
Figures, tables, and some mathematical expressions are available in GIF format in this directory. These files have the naming convention FIGn.GIF, TABn.GIF or EQNn.GIF. Images taken from the paper should be considered parts of the paper, and all copyrights must be respected.

IEEE Transactions on Geoscience and Remote Sensing
January, 1980 Volume GE - 18 Number 1 ISSNO196-2892
Special Issue on Instrumentation for the Pioneer Venus Spacecraft

---

Pioneer Venus Orbiter Planar Retarding Potential Analyzer Plasma Experiment

William C. Knudsen, Karl Spenner, Jack Bakke, and Vit Novak

Abstract

The retarding potential analyzer (RPA) on the Pioneer Venus Orbiter Mission measures most of the thermal parameters within and near the Venusian ionosphere. Parameters include total ion concentration, concentrations of the more abundant ions, ion temperatures, ion drift velocity, electron temperature, and low-energy (0-50 eV) electron distribution function. Several functions not previously used in RPA's were developed and incorporated into this instrument to accomplish these measurements on a spinning spacecraft with a small bit rate. The more significant functions include automatic electrometer ranging with background current compensation; digital, quadratic retarding potential step generation for the ion and low-energy electron scans; a current sampling interval of 2 ms throughout all scans; digital logic inflection point detection and data selection; and automatic ram direction detection.

I. Introduction

The planar retarding potential analyzer (RPA) designed and developed for the Pioneer Venus Orbiter Mission is an instrument of advanced design benefitting from steady progress in planar RPA design over the past approximately twenty years of the space age [1] - [8].

It measures most of the essential plasma quantities required to define the state and motion of the ionospheric plasma, and also measures the temperature and concentration of the solar wind electrons.

The Pioneer Venus Mission is described in some detail elsewhere and will not be repeated here [9], [10]. The RPA repeatedly enters the ionosphere of Venus aboard the spinning orbiter spacecraft, and measures ionospheric plasma quantities of the solar-wind-ionosphere interaction region in the energy range 0-50 eV.

The quantities measured by the orbiter RPA are electron temperature Te, total ion concentration Ni, individual ion temperature Tji of the most abundant species, their concentration Nji, thermal ion drift velocity D, and energy distribution of suprathermal electron and ion fluxes f(E) up to 50 eV. Table I summarizes these quantities and gives the expected spatial resolutions, ranges, and uncertainties.

II. Instrument Principles and Characteristics

Fig. 1, a photograph of the assembled RPA, illustrates the sensor surrounded by a 30-cm diameter ground plane. Fig. 2 shows the RPA integrated with the Pioneer Venus orbiter spacecraft. An alignment fixture is covering the sensor grids in this latter photograph. The planar sensor consists of a sequence of grids as shown in Fig. 3. The physical quantities can be derived for a plasma from the integral flux of ions or electrons, gathered by collector C, as a function of energy. Only particles whose energy is greater than the retarding voltage applied on the retarding grid G2 can strike the collector. Use of appropriate voltage programs allows analysis of the particle energy. The other grids and the collector are biased with control voltages which separate positive and negative particles and minimize secondary electrons produced by particle impact and photons.

The orbiter RPA operates in three principal modes, a thermal electron mode, an ion mode, and a suprathermal electron mode. The control voltages and retarding potential programs for these modes are defined in Tables II and III. The principal modes with different operating options are selected through ground command.

III. Electron Mode

In the electron mode, the ion current to the collector is negligible with the collector at 47 V. A potential difference of 20 V between G4 and C was found sufficient to suppress most of the secondary electrons produced by ion or electron impact at the collector. The three front grids G0, G1, and G2 are the energy analyzing grids. They are stepped together from +6.8 to -4.2 V in the coarse scan. The corresponding collector current is measured by a logarithmic electrometer and then digitized. Fig. 4 illustrates a characteristic curve returned by the RPA while operating in the electron mode with I-V option. The straight-line portion of the characteristic curve in which the logarithm of the current is proportional to the retarding potential is the retarding region, and the shape of the straight line determines the electron temperature by the relation

$$T_e = -\frac{e}{k}\,\frac{D\,V}{D\,\log(-I_e)}$$

where e is the electron charge; k the Boltzmann constant; and Ie the electron current. The left side with larger positive voltage is the attractive region. The voltage Vp at which these two portions of the curve join is the potential of plasma relative to spacecraft. Within the ionosphere, it has been varying from a few tenths volt negative to three volts positive. At the lower end of the retarding region, the current decreases more slowly with an increase in retarding potential than it did in the retarding region because of a population of ambient photoelectrons with high energy. The strong decrease in current at the end of the retarding voltage range results from the presence of a compensating current added by the RPA instrument. At the maximum retarding voltage of each mode, the RPA adds current of the appropriate sign and magnitude to the electrometer input to decrease the absolute value of the total current to less than approximately 2 x 10-12 A [8]. This current compensation reduces the influence of high-energy particles and photo-electrons produced within the RPA by solar radiation of the measurement of thermal plasma quantities.

The RPA is usually operated in a "peak option" state in which the retarding region is automatically recognized by the RPA, and either 5 or 11 values of D log (-Ie)(=log + (Ie,J/Ie,J+1)) spaced around the retarding region are selected depending on command option and returned to earth. Onboard logic forms the first and second finite differences of the successively digitized values of log (-Ie). When a sequence of these values satisfy a peak criterion, the logic selects 5 or 11 values of D log (-Ie) about the peak and the retarding potential step number for transmission to earth. Values of D log (-Ie) selected and returned from Venus by the RPA are illustrated in the lower portion of Fig. 4. The retarding voltage step program in the "peak option" consists of a coarse scan over the entire voltage range followed by one or three fine scans over the appropriate subrange centered where the largest difference in the coarse mode has occurred (Table III). The D log (-Ie) values measured in the fine scan have been multiplied by four for proper comparison with the values measured in the coarse scan. The retarding voltage at which the largest value of D log (-Ie) occurs in the coarse electron scan is quite close to the plasma potential and is used as the starting potential (reference potential) for the quadratic ion retarding potential step program.

The purpose for the coarse and fine electron retarding scan is to measure a large range of temperatures. The RPA has operated successfully in the thermal-electron peak mode from 300 to 25 000 K. Temperatures above approximately 25 000 K are measured in the suprathermal electron mode.

IV. Ion Mode

With the collector at -4.6 V and suppressor grid at -24.6 V, ambient electrons with energy less than approximately 24.6 eV are not collected. Ions with sufficient kinetic energy to overcome the retarding potential on grid G2 (Fig. 3) are collected. An ion-characteristic curve measured by the RPA in the Venus ionosphere is illustrated by the dots in Fig. 5. The retarding potential V is related to the step lettered J by the equation

$$VJ - V\ ref = \frac{J\ (j - 1)}{2}\ 0.011\ V$$

where V ref is a voltage close to the plasma potential sensed and established in the electron mode. The current corresponding to every other step value is returned by the RPA when operating in the ion mode with I-V option. The solid line is the least square fit of the appropriate theoretical expression for the total current to the data points [8]. The derived quantities are listed in the figure.

When operating in the "peak option" the RPA forms difference in current delta IJ(=IJ-IJ+1) measured at successive retarding potential steps and returns either 5 alternate or 11 successive values of delta IJ around sensed peaks in delta I.

Examples of delta I values returned around 0+ and 0+2 peaks are also illustrated in Fig. 5. The same digital peak criterion is used to recognize the ion peaks as is used to recognize the retarding region of the electron characteristic curve. It is shown elsewhere [8] that the delta I values about peak are approximately Gaussian in shape. The half-width of the peaks is proportional to the square root of the ion temperature Ti, and the peak value of delta IJ is proportional to the ion concentration divided by square root Ti. The value of J at which the peak occurs is proportional to the square root of the ion kinetic energy normal to the RPA grids. The ion temperature, concentration, mass, and velocity normal to the RPA grids are derived by numerically fitting the theoretical expression for delta IJ to the measured values of delta IJ with use of the least squares criterion. The solid curve in the lower-half of Fig. 5 is drawn through the theoretical values of delta IJ. The geophysical quantities derived from the fit are listed. In computing the theoretical values of delta IJ (and also IJ), an ion mass 13 was assumed present with a concentration equal to 7 percent of the 0+ concentration.

V. Vector Ion-Drift Velocity

Vector ion-drift velocity is measured by measuring three single components of the velocity in three different directions. Fig. 6 illustrates the principle of measurement. From the analysis of data from a single sweep of the RPA, the component of total ion velocity normal to the RPA grids is derived. A single sweep of the RPA requires approximately 0.16 s during which time the spacecraft rotates through 5 degrees about its spin axis. The telemetry bit rate assigned to the RPA permits only one sweep of data to telemetered to earth per spacecraft spin period. Consequently, to achieve a vector measurement of the ion-drift velocity, one sweep of data is recorded in each of three successive spin periods at three different roll angles. With the RPA measurement axis offset from the spin axis by 25 degrees the necessary three independent components measurements are achieved. The first ion sweep designated I1 is recorded when the total ion velocity relative to the spacecraft lies in or close to the plane defined by the spacecraft spin axis and the RPA period 45 degrees in roll angle before that at which I1 was recorded. Sweep I3 is recorded in the third spin period at a roll angle 45 degrees greater than that at which I1 was recorded.

The roll angle at which I1 is recorded is defined by receipt of a "Ram" signal from the spacecraft or by sweep with largest saturation ion current.

VI. Supra Thermal Electron Mode

The collector and guard ring are biased at +47 V in the suprathermal electron mode to collect electrons and the grid G1 is biased at +47 V to prevent positive ionospheric ions from impinging on the retarding grid G2 [11]. The retarding grid G2 is stepped quadratically from 0 to -50 V during which time the electron currents are digitized for telemetering to earth. The RPA may be programmed to record one suprathermal-electron characteristic curve every fifth-spin revolution, the other four revolutions being used to record one thermal-electron sweep followed by three ion sweeps, or it may be programmed to record one suprathermal-electron sweep every spin revolution with successive sweeps spaced 90 degrees in roll angle from each other. In this latter mode of operation, only suprathermal-electron data are recorded.

The electron energy distribution function fe is derived from the set of electron currents with use of the Druyvesteyn [12] relation:

$$fe = \frac{V}{\qquad} \quad \frac{d2I}{\qquad}$$

e2   dV2

In regions of space where the electron energy distribution is expected to be Maxwellian, the parameters of the Maxwellian distribution, temperature, and concentration are derived by fitting a straight line to the curve of log Ie versus V.

Fig. 7 shows an example of the suprathermal-electron currents measured in the dayside ionosphere and the derived electron-energy distribution.

VIII. Inflight Calibration

The RPA is commanded periodically into an inflight calibration sequence. In the first part of the sequence, the electrometer is disconnected from the collector and a sequence of internal calibration currents satisfying the peak selection criteria are applied to the electrometer to evaluate the electrometer sensitivity and peak selection logic. In subsequent portions of the calibration sequence, the internal noise of the electrometer in its most sensitive range is measured, and the retarding voltages are sample to verify amplifier gain and proper logic operation.

VIII. Instrument Parameter Summary

The following table summarizes the more important physical and electrical properties of the RPA.

IX. Conclusions

The Pioneer Venus orbiter RPA is measuring a large number of the plasma quantities needed to define the state and motion of the ionospheric plasma. These measurements are contributing to a detailed definition of the ionosphere and to an understanding of the processes affecting it [13] - [15]. Measurements from the suprathermal-electron mode are contributing to the detailed definition of the ionosheath, ionosphere and mantle plasmas, and the boundaries separating them [16]. The RPA is an instrument of advanced design and has been operating continuously and as designed for approximately fifteen months since launch at the time of preparation of the manuscript. (Aug. 1979).

Acknowledgment

We wish to acknowledge the dedicated efforts of many people who contributed to the development of the orbiter RPA. Special mention should be made of Dr. J. Reagan, S. Bjerklie, J. McDaniel, V. Waltz, J. Parker, and K. Fong of the Lockheed Palo Alto Research Laboratory, W. Ott of the Institut fur Physikalische Weltraumforschung, K. Polzer, G. Kupfahl, E. Eichhorn, H. Bauer, V. Gerber, K. Sudholt, A. Kronthaler, and E. Spermann of Messerschmitt-Bolkow-Blohm GmbH, Mr. Guenther and Dr. Klinkman of DFVLRIBPT, and E. Tischler and A. Wilhelmi of NASA/AMES.

The financial support for W.. Knudsen, J. Bakke, and the Lockheed Palo Alto Research Laboratory for the development of the control electronics subassembly and integration of the instrument of the spacecraft was provided by NASA. The financial support for K. Spenner, V. Novak, the Institut fur Physikalisches Weltraumforschung and Messerschmitt-Bolkow-Blohm GmbH for the development of the sensor subassembly and its electronics was provided by the Bundesminister fur Forschung und Technologie of the Federal Republic of West Germany.

References

[1] H. E. Hinteregger, "Combined retarding potential analysis of photoelectrons and environment charge particles up to 234 km," Space Res., vol. 1, pp. 304-327, 1960.

[2] W. B. Hanson and D. D. McKibbin, "An ion trap measurement of the ion concentration profile above the F2 peak," J. Geophys. Res., vol. 66, pp. 1667-1671, 1961.

[3] W. C. Knudsen, "Evaluation and demonstration of the use of retarding potential analyzers for measuring several ionospheric quantities," J. Geophys. Res., vol. 71, pp. 4669-4678, 1966.

[4] K. K. Harris, G. W. Sharp, and W. C. Knudsen, "Ion temperature and relative ion composition measurements from low-altitude polar-orbiting satellite," J. Geophysics. Res., vol. 72, pp. 5939-5948, 1967.

[5] W. B. Hanson, S. Sanatani, D. Zuccaro, and T. W. Flowerday, "Plasma measurements with the retarding potential analyzer on Ogo 6," J. Geophys. Res., vol. 75, pp. 5483-5501, 1970.

[6] W. B. Hanson, D. R. Zuccaro, C. R. Lippincott, S. Sanatani, "The retarding potential analyzer on atmosphere explorer," Radio Sci., vol. 8, pp. 333-340, 1973.

[7] K. Spenner and A. Dumbs, "The retarding potential analyzer on Aeros-B," J. Geophys. Res., vol. 40, pp. 585-592, 1974.

[8] W. C. Knudsen, K. Spenner, J. Bakke, and V. Novak, "Retarding potential analyzer for the Pioneer-Orbiter mission," Space Sci. Inst., vol. 4, pp. 351-372, 1979.

[9] L. Colin and C. F. Hall, "The Pioneer-Venus program," Space Sci. Rev., vol. 20, pp. 283-306, 1977.

[10] L. Colin, "Encounter with Venus," Science, vol. 203, pp. 743-745, 1979.

[11] W. C. Knudsen and K. K. Harris, "Ion-empact-produced secondary electron emission and its effects on space

instrumentation," J. Geophys. Res., vol. 78, pp. 1145-1152, 1973.

[12] M. J. Druyvesteyn, "Der Niedervoltbogen," Z. Phys., vol. 64, pp. 781-798, 1930.

[13] W. C. Knudsen, K. Spenner, R. C. Whitten, J. R. Spreiter, K. L. Miller, and V. Novak, "Thermal structure and major ion composition of the Venus ionosphere: First RPA results from Venus orbiter," Science, vol. 203, pp. 757-763, 1979.

[14] __, "Thermal structure and energy influx to the day and nightside Venus ionosphere," Science, vol. 205, pp. 105-107, 1979.

[15] W. C. Knudsen, K. L. Miller, K. Spenner, R. C. Whitten, and J. R. Spreiter, "Ion drift velocity measurements in the Venusian ionosphere," in Abstract, EOS, vol. 60, p. 303, 1979.

[16] K. Spenner, W. C. Knudsen, K. L. Miller, and V. Novak, "Observations of the Venus ionospheric mantle formed between ionosphere and ionosheath," in Abstract, XVIIth General Assembly of the Int. Union Geodesy and Geophysics (Canberra, Australia), Dec. 3, 1979.