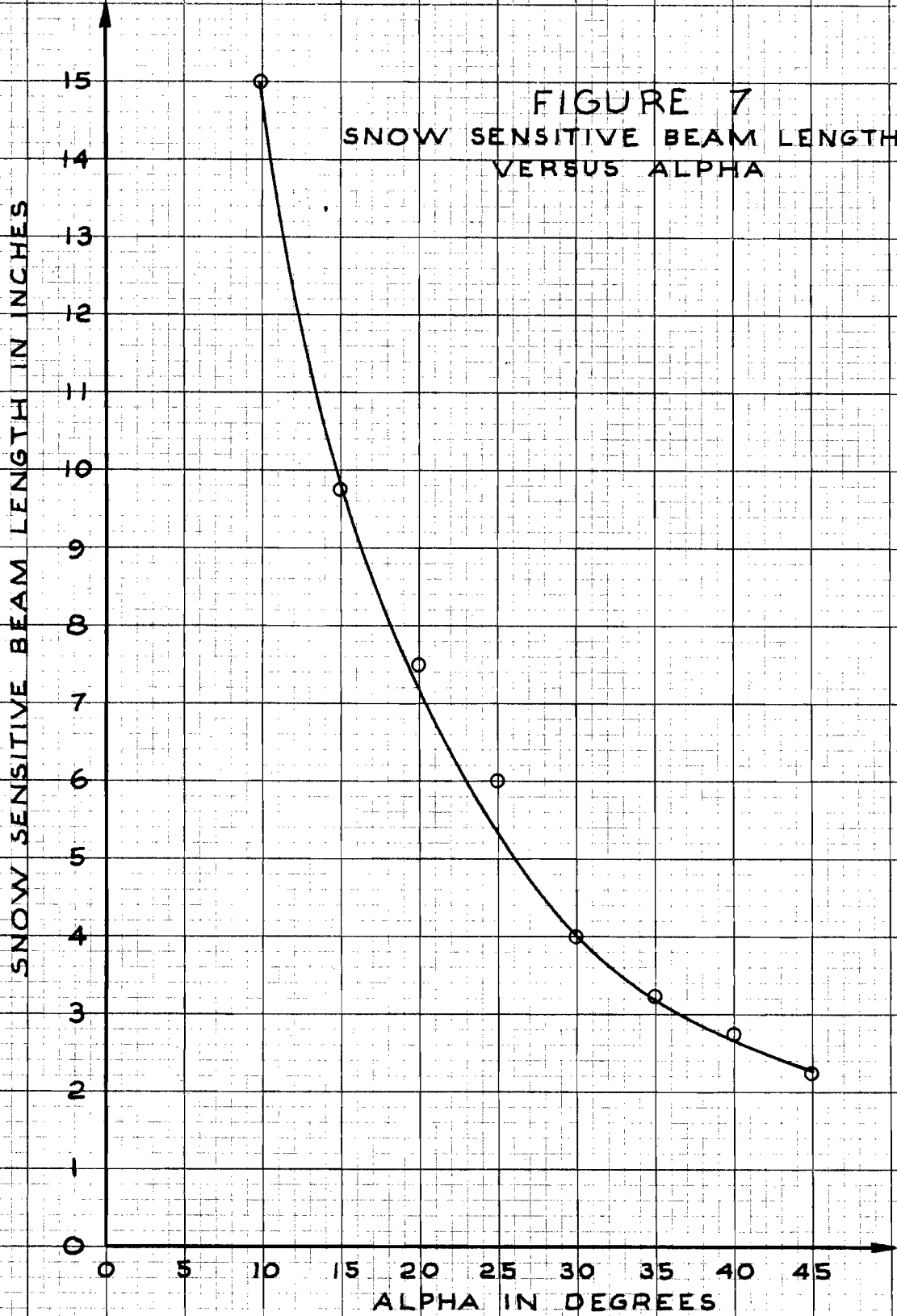
The distances R, D, and the sum of D and S were measured for various values of alpha in the range of 10 to 45 degrees. From these data S was calculated. The results are tabulated in Table 3 below. A plot of the beam length S as a function of alpha is shown in Figure 7 on the following page.

Table 3

GEOMETRIC CHARACTERISTICS OF OPTICAL SYSTEM PERFORMANCE

Alpha (degrees)	D (inches)	S - D (inches)	S (inches) (calculated)	R (inches)
10	5 $1/2$	20 $1/2$	15	9
15	3 $1/2$	13 $1/4$	9 $3/4$	6
20	3	10 $1/2$	7 $1/2$	5 $1/2$
25	2 $1/2$	8 $1/2$	6	4
30	2	6	4	3 $1/4$
35	1 $1/2$	4 $3/4$	3 $1/4$	3
40	1 $1/2$	4 $1/4$	2 $3/4$	2 $1/4$
45	1 $3/8$	3 $5/8$	2 $1/4$	2

FIGURE 7  
SNOW SENSITIVE BEAM LENGTH, S,  
VERSUS ALPHA



It was noted while determining the snow sensitive beam length, that the sensitive area was roughly a parallelogram as is shown in the shaded cross sectional beam area illustrated in Figure 1c, page 14. Assuming a constant beam width (non-divergent) the total cross sectional area for which the instrument is snow sensitive is then proportional to the beam length  $S$ . The beam width of the light source used in this experiment was approximately two inches. The sensitive cross-sectional area for an alpha of ten degrees is then approximately 30 square inches.

The critical section at which multivibrator A was triggered by water droplets was found to occur within the snow sensitive area for every angle tested. The length of this section was not recorded due to difficulties in producing these erroneous outputs. This length was never observed to be greater than one inch in any case except when the intersection angle, alpha, was set equal to ten degrees. In this case, detection errors were observed for approximately two inches of the beam length. In a functional system, this section would have to be shielded from precipitation particles to assure reliability of results.

### 3. Nature of Recorded Outputs

In order to demonstrate the manner in which rain is distinguishable from snow on a graphical recording, a model 135A, X-Y recorder made by the Moseley Company was connected to the OR circuit output.

The operational configuration was arranged for an alpha of ten degrees, since a greater snow sensitive beam length is obtained for lesser values of alpha. The distance from the light source to the lens opening of the photodiode B housing was set at 15 inches. A 30 volt supply was used to supply photodiode B. The bias current was 0.6 milliampere. The simulated precipitation particles were passed through the beam and characteristic detection outputs were observed on the recorder. Care was exercised to assure that no water droplets were produced in the area from nine to eleven inches from the light source to assure that errors were not made due to the water droplet sensitivity of multivibrator A in this section.

Three of these recordings are illustrated in Figure 8. The different recordings of the figure are (a) characteristic snow detection output for a 12 volt, photodiode A supply, (b) characteristic snow detection output for a 30 volt, photodiode A supply, and (c) rain detection characteristic output. For the recordings the functional sensitivity of the recorder was set at one volt per inch of deflection. A time sweep of five seconds per inch was used.

The recorder responded to water droplet detections with recorded pulses of about 0.35 inch. The snow detection response was a recorded pulse varying in height from 0.70 inch to 0.85 inch. The differences in these pulse heights are due to the presence or absence of outputs from multivibrator B occurring slightly before or after an output from multivibrator A. With photodiode B disabled, it was found that the snow detection output recorded pulses were consistently 0.70 inches in height. The snow detection outputs are easily distinguish-

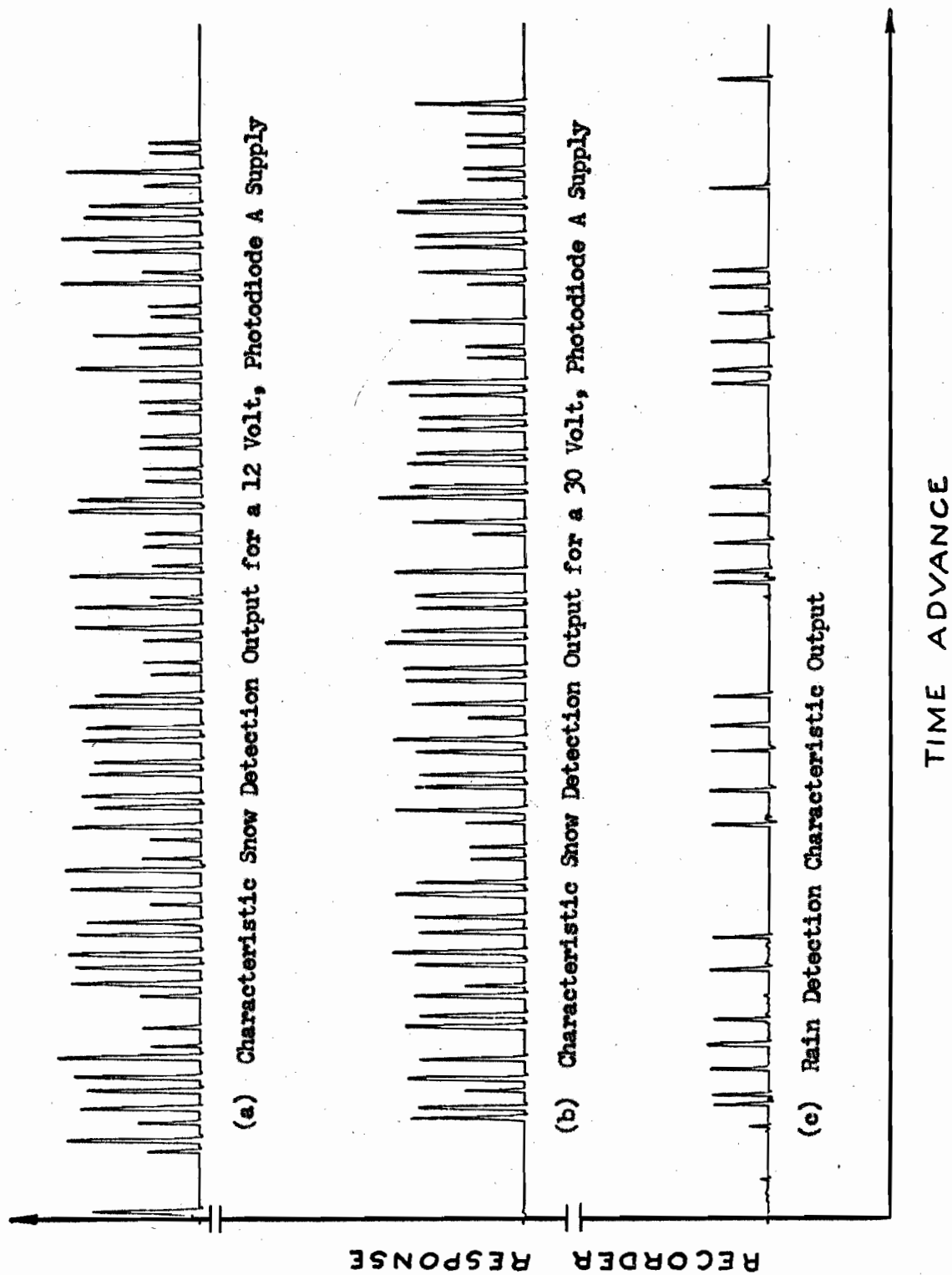


Figure 8. Illustration of Recorded Outputs

able from the rain detection outputs, however. Due to the short duration of the output pulses, the recorder did not respond entirely to a height representative of the output pulse magnitudes.

Random errors were detected for the snow recordings. Snow detection was distinguishable from that of rain, however, by the intermixed appearance of snow and rain characteristic outputs. It was found that the snow detecting capability of the instrument was dependent upon the orientation of the particle as it fell through the sensitive area. Particle orientation was difficult to regulate since the particle was manually manipulated. In general it was observed that best results were achieved when the particle was placed with the broadside vertical in such a manner as to reflect light toward the detector. Snow detections could be made, however, with a particle held horizontally presenting a reflecting area of about  $1/8$  inch by  $3/32$  inch rectangular dimensions to the beam. To detect these smaller particles, it was necessary to pass them in portions of the beam within  $7\frac{1}{2}$  inches of the light source, and also within the detection sensitive area.

#### 4. Photodiode Supply Voltage Effect

For a given constant illumination intensity, the output current of the 1N2175 remains nearly constant for a wide range of bias voltages. It functions essentially as a current source in a manner analagous to the vacuum pentode. For this reason, the photodiode supply voltage used should not greatly affect the instrument sensitivity as long as a good

linear quiescent point is maintained. Photodiode A was found to respond well to supply voltages varying from 2 to 30 volts. The snow detection recordings of Figure 8 illustrate this effect. When a 12 volt supply was used, 35 correct detections and 29 erroneous detections were produced. A 30 volt supply produced 42 correct and 15 erroneous outputs. Although less errors were produced using the 30 volt supply, this improved performance can not be directly traced to the increased voltage. Errors tend to be produced in uninterrupted succession. For this reason it appears that they result from variations in the simulated snow particle orientation.

Due to saturation effects, the system was found unable to detect water droplets when the photodiode B supply potential was lowered below 18 volts. The tendency of the diode to saturate as the supply voltage is lowered is illustrated in Table 4. In this case it appears that the light source was too intense to produce good operation of the photodiode at low supply voltages.

Table 4

SATURATION EFFECT OF LOWERING PHOTODIODE SUPPLY VOLTAGE

Supply Voltage	Photocurrent (milliamperes)	Bias Voltage
30	0.50	7.0
25	0.46	4.5
20	0.41	0.92
15	0.32	0.09
10	0.22	0.05

## CONCLUSION AND RECOMMENDATIONS

1. Conclusion

The luminous reflectivity of snow, as compared to that of rain, is a suitable property by which a system may be developed which is sensitive only to the presence of falling snow and not to rain. If both solid and liquid phases are to be detected and identified, the reflective properties of snow may be used in conjunction with the light attenuant properties of both phases to successfully accomplish this function.

2. Recommendations

Experiments with the laboratory prototype model were successful in distinguishing between the simulated particles of the two precipitation phase types. A field model of the instrument should be constructed and tested under the actual operational environment in order to determine necessary adjustments required to render the detection scheme reliable. The output data must correlate well with phase data from another reliable source before the detection method can be considered successful. Lack of another available phase detection scheme will probably require that data taken by human observation be used to establish the reliability of the instrument. It is recommended that further research be directed toward (a) the establishment of the best geometric configuration of the detectors and light source, (b) the development of an optimum circuit which will perform satisfactorily with a minimal amount of power consumption



and (c) the design of an adequate instrument encasement and mounting structure. Recommendations for the conduct of each of these research areas is discussed below.

(a) Geometric Configuration

A desirable operational angle, alpha, should be established. In general as alpha is decreased the snow sensitive beam length is increased, assuming that no variation in light intensity occurs along the locus of the light path. Larger angles of alpha not only give a smaller sensitive beam length, but the critical section of the beam for which the instrument is subject to error becomes a larger portion of the snow sensitive area.

A study is also recommended which would determine the feasibility of using multiple snow detectors placed radially around the light source. This configuration would increase the probability of a given snow particle being sensed by one of the elements. A separate amplifier would not be necessary for each additional detector since all detector outputs could be fed to an OR-type circuit, the output of which would be used as a signal input to the amplifier.

The effect of variations in the background light level should be determined. The device responds only to variations in the incident light intensity. The possibility of outputs occurring due to variations in the background light level, as may occur in an outdoor environment, should be investigated. A black background-type shield may be required to minimize these effects.

(b) Circuit Optimization and Sensitivity

Because of the relative inaccessibility of the operational site it would be desirable that the instrument operate on battery power for the duration of periods between site visitations. Due to the expense of supply batteries, it would be desirable to minimize battery drain and extend the duration of periods for which the instrument may operate unattended. The light source used in the laboratory prototype model requires 1.5 watts of dissipation and 0.5 ampere of battery drain. The battery drain rate for this source is twelve ampere-hours per day of continuous operation. The remaining portion of the instrument requires 7.7 milliamperes of current, excluding the bias current used by photodiode B, and dissipates 92.4 milliwatts. The drain rate for this circuitry is 0.185 ampere-hour per day of continuous operation. In order to reduce this required drain, it is recommended that a search be conducted to obtain the light source which will produce the required light intensity for satisfactory detection and requires a minimum of battery drain. Further circuit design directed at minimizing power consumption of the logic circuitry might also be desirable.

A study to determine the feasibility of using a cycling ON-OFF time switching mechanism to further reduce battery capacity demands is also recommended. The ON-time duration would be determined by a statistical study to establish the probability of a precipitation particle passing within detectable proximity of the instrument in a given length of time, for the least intense storm which is to be detectable. The OFF-time would be determined by the degree of refinement required of the samplings.

Because of the amount of power drain involved, batteries may be the most costly item in the system. The use of cadmium-nickel or another type of rechargeable battery is recommended since a maximum of ampere-hour drain per investment cost may be obtained from these types over long periods of service.

The circuit sensitivity required to detect the smallest desired precipitation particle should be determined. If a greater amplifier gain is required than that of the prototype model, stability problems resulting from feedback of the snow output multivibrator to the amplifier input may develop. These problems will at least partially determine the circuit layout and possible shielding scheme used with the instrument case itself.

Temperature cycling tests should be conducted on the circuitry. Assurance must be obtained that the multivibrators are stable and that the amplifier gain remains sufficient to maintain minimum instrument sensitivity requirements for the temperature extremes under which the device must operate.

#### (c) Instrument Encasement and Mounting Structure

Aside from structural stability and spacing requirements, certain other factors will affect the design of an instrument housing facility. Due to the gain of the amplifier, the system is subject to interference from outside noise sources. The logic circuits should be enclosed in a metallic container to reduce the interference effects of atmospheric electrical disturbances. If the diodes are mounted in housings separate from the main housing, it is recommended that a coaxial-type

cable provide the interconnection between the photosensors and the logic circuitry. Shielding within the main housing itself may be necessary to prevent internal instability of the circuitry.

The photodiode housings should be designed to avoid loss of lens transparency due to moisture collection on the lens. Provision should also be made to allow fine alignment of the lens, photodiode and light source combination to provide accurate focusing and manipulation of the optic system.

A method of shielding the critical beam section from the incidence of any type of precipitation particle must also be devised to avoid errors. One possibility is to locate the housing of photodiode B (if used) within this area. A portion of the snow sensitive section is lost by this method, however.

LIST OF REFERENCES

1. "Precipitation Measurement Study." Illinois State Water Survey Meteorologic Laboratory, University of Illinois, Urbana, Illinois, Final Report, February 15, 1964, pp. 24-36.
2. Ukichiro Nakaya, Snow Crystals Natural and Artificial. (Cambridge: Harvard University Press, 1954), pp. 117-125.
3. J. Alan Chalmers and F. Pasquill, "The Electric Charges on Single Raindrops and Snowflakes." Physical Society of London Proceedings (The University Press, Cambridge), Vol. 50, 1938, pp. 1-15.
4. David O. Zopf, "Engineering Aspects of Weather Modification." Proceedings of the Thirty-Third Western Snow Conference, Colorado Springs, Colorado, 1965.
5. Personal correspondence to author from Mr. C. P. Edwards, Senior Engineer, E. Bollay Associates, Incorporated, Boulder, Colorado, June 22, 1965.
6. Malcolm Mellor, "Properties of Snow." Cold Regions Science and Engineering, Part III, Section A, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, December 1964, pp. 86-91.
7. George F. Taylor, Elementary Meteorology. (New York: Prentice-Hall, 1954), pp. 154-155.
8. Malcolm Mellor, "Properties of Snow." Cold Regions Science and Engineering, Part III, Section A, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, December 1964, p. 3.
9. Malcolm Mellor, "Properties of Snow." Cold Regions Science and Engineering, Part III, Section A, Cold Regions Research and Engineering Laboratory, New Hampshire, December 1964, p. 84.
10. Joseph A. Walston and John R. Miller, Editors, Transistor Circuit Design. (New York: McGraw-Hill Book Company, Inc., 1963), pp. 380-381.

## APPENDIX

1N2175 Photodiode

Characteristics

Source: Texas Instruments, Incorporated  
Dallas, Texas  
Bulletin No. DL-S 623313  
December, 1962

