THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Electrical Engineering   Space Physics Research Laboratory

Report No. GQ-6

1 February 1960 to 1 July 1960

MEASUREMENTS OF ATMOSPHERIC PRESSURE, TEMPERATURE, DENSITY, AND COMPOSITION AT VERY HIGH ALTITUDES

Prepared for the project by

A. F. Nagy

UMRI Project 2804

under contract with:

DEPARTMENT OF THE ARMY
U. S. ARMY SIGNAL CORPS SUPPLY AGENCY
CONTRACT NO. DA-36-039-sc-78131
FORT MONMOUTH, NEW JERSEY

administered by:

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE   ANN ARBOR

July 1960

INDIVIDUALS CONTRIBUTING DURING THE REPORT PERIOD

Boyd, R. L.	Engineer
Hescheles, C. S.	Draftsman
Kanal, M.	Mathematician
Nagy, A. F.	Engineer
Nary, D. B.	Secretary
Niemann, H. B.	Engineer
Spencer, N. W.	Project Director

1.0 INTRODUCTION

This is the sixth report in a series which outlines a research effort whose object is the determination of the ambient pressure, temperature, density and composition of the earth's atmosphere at altitudes where the mean free path of the neutral particles is appreciably greater than the dimensions of the measuring object.

As noted in previous reports, the effort is devoted to the following tasks:

(a) a theoretical study of the general measurement problem, and several associated problems;

(b) development of suitable sensors;

(c) development of associated instrumentation to permit fruitful employment of the sensors; and

(d) development of an ultra-high-vacuum system capable of achieving pressures as low as the state of the art permits, with the final objective of sensor calibration and testing.

The following sections describe the work done in these areas since the last report.

2.0 THEORETICAL STUDY

In previous reports it has been mentioned that an investigation directed towards the determination of the optimum orifice size with reference to the main spherical body and its motion is being carried out. The result of this work is included in this report as an appendix.

Using Eq. (7) from the appendix, values of the orifice area have been computed for a response time of 10^{-3} sec and a chamber volume of 10 cm^3 at various altitudes. They are given in Table I. These values indicate that for this experiment an orifice area of 0.5 cm^2 will be a good compromise.

TABLE I

ORIFICE AREA FOR A RESPONSE TIME OF 10^{-3} SEC, AND CHAMBER VOLUME OF 10 CM^3 AS A FUNCTION OF ALTITUDE

Height (km)	Temperature (K°)	Orifice Area (cm^2)
100	199	1.031
125	571	0.609
150	1031	0.453
175	1359	0.395
200	1404	0.388
225	1414	0.387
250	1415	0.387

3.0 SENSOR DEVELOPMENT

The "prototype" omegatron (Serial No. 8) which was outlined in the last report has been built and is presently undergoing extensive tests. It is a metallic tube consisting of two main parts, as shown in Fig. 3.1: the envelope, which has the polepieces brazed into position, and the base plate, which supports the tube elements mounted on four sapphire rods. The "plates" are made from nonmagnetic stainless-steel mesh to permit free particle movement. The electron emission is produced by a short .003-in. tungsten filament supported by two molybdenum rods. These rods are glass-coated and are attached to a platinum sheet which is, in turn, spot-welded to the stainless-steel mesh. The anode which collects the electrons is mounted in a similar fashion on the opposite side of the chamber. Electric connections to the tube elements are made by molybdenum rods pushed through a 1/2-in. Teflon gasket supported by the bottom plate. A Teflon O-ring is used to vacuum-seal the base plate to the envelope.

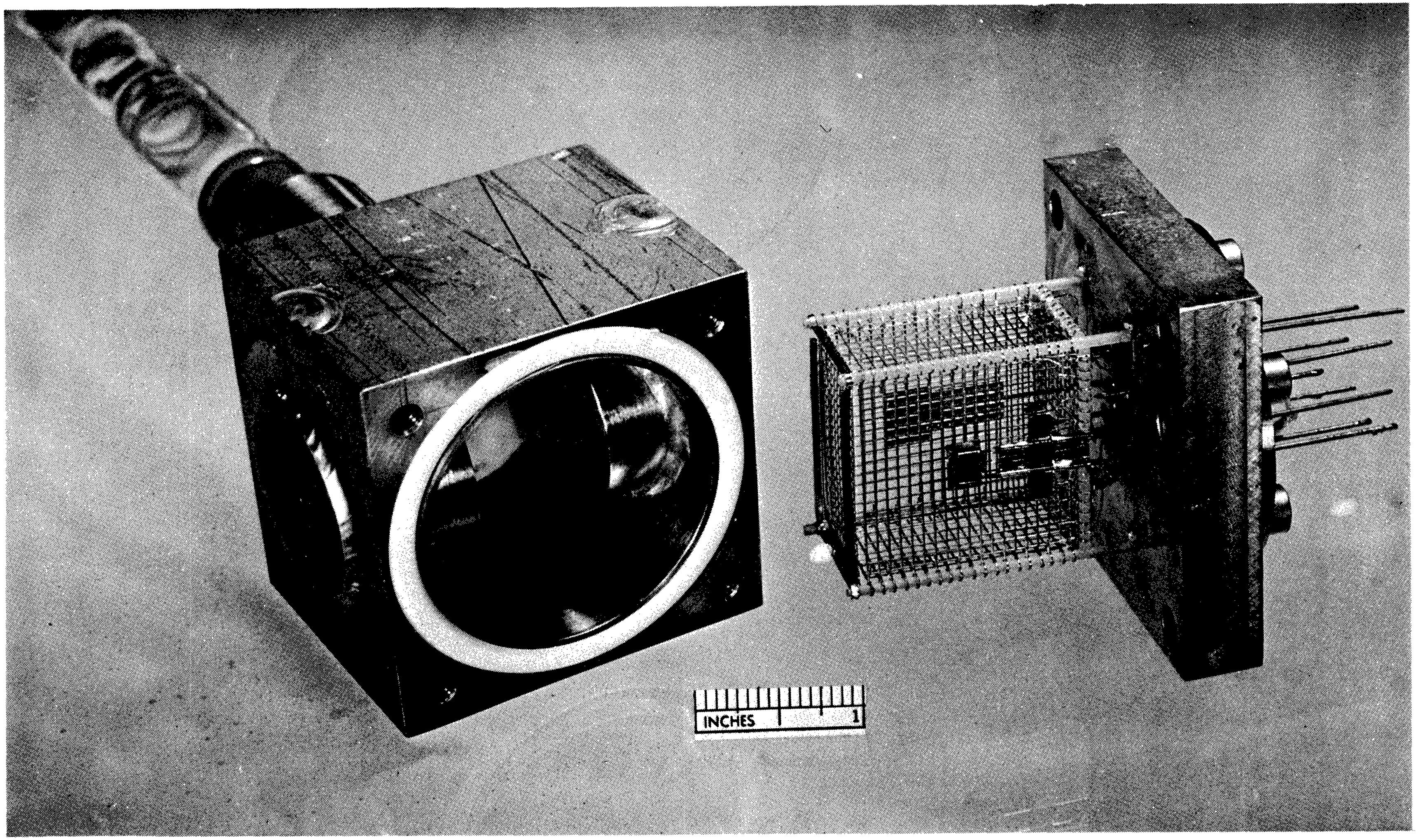


Fig. 3.1. Omegatron, Serial No. 8.

4.0 INSTRUMENTATION

4.1 SPHERE

The Vector TRPT 250 all-transistor 1/3 Watt telemetry transmitter has been chosen as the most suitable for this experiment, taking into consideration such factors as size, availability, and power requirements.

As mentioned in the last report, the electrometer system necessary to convert the output current of the omegatron and the ionization gauge to suitable voltage levels for telemetry has been developed and built for another experiment and will be flight-tested in the near future.

The filaments of both the omegatron and the ionization gauge must maintain a constant emission over a wide range of ambient conditions. To achieve this, a filament regulator is necessary. For testing purposes in the laboratory, a series type regulator is satisfactory; such a device has been designed and built, the circuit diagram of which is shown in Fig. 4.1. While the series regulator is a good enough laboratory apparatus, it is not practical for flight use as it is very inefficient. A large fraction of the power from the battery is lost in the series transistor,thus increasing the ampere-hour capacity requirement of the battery and also presenting a secondary problem in heat dissipation.

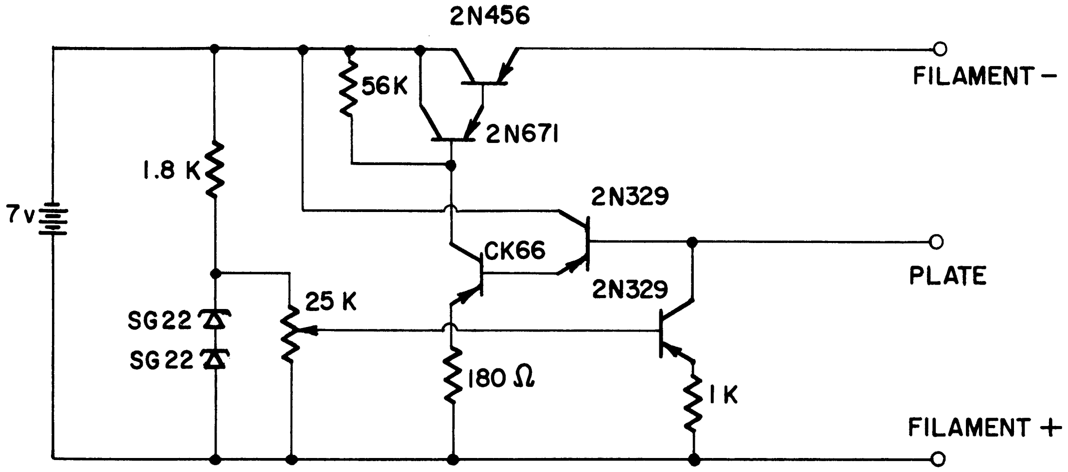


Fig. 4.1. Circuit diagram of the series type filament regulator.

It has been decided that a switching type regulator circuit using transistors would be the most suitable for our purposes. Such a regulator was designed, built, and tested. Figures 4.2 and 4.3 show the completed printed circuit board and the circuit diagram, respectively. To provide the proper heat sink for the power transistor, it is mounted separately from the board. The regulator is basically an asymmetric free-running multivibrator with controllable on-off periods. The operation of the system can be described as follows. Transistors T_4, T_5, and T_6 make up the emitter coupled multivibrator. The filament of the device to be regulated is used as the common emitter resistor. Transistors T_5 and T_6 are coupled together so as to be able to handle the power requirements of the filament. To obtain maximum battery economy, the power supply is made up of two batteries connected in

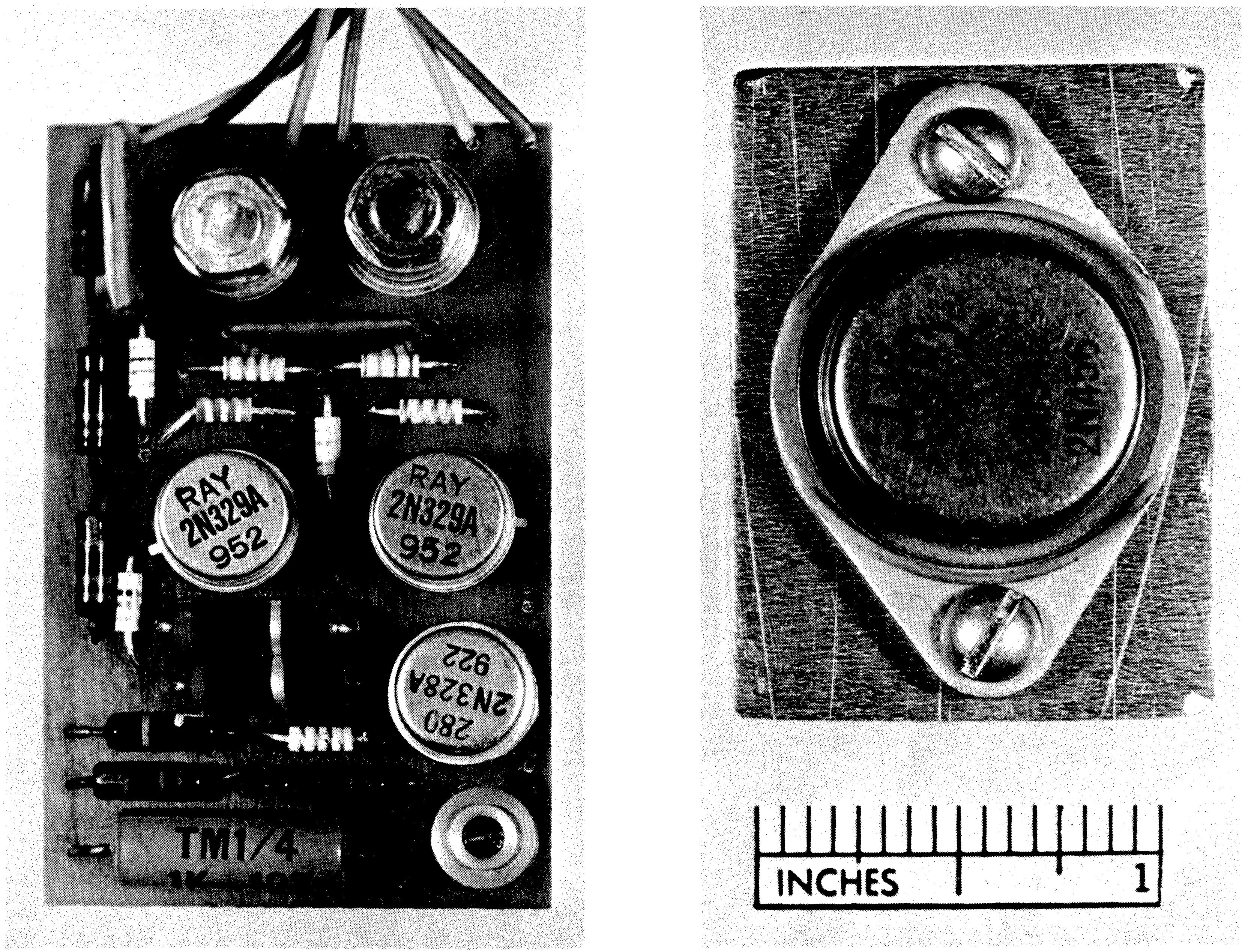


Fig. 4.2. The switching type filament regulator.

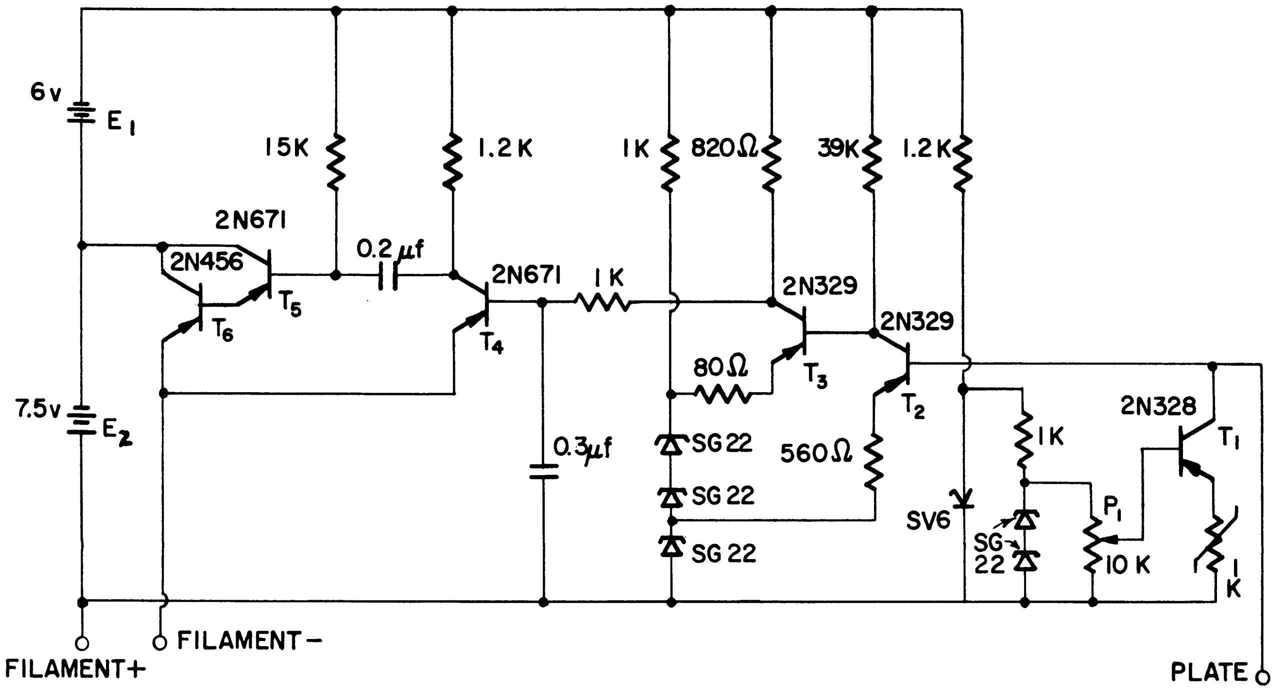


Fig. 4.3. Switching type filament regulator circuit.

series. There is a 7.5-volt high-current-capacity SilverCell providing the power for the filament, and a 6-volt mercury battery connected in series with it, providing a total of 13.5 volts to supply the rest of the circuit. Variation in the on-off rate of the T_5 and T_6 half of the multivibrator is accomplished by varying the base potential of T_4. This potential is set by T_3 and T_2 which are connected as conventional common emitter amplifiers. To get maximum sensitivity, the base current of T_1 is the algebraic difference between the current from the constant current supply T_7 and the emission current of the device to be regulated. Potentiometer P_1 permits adjustment in the emission level of the filament. The emission current stays constant, to within 1% when E_1 changes from 2.5 to 7.5 volts, and within 4% when filament supply E_2 changes from 6.5 to 9 volts.

Extensive temperature tests have been carried out and it was established that the only component requiring temperature compensation is the transistor T_1 of the reference supply. It has been pointed out[25] that temperature drifts in silicon amplifiers, properly biased and operating at temperatures below 80°C, are due primarily to changes in the base to emitter voltage V_{be}. These changes are stable with time, and are a linear function of temperature, so they can be compensated for by positive temperature coefficient resistors. This was done in our circuit by placing a Texas Instrument 1 KΩ sensitor in series with the emitter of transistor T_1. With this compensation in the circuit the variation in operating level was less than 1% up to temperatures of 60°C.

There is available from the electrometer system a 400 c/s square wave with an amplitude of 70 volts peak to peak, which is used after rectification to provide the high voltages necessary to operate the omegatrons and the thermionic gauges. Figures 4.4 and 4.5 show the printed circuit board and the circuit diagram of the high-voltage supply, respectively. It consists of two voltage doublers in series with a floating center point. Six zener diodes are connected in series to provide a regulated output voltage of approximately 110 volts.

The omegatron also needs a stable rf oscillator. Such a transistor oscillator is being developed and is ready for testing. It will be described in the next report.

4.2 ROCKET NOSE CONE

It was noted in the last report that for proper functioning of the experiment a stable platform is required for launching the sphere. It was also pointed out that, if proper precautions are taken, the rocket can be expected to remain essentially upright as it passes the 100- to 125-km level. At these heights the rocket would normally be spinning at about 1-3 rps, but a simple system employing the pressurizing helium has now been developed by Aerojet which despins the rocket at the end of the powered flight. This is done by diverting the helium to a number of small jets situated in the front end of the rocket which are controlled by a roll gyro. As this system is readily available, it will not be necessary to rotate either the sphere or the nose cone as was originally anticipated. The nose cone carrying the sphere and some associated equipment will be vacuum-sealed at a pressure of approximately 10^{-6} mm Hg to provide vacuum cleanliness and to avoid contamination.

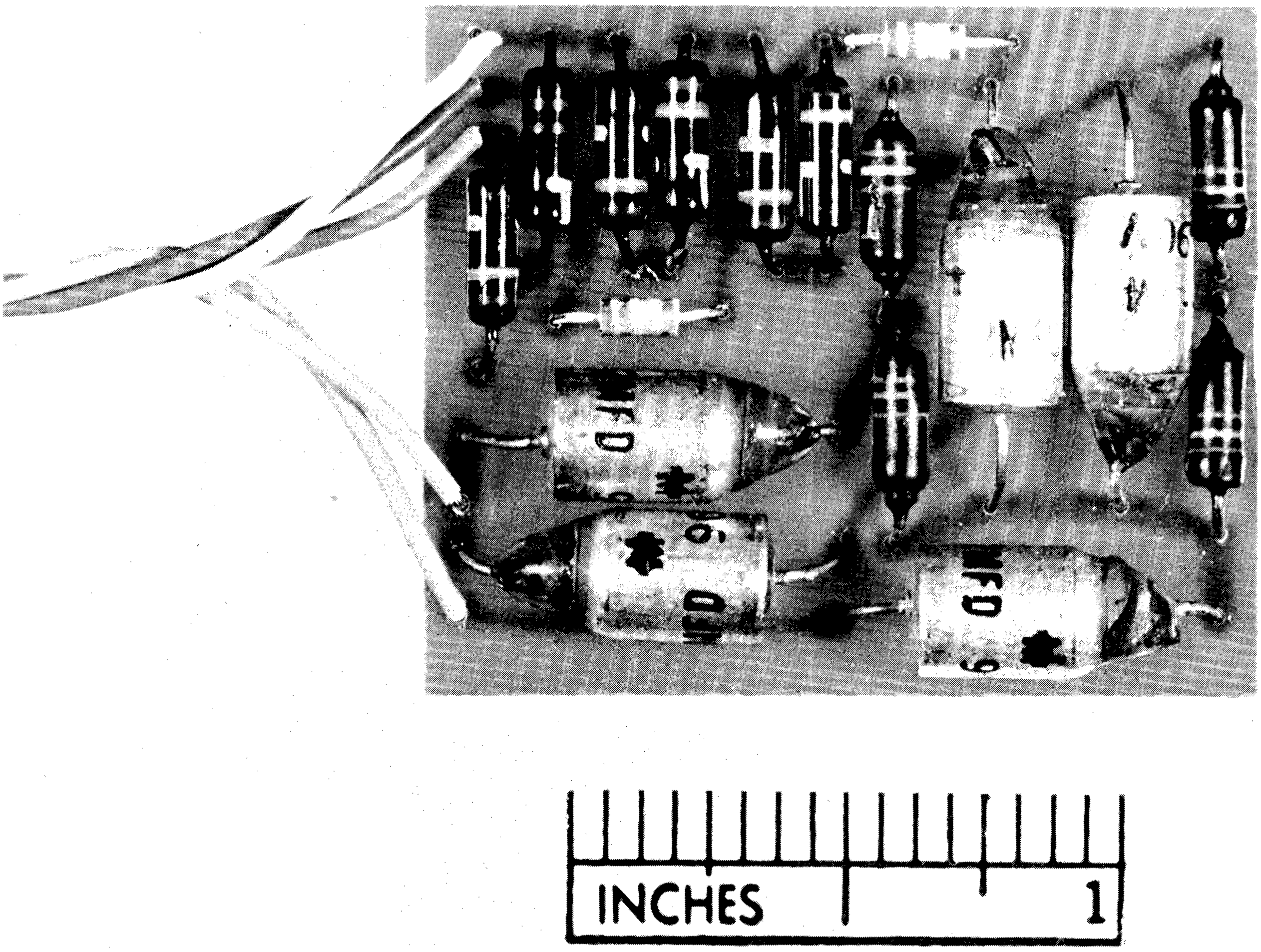


Fig. 4.4 The high-voltage supply.

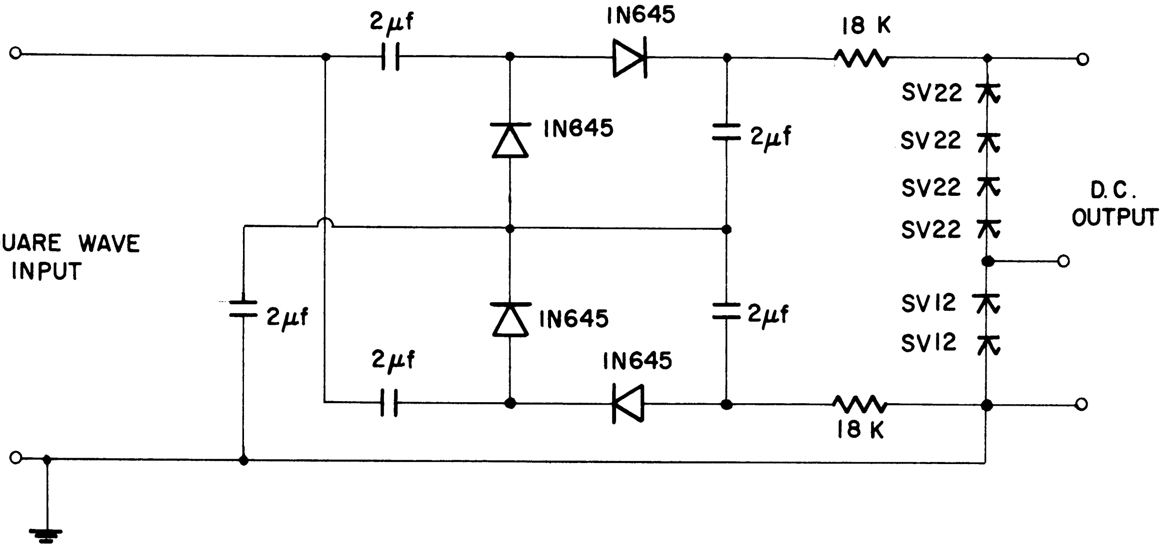


Fig. 4.5. High-voltage supply circuit.

5.0 ULTRA-HIGH-VACUUM SYSTEM

No further effort has been devoted to the UHV system. It has been reported earlier that the system is capable of attaining a pressure of ~ 5 x 10^{-11} mm Hg and is available for use.

6.0 FUTURE WORK

The extended contract is scheduled to terminate on July 31, but as the task has not yet been completed, a further no-cost extension was requested. The funds remaining under this project are expected to cover the launching and associated expenses. However, for the completion of the development and construction of the nose-cone system, the sensors and associated instrumentation, some of which has been developed for separately financed work, support from other sources is being used. It is now planned that the launching will take place late in the fall of this year.

BIBLIOGRAPHY

The following listing includes papers and reports relevant to the subject of the research effort, and which may have been mentioned in this or the previous quarterly report.

1. Sommer, H., Thomas, H. A., and Hipple, J. A., "Measurement of e/m by Cyclotron Resonance," Phys. Rev., 82, 697-702 (June, 1951).

2. Edwards, A. G., "Some Properties of a Simple Omegatron Type Mass Spectrometer," Brit. J. Appl. Phys., 6, 44-48 (February, 1955).

3. Bell, R. L., "Omegatron as a Leak Detector," J. Sci. Instr., 33, 269 (July, 1956).

4. Wagener, J. S., and Marth, P. T., "Analysis of Gases at Very Low Pressures by Using the Omegatron Spectrometer," J. Appl. Phys., 28, 1027-1030 (September, 1957).

5. Alpert, D., "New Developments in the Production and Measurement of Ultra-High Vacuum," J. Appl. Phys., 24, 860 (July, 1953).

6. Sommer, H., and Thomas, H. A., "Detection of Magnetic Resonance by Ion Resonance Absorption," Phys. Rev., 78, 806 (June, 1950).

7. Alpert, D., and Buritz, R. S., "Ultra-High Vacuum II. Limiting Factors on the Attainment of Very Low Pressures," J. Appl. Phys., 25, 202 (February, 1954).

8. Berry, C. E., "Ion Trajectories in the Omegatron," J. Appl. Phys., 25, 28 (January, 1954).

9. Brubaker, W. M., "Influence of Space Charge on the Potential Distribution in Mass Spectrometer Ion Sources," J. Appl. Phys., 26, 1007 (August, 1955).

10. Brubaker, W. M., and Perkins, G. D., "Influence of Magnetic and Electric Field Distribution on the Operation of the Omegatron," Rev. Scien. Inst., 27, 720 (September, 1956).

11. Hopkins, N. J., "A Magnetic Field Strength Meter Using the Proton Magnetic Moment," Rev. Scien. Inst., 20, 401 (June, 1949).

12. Spencer, N. W., Boggess, R. L., Lagow, H. E., and Horowitz, R., "On the Use of Ionization Gage Devices at Very High Altitudes," *Jour. Amer. Rocket Soc.*, to be published.

13. Spencer, N. W., and Boggess, R. L., "Radioactive Ionization Gage Pressure Measurement System," *Jour. Amer. Rocket Soc.*, *29*, 68 (January, 1959).

14. Spencer, N. W., *Bi-polar Probe Instrumentation No. 1*, UMRI Report 2521, 2816:1-1-S, Ann Arbor, October, 1958.

15. McNarry, L. R., *Development of a Miniature Mass Spectrometer of the Omegatron Type*, N. R. Council of Canada Report No. 4259 (ERA-31), December, 1956.

16. Paul, W., and Raether, M., "Electric Mass Filter," *Zeitschrift für Physik*, *140*, 262-273 (1955).

17. Todd, J. B., "Outgassing of Glass," *J. Appl. Phys.*, *26*, 1238-1243 (October, 1955).

18. Robinson, C. F., "Compound Ion-Resonance Mass Spectrometer," *Rev. Scien. Inst.*, *27*, 88-89 (February, 1956).

19. Dow, W. G. and Reifman, A., *Technical Report on the Measurement of Temperature and Pressure in the Ionosphere*, Univ. of Mich. Eng. Res. Inst. Report, Ann Arbor, 1946.

20. Horowitz, R., Lagow, H. E., and Giuliani, J. F., "Fall day Auroral Zone Atmospheric Structure Measurements from 100 to 188 km," *Journal of Geophysical Research*, *64*, 2287-2295 (December, 1959).

21. Morgan, W. A., Jernakoff, G., and Lanneau, K. P., "Ion Resonance Mass Spectrometer," *Industrial and Engineering Chemistry*, *46*, 1404-1409 (July, 1954).

22. Warnecke, R. J., "Étude et Realisation d'un Spectromètre de masse du Type Omégatron," Extrait des *Annales de Radioelectricité*, *XIV*, No. 58 (October, 1959), and *XV*, No. 60 (April, 1960).

23. Woodford, H. J., and Gardner, J. H., "Method for Eliminating Omegatron Radial Field Errors or for Direct Measurement of Mass Ratios," *Review of Scientific Instruments*, *27*, 378-381 (June, 1956).

24. Wagener, J. S., and Marth, P. T., "Analysis of Gases at Very Low Pressures by Using the Omegatron Spectrometer," *J. Appl. Phys.*, *28*, 1027 (1957).

25. Matzen, W. T., and Baird, J. R., "Differential Amplifier Features D-C Stability," *Electronics*, January 16, 1959.

26. Benton, H. B., "Small Lightweight Ionization Gauge Control Circuit," *Rev. Scien. Inst.*, *30*, 887 (1959).

APPENDIX

Prepared by Mr. Madhoo Kanal for inclusion in this report.

NOMENCLATURE

Σ = Area of the chamber hole.

Δt_o = Response time of the detector.

Δt = Time interval

N_i = Initial number density of the gas in the chamber.

V = Volume of the chamber.

C_{m_i} = Most probable velocity of the gas particles.

N_t = Number density of the gas in the chamber at any instant.

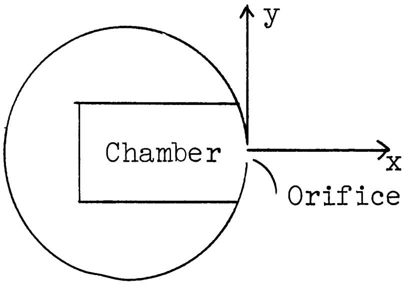
N_{io} = Number density of the gas in the chamber at $t = 0$.

INTRODUCTION

This section will deal with the study of the relation between the orifice size and the response time of the detector. In the experiment a sphere of radius R is ejected from the rocket in the upper atmosphere. The sphere moves through this atmosphere and collects certain samples of the gas from it. The gas is collected in a chamber, which is inside the sphere. The chamber has an orifice through which the flow of the gas occurs. Initially the chamber contains a gas at pressure P_1 and temperature T_1 in equilibrium with the outside medium. The equilibrium implies that the number of particles flowing into the chamber is equal to the number of particles flowing out into the surrounding medium in a certain time interval Δt. It is assumed that the gas, the walls of the chamber, and the detector are at the same temperature. A sudden change of density in the outside medium will unbalance the equilibrium between the number of particles flowing in and out of the chamber. If such sudden changes occur in short intervals of time, the orifice should be of that size which will allow the detector to sense these changes in the time interval in which they occur.

ORIFICE SIZE AND THE RESPONSE TIME OF THE DETECTOR

We begin by deriving the simple relation between the orifice size Σ and the time interval during which any sudden unbalance of equilibrium is brought to equilibrium again. Assume the gas inside and outside of the chamber to have the same law of distribution of velocities at every point of space.



Take the center of the orifice as the origin and draw from the point a system of lines to represent in magnitude and direction the velocities of the different molecules of the gas. Referred to the orthogonal axes, the coordinates of the extremity of any line will be u_x, u_y, u_z, the components of velocity of the corresponding molecules. Velocity of the sphere will add no components to the components of the particle velocity because of the way the coordinates are chosen. Since only the particles with the x-component of velocity have the probability of getting out of the chamber, the only direction taken into consideration will be the x-direction. Let N_i be the number density of the gas inside the chamber and C_{m_i}, their most probable velocity. Then the fraction of the number of particles per unit volume with the velocity component between u_x and $u_x + du_x$ is given by the Maxwellian distribution law,

$$\frac{dN_i}{N_i} = \frac{1}{\sqrt{\pi}} \exp\left(- \frac{U_x^2}{C_{m_i}^2}\right) d\left(\frac{U_x}{C_{m_i}}\right) . \qquad (1)$$

The number of particles, G_i, leaving the chamber in time Δt is then given by

$$G_i = \frac{\Sigma\ \Delta t\ N_i\ C_{m_i}}{\sqrt{\pi}} \int_0^\infty \frac{U_x}{C_{m_i}} \exp\left(- \frac{U_x^2}{C_{m_i}^2}\right) d\left(\frac{U_x}{C_{m_i}}\right) ,$$

from which we get

$$G_i = \frac{\Sigma\ \Delta t\ N_i\ C_{m_i}}{2\sqrt{\pi}} . \qquad (2)$$

Let the number density of the particles in the chamber at any instant, in the state of unbalanced equilibrium, be N_t, and let N_i be the density when the equilibrium is established. Then the net flow of particles at the orifice in infinitesimal time δt is given by

$$\delta NV = - \frac{\Sigma\, Cm_i\, (N_t - N_i)}{2\sqrt{\pi}}\, \delta t \quad , \tag{3}$$

where δN is the infinitesimal change in density of the gas in the chamber during time δt. The minus sign in Eq. (3) signifies that, if $N_t > N_i$, there is a net flow of particles from the chamber to the outside medium and hence a decrease in density. From Eq. (3) we get

$$\lim_{\delta t \to 0} \frac{\delta N}{\delta t} = \frac{dN}{dt} = - \frac{\Sigma\, Cm_i\, (N_t - N_i)}{2\sqrt{\pi}\; V} \quad . \tag{4}$$

The amount of time required for equilibrium to establish is determined by solving the simple differential Eq. (4), with the condition that at $t = 0$, $N_t = N_{io}$, where N_{io} is the initial density, i.e., before the equilibrium was unbalanced. Thus from Eq. (4) we get

$$\int \frac{dN}{(N_t - N_i)} = - \frac{\Sigma\, Cm_i}{2\sqrt{\pi}\, V} \int dt$$

or (5)

$$\mathrm{Ln}\, (N_t - N_i) = - \frac{\Sigma\, Cm_i}{2\sqrt{\pi}\, V}\, t + C \ ,$$

Where C is the constant of integration.

Now

$$\text{at} \quad t = 0 \qquad\qquad N_t = N_{io}$$

$$\therefore \quad C = \mathrm{Ln}(N_{io} - N_i) \quad .$$

Substituting the value of C in Eq. (5), we get

$$\mathrm{Ln} \left[\frac{(N_t - N_i)}{(N_{io} - N_i)} \right] = - \frac{\Sigma\, Cm_i\, t}{2\sqrt{\pi}\; V}$$

$$\therefore \quad N_t = N_i + (N_{io} - N_i)\, \exp \left(- \frac{\Sigma\, Cm_i\, t}{2\sqrt{\pi}\; V} \right) \tag{6}$$

From Eq. (6) let us define the time constant Δt_o:

$$\Delta t_o = \frac{2\sqrt{\pi}\,V}{\sum C_{m_i}} \tag{7}$$

Substituting Δt_o for $\frac{2\sqrt{\pi}V}{\sum C_{m_i}}$ in Eq. (6), we get

$$N_t = N_i + (N_{io}-N_i)\exp\left(-\frac{t}{\Delta t_o}\right) . \tag{8}$$

DISTRIBUTION LIST

(One copy unless otherwise indicated)

Director
Advanced Research Projects Agency
The Pentagon
Washington 25, D.C.
Attn: Dr. Roger S. Warner

Director
U. S. Naval Research Laboratory
Washington 25, D.C.
Attn: Code 2027

Director
Office of Naval Research
Department of the Navy
Washington 25, D.C.
Attn: Code 410

Commanding General
U. S. Army Ballistic Missile Agency
Redstone Arsenal, Alabama
Attn: Dr. E. Stuhlinger

Commanding General
U. S. Army Rocket and Guided Missile Agency
Redstone Arsenal, Alabama

Commander
Command and Control Development Division
L. G. Hanscom Field
Bedford, Massachusetts
Attn: CROTR

Commander
Wright Air Development Division
Wright-Patterson Air Force Base
Ohio
Attn: WCOSI-3

Commander (4)
Armed Services Technical Information Agency
Arlington Hall Station
Arlington 12, Virginia

Commander
U. S. Army Ordnance Ballistics Research Laboratory
Aberdeen Proving Ground
Aberdeen, Maryland
Attn: Mr. W. W. Berning

Commanding General
U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

Commanding Officer
U. S. Army White Sands Signal Agency
White Sands, New Mexico
Attn: Missile Geophysics Program

Commander
Commander and Control Development Division
L. G. Hanscom Field
Bedford, Massachusetts
Attn: Dr. W. K. Widger, CRZF

Commanding Officer and Director
U. S. Navy Electronics Laboratory
San Diego 52, California

Commander
Rome Air Development Center
Griffiss Air Force Base, New York
Attn: RCSSL-1

Chief Signal Officer
Department of the Army
Washington 25, D.C.
Attn: SIGRD-2

Chief Signal Officer
Department of the Army
Washington 25, D.C.
Attn: SIGRD-4

Chief of Research and Development
OCS, Department of the Army
Washington 25, D.C.

U. S. Weather Bureau
Washington 25, D.C.
Attn: David S. Johnson, MSS

U. S. Weather Bureau
Washington 25, D.C.
Attn: Dr. Sigmund Fritz, Chief
Met. and Sat. Division

U. S. Weather Bureau
Scientific Services Division
2400 M Street, N.W.
Washington 25, D.C.
Attn: Dr. Harry Wexler

National Aeronautics and Space Administration (2)
Goddard Space Flight Center
Anacostia Naval Receiving Station
Washington 25, D.C.
Attn: W. G. Stroud, Met. Branch

DISTRIBUTION LIST (Concluded)

National Aeronautics and Space Administration
1512 H Street, N.W.
Washington 25, D.C.
Attn: Dr. Morris Tepper

National Aeronautics and Space Administration
Goddard Space Flight Center
Anacostia Naval Receiving Station
Washington, D.C.
Attn: Dr. W. Nordberg
Meteorology Branch

Chief
OASD (R and D)
Room 3E1065
The Pentagon
Washington 25, D.C.

Library
Boulder Laboratories
U. S. National Bureau of Standards
Boulder, Colorado

Research and Development Board
Committee on Geophysical Science
National Defense Building
Washington, D.C.
Attn: Deputy Executive Director

Applied Physics Laboratory
Johns Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland
Attn: Mr. W. L. Fraser

Astrophysical Observatory
Smithsonian Institute
Washington 25, D.C.
Attn: L. R. Aldrich

University of Arizona
Tuscon, Arizona

University of California
Low Pressure Research Project
College Avenue Laboratory
Berkeley, California

Dr. J. A. Van Allen
University of Iowa
Department of Physics
Iowa City, Iowa

University of Chicago
Meteorology Department
Chicago 37, Illinois

Boston University
Upper Atmosphere Research Laboratory
765 Commonwealth Avenue
Boston 16, Massachusetts
Attn: Mr. C. Low

New York University
Department of Meteorology
New York 53, New York

Mass. Inst of Tech., Dept. of Meteor.
Cambridge, Massachusetts

Professor Sidney Chapman
The University of Michigan

Director
Electronics and Atmosphere Division
Holloman Air Force Base
New Mexico

Commander
U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey
Attn: SIGFM/EL-DR

Commander (4)
U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey
Attn: SIGFM/EL-ADT

Commander
U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey
Attn: SIGFM/EL-NA

Commander (5)
U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey
Attn: SIGFM/EL-NAI

Commander (2)
U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey
Attn: SIGFM/EL-SMA