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Instrumentation Development for LASSII Equatorial Measurements

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A quadrupole ion mass spectrometer capable of measuring ion composition during equatorial ionospheric irregularities with a spatial resolution of 4 m over a range of 1 to 56 AMU is discussed. Instrument sensitivity has been adjusted to cover an ion concentration range of 10 ions/cm^3 to 10^6 ions/cm^3. A separate measurement of ion density and its fluctuations is also made. The instrument was developed to fly on a space-shuttle-launched LASSII satellite.

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Preface

I would like to thank the following AFGL personnel who contributed to the successful completion of this in-house work unit: Dr. R. S. Narcisi for his guidance and support, G. Federico for his contributions to the mechanical design of the sensor package, and L. E. Wlodyka for her calibration of the instruments.

Thanks are also extended to G. Murphy of Tri-Con Associates, Inc., who was responsible for the design and fabrication of the electronics under an associated contract work unit (2310G3AK).

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Instrumentation Development for LASSII Equatorial Measurements

I. INTRODUCTION

The purpose of this program was to develop a quadrupole ion mass spectrometer instrument capable of measuring positive ions in the range of 1 to 56 AMU (atomic mass units) with a spatial resolution of 3 m at satellite velocity. The resultant data from this instrument will provide measurements essential to an understanding of the physical chemistry and transport processes involved in the creation of ionospheric irregularities which degrade VHF/UHF transionospheric radio signals.

The work was done under two parallel efforts, one consisting of the design, fabrication, and testing of the sensor package, and the other the design, fabrication, and testing of the electronics package under a supporting contract. At the completion of the two individual efforts, the packages were integrated, tested, and calibrated in preparation for integration on a shuttle-launched LASSII satellite.

(Received for publication 22 April 1980)

2. DISCUSSION OF ELECTRONICS

2.1 Spectra Amplifier

To accomplish a 3 m spatial resolution at a velocity of 8×10^5 cm/s for any single ionic mass requires a sample rate of 2.67×10^3 per second. Coupled with the need of a dynamic range of 10^5 (10 ions/cc to 10^6 ions/cc) for the preamplifier, a logarithmic amplifier was chosen to satisfy the requirement. To alleviate any possible amplifier response problems at the lower input current levels, the sensor was designed to output 5×10^{-11} A for a number density of 10 ions/cc. For a dynamic range of 10^5, the amplifier outputs a voltage of 0 to 5 V for a sensitivity range of from 5×10^{-11} A to 5×10^{-6} A. The amplifier response is sufficiently fast for all currents greater than 1×10^{-10} A to produce an accurate output voltage conversion of its input current, at a sample rate of 2000 per second, that will be supplied by the LASSII satellite encoder. A more detailed discussion of all system electronics is given by Murphy[1] in an associated report. A typical logarithmic amplifier I-V calibration curve is shown in Figure 1.

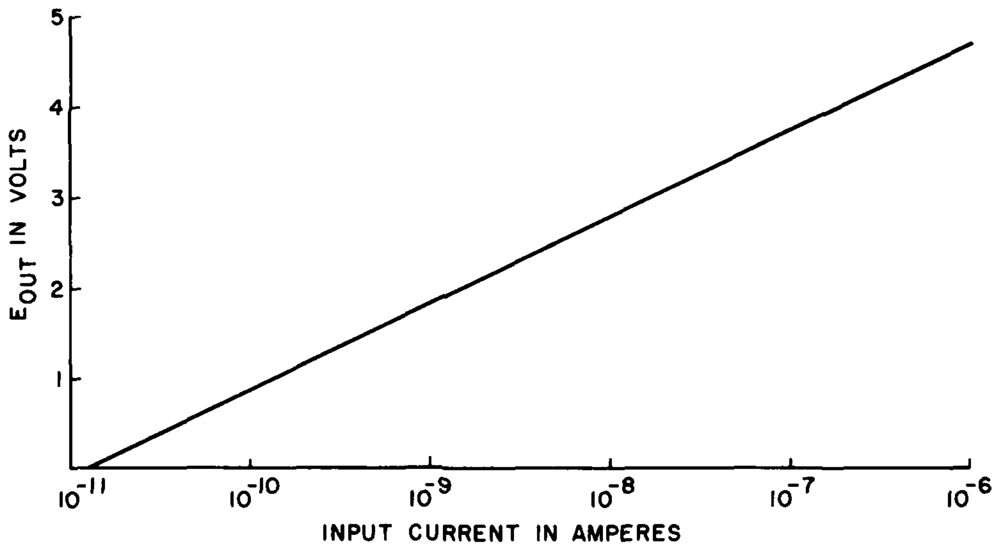

Figure 1. Spectra Calibration

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1. Murphy, G. P. (1979) The Design of Mass Spectrometer Assemblies for Space Shuttle Launched Satellites, AFGL-TR-79-0233, AD

2.2 Aperture Amplifier

The output of the spectra amplifier just described gives a measure of the ionic species that are present, as well as their relative concentrations, over the range of 1 to 56 AMU. A second identical type logarithmic amplifier of opposite polarity is used to measure the positive ion current collected on a disk-shaped aperture plate, thus giving a measure of the total positive ion density and its fluctuations. For an aperture plate of 1.725 in. diam, a velocity of 8×10^5 cm/s, and a number density range of 10 ions/cc to 10^6 ions/cc, the expected current collection will be approximately 2×10^{-11} A to 2×10^{-6} A. This output will also be sampled at a rate of 2000 per second, resulting in a spatial resolution of 4 m.

2.3 Command Modes

To provide experiment flexibility, five ground-commandable modes were designed into the instrument. Modes I through IV are identical in capability; that is, any number of masses from 1 to 8 in the range of 1 to 56 AMU can be sampled in any order in either of the four independent modes, as programmed into a "read only memory" or ROM. Mode V has the capability of sampling up to 32 masses in any order. Minimum mass switching time in any mode is 10 ms per AMU. The total sampling period in Mode V is, therefore, 320 ms, resulting in a degradation of the spatial resolution. This mode does, however, provide the experimenter the opportunity to determine the identity of the ionic species present as well as their relative abundances. The ROMS used for the above programming are the fusible link type; thus, once burned in, program changes can be accomplished only by replacing the original ROMS with newly programmed ROMS. This is a relatively simple and inexpensive procedure that allows the experimenter the capability to change programs between instrument flights if desired.

2.4 Supporting Electronics

The quadrupole ion mass spectrometer (QIMS) consists of an electronics package and a sensor package. In addition to the program circuitry already described, the electronics package (Figures 2a and 2b) houses a dc-dc converter that generates all the voltages required to operate the system, command logic, dc amplifiers, rf and dc control amplifiers, and system monitors. The remainder of the electronics, which includes the spectra and aperture amplifiers, rf oscillator circuitry, and high voltage power supply (Figures 3a and 3b), is mounted on the sensor package baseplate. As mentioned earlier, a more detailed description of the electronics is given by Murphy.[1]

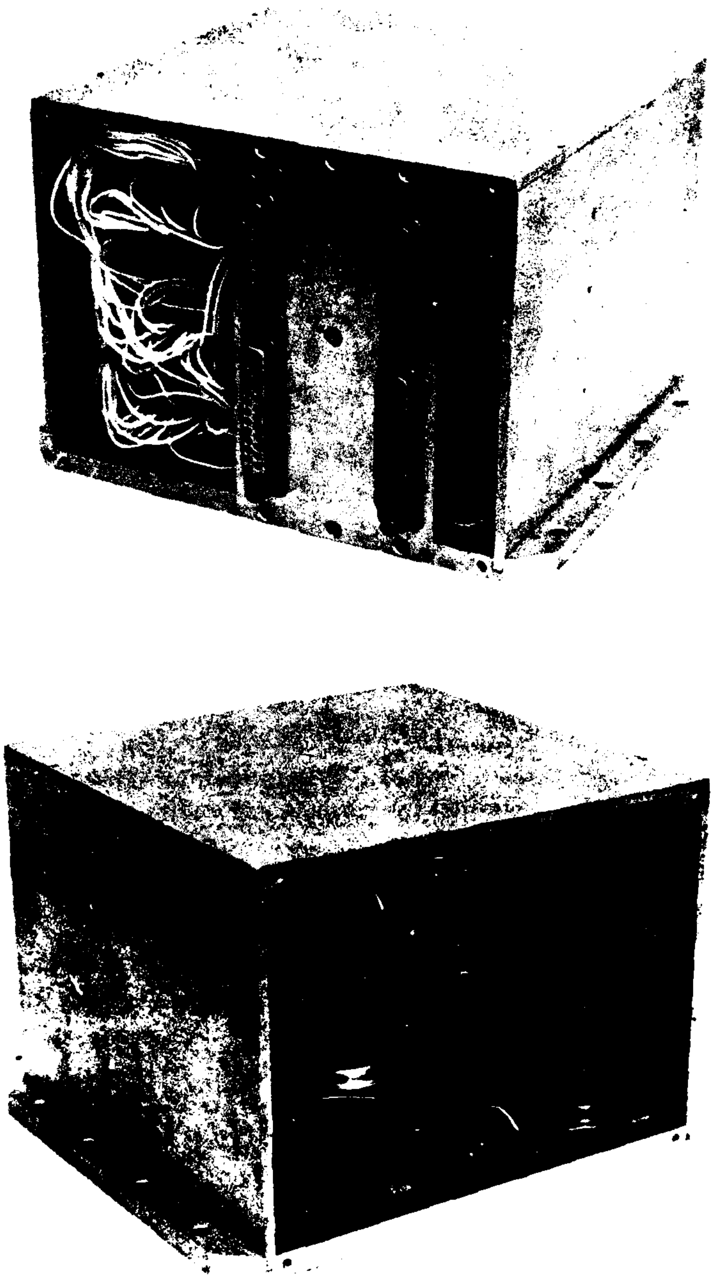

Figure 2. Electronic:

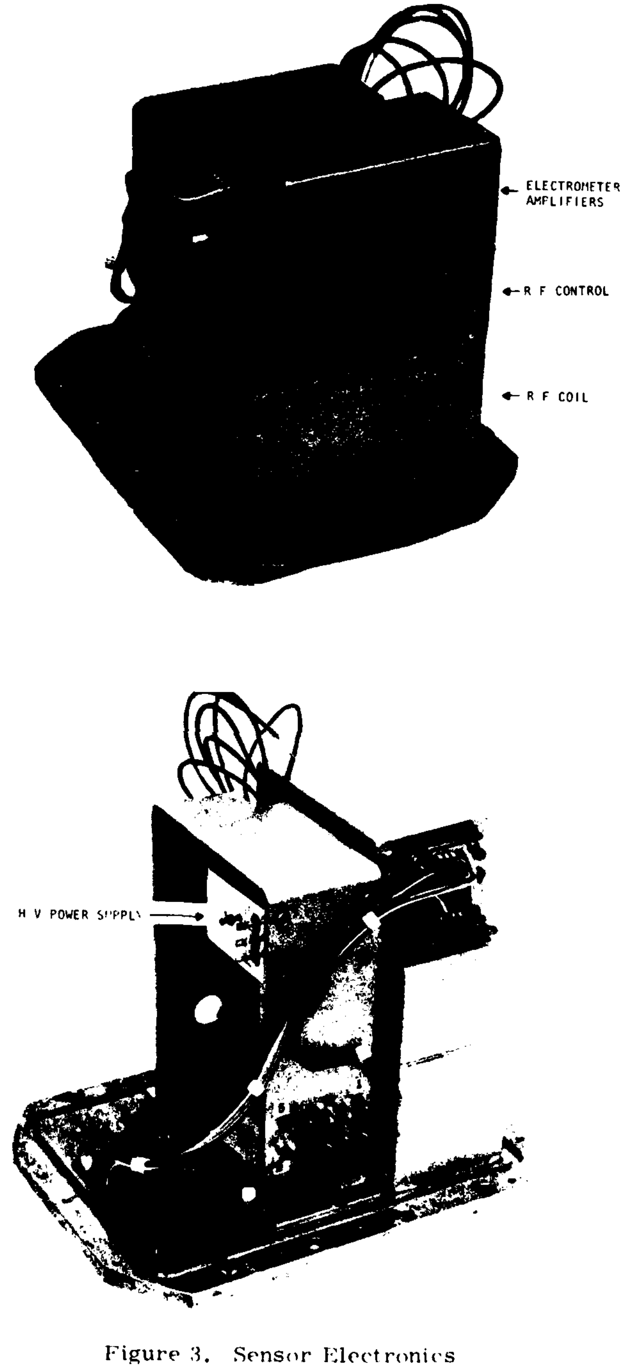

Figure 3. Sensor Electronics

3. SENSOR DISCUSSION

3.1 Configuration

All the sensor components—the aperture plate, accelerating grid, quadruple rods, the ceramics, and rod housings—are mounted to the front of the sensor baseplate. A functional drawing of the sensor is shown in Figure 4.

To insure maximum transmission of the ions passing through the aperture, it is essential that the aperture is centered over the quadruple axis and the quadrupole rods are perpendicular to the aperture plate. Precise alignment is maintained through the use of precision-ground ceramics and precision-machined rods, rod housing, and baseplate.

Below the aperture is an accelerating grid. Since the potential on this grid is the same as the rod dc reference potential, it determines the axial accelerating potential for ions entering the quadrupole. Below the quadrupole is another grid with yet another small accelerating potential. Ions exiting this grid are bent around by a negative 2.5 kV potential on the first dynode of the secondary emission multiplier. Electrons collected at the anode are then processed by the aforementioned spectra amplifier.

3.2 Design Parameters

From satellite considerations, the following design values were used to construct the quadrupole sensor:

rod diameter	0.250 in.
rod length	6.338 in.
entrance aperature	0.020 in.
aperture plate diameter	1.725 in.

To best approach an ideal hyperbolic field using cylindrical cross section rods, a ratio of r_{rod}/r_o of 1.1486 was used (Denison[2]), where r_{rod} is the rod radius and r_o is half of the distance between rod pairs that constitutes the field radius. This results in an r_o of 0.1088 in. or 0.2764 cm. To maintain a constant r_o, the quadrupole rods were fabricated from centerless ground stainless steel rods to a tolerance of +0.000, -0.0002 in. in diameter and ±0.005 in. in length. Rod alignment ceramics are ground to allow a minimum clearance of 0.0002 in. and a maximum of 0.0009 in. Any misalignment that may result is within the 1 percent r_o tolerance required for this system.

2. Denison, D.R. (1971) J. Vac. Sci. Technol. 8:266.

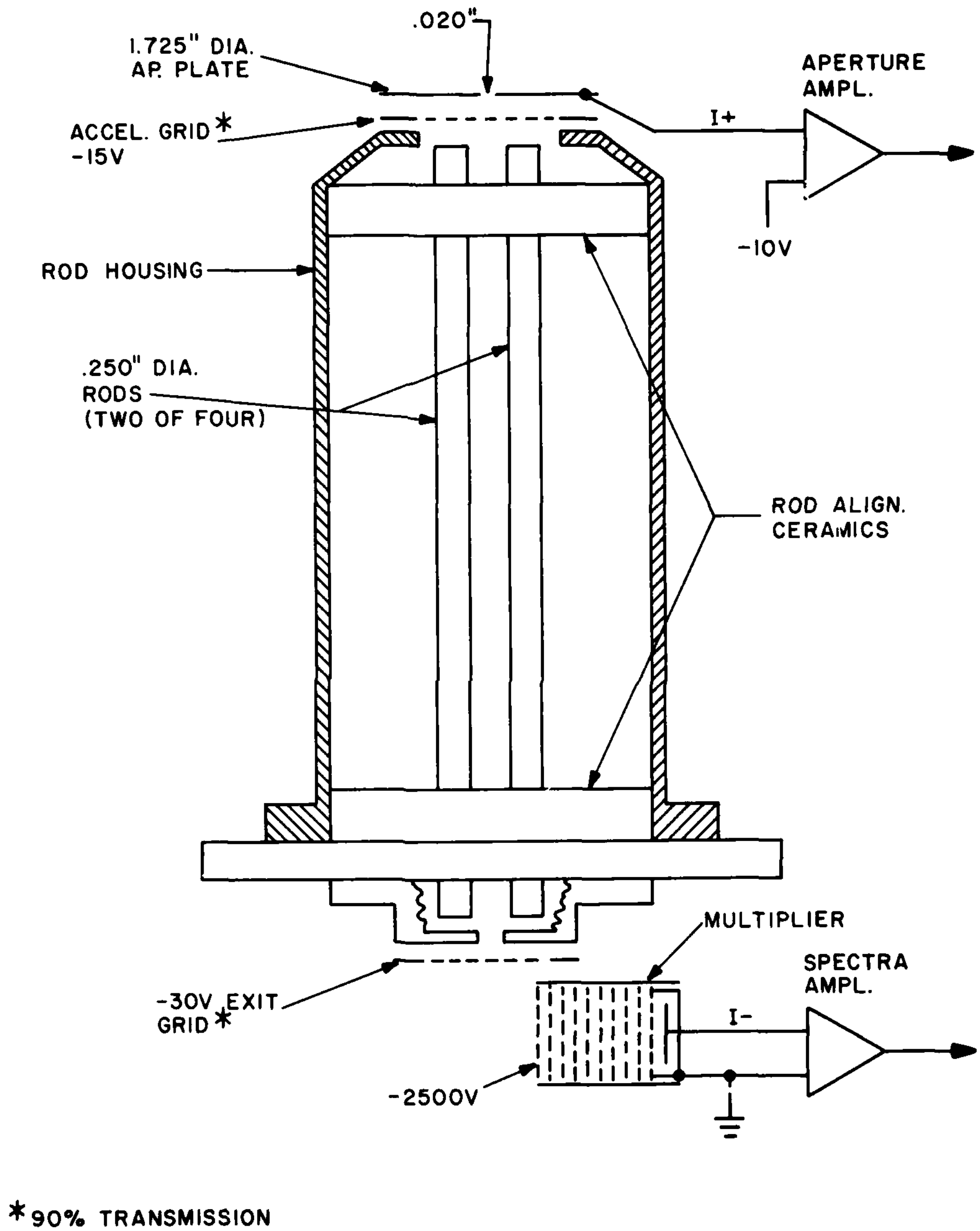

Figure 4. Quad. Sensor

Using the electric mass filter equations developed by Paul, Reinhard, and von Zahn,[3] the ratio U/V of the applied dc to rf potentials for a constant resolution ($m/\Delta m$) of 25 is given by:

$$U/V = 0.16784 - \frac{0.126}{m/\Delta m} \tag{1}$$

$$= 0.16280 \ .$$

The optimum entrance aperture for the ions is:

$$a = \frac{r_o}{\sqrt{m/\Delta m}} \tag{2}$$

$$= 0.022 \text{ in.}$$

The maximum axial accelerating potential to assure that an ion is in the field long enough to be rejected is:

$$E_{acc} \approx \frac{1}{25} \times f^2 \times L^2 \times \frac{\Delta m}{m} \times m$$

$$\approx 5.1m \text{ volts} \quad , \tag{3}$$

where

f = 3.5 MHz rf applied to the quadrupole

L = 16.1 cm rod length, and

m = mass in atomic mass units.

The maximum radial energy allowable to insure collection of any ion injected at the field axis is:

$$E_{radial} = \frac{1}{2} m f^2 r_o^2 \frac{\Delta m}{m} \tag{4}$$

$$= 0.019 \text{ m volts} \ .$$

For a constant resolution of 25, the rf and dc potentials applied to the rods must be stabilized to within 2 percent, and the rf and field radius r_o must be held to within 1 percent of their nominal values. Both electrical and mechanical parameters were held within the required limits.

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3. Paul, W., Reinhard, H. P., and von Zahn, U. (1958) Zeitschift für Physik 152(2):143-182.

4. SYSTEM SET-UP

4.1 Resolution Adjustment

The method chosen to operate these instruments was to maintain a fixed rf (3.5 MHz) while varying the rf and dc potentials and maintaining a fixed U/V ratio. The results of Eq. (2) suggest that the ratio be set by measuring both the rf and dc potentials and making adjustments until the calculated ratio has been achieved. A more practical method is by operating the instrument while adjusting the ratio until the proper resolution is achieved. The output spectra can be recorded on paper from which the half-width resolution can be checked. These units were adjusted for a half-width resolution of approximately 25 at mass 28.

For constant resolution, the peak width is directly proportional to the mass; therefore, discrimination occurs at the lower mass levels. To achieve a more constant peak width at these levels, a constant offset voltage is introduced into the rf circuit, resulting in a lower ratio at the lower mass end. Since both the ratio and offset adjustments are interactive, they are alternately trimmed until the desired result is achieved without mass discrimination (see Figure 5). This constant offset adjustment is useful, however, only over a limited mass range.

4.2 Sensitivity Adjustment

As determined earlier, the required current output from the electron multiplier is from 5×10^{-11} A to 5×10^{-6} A for an ion density range of from 10 ions/cm^3 to 10^6 ions/cm^3. In the satellite ram position, the current at the input of the quadrupole is given by the following expression:

$$I = n\,e\,a\,v$$

where

n = number density

$e = 1.6 \times 10^{-19}$ coulombs

$a = 5.07 \times 10^{4}$ cm^2

$v = 8 \times 10^{5}$ cm/s.

For a number density of 10 ions/cm^3, the quadrupole input current I is 6.5×10^{-16} A. Assuming an overall transmission of 60 percent (including losses through two 90 percent transmission grids), the current impinging on the first dynode of the multiplier is 3.9×10^{-16} A. Consequently, the multiplier gain required to output 5×10^{-11} A is 1.28×10^{5}. Calibration curves for the Johnson Laboratories' multiplier used show a high voltage requirement of 2.4 kV to

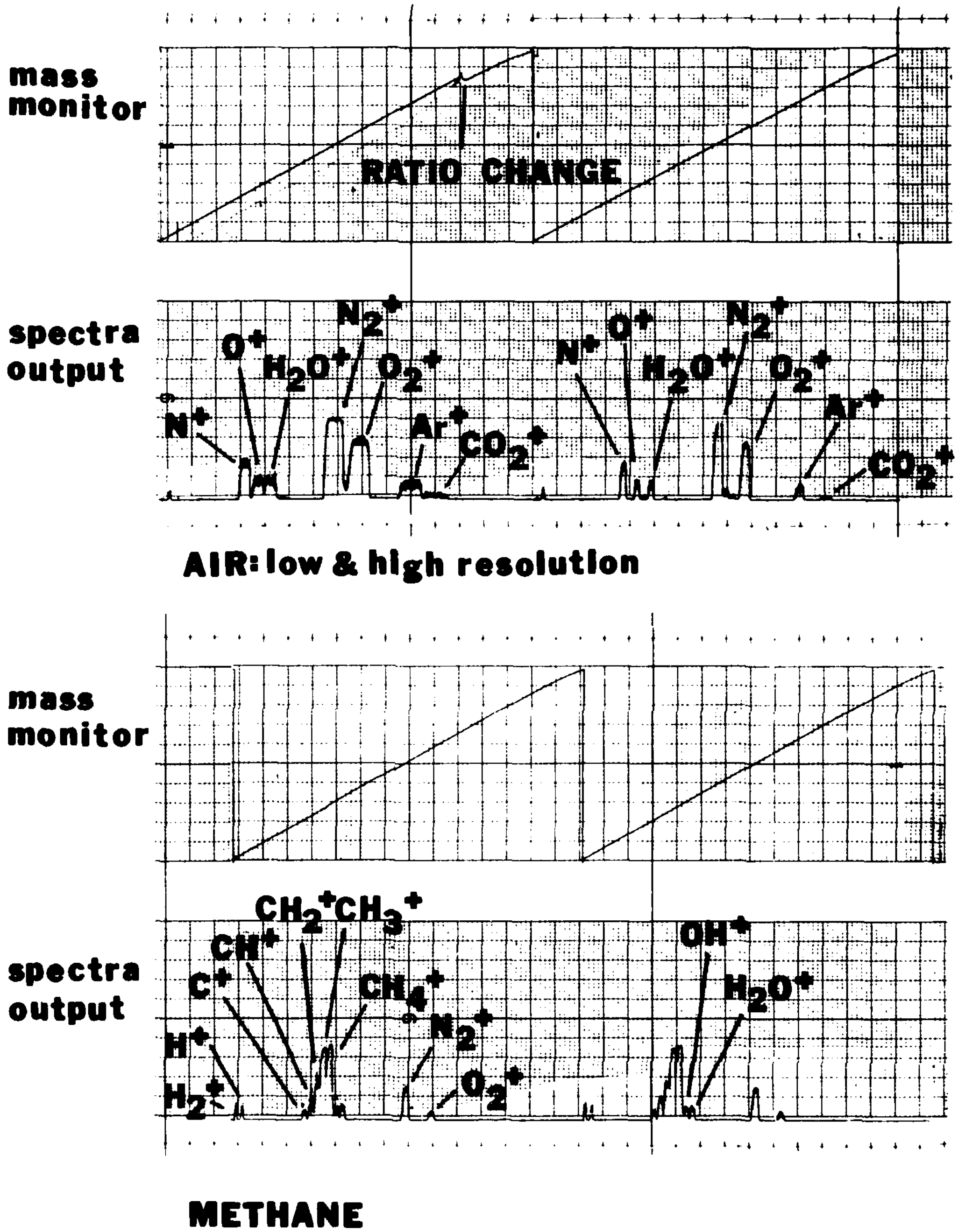

Figure 5. Air and Methane Spectra

achieve this gain. A reserve multiplier gain factor in excess of 100 is available for adjustment to compensate for any gain losses that may occur with time.

5. CONTROL CONSOLE

A control console (Figure 6) designed and fabricated under contract and described by Murphy[1] was used to operate the quadrupole system during all testing. The console simulated all the necessary satellite functions such as synchronization, clock pulse, power command, and system monitoring. Meters and jacks were made available for both visual and paper recording of all telemetry outputs. Meters were also available to monitor system input voltage and current.

Figure 6. Control Console

6. CONCLUSION

A quadrupole ion mass spectrometer capable of measuring positive ions over the range of 1 to 56 AMU has been designed, fabricated, and tested. The instrument has five separate commandable program modes and can measure any single ion species with an accurance of ±5 percent and a spatial resolution of 4 m. The programs are ROM controlled and can be changed simply by replacing with newly programmed ROM's. The system consists of a two-package design with a total weight of 18 lb and an average power consumption of 14 W at 28 V. The instrument was designed to measure ionospheric irregularities from a shuttle-launched LASSII satellite.

The 1 to 56 AMU range for which these instruments were designed is not restrictive. By modifying the rf oscillator to operate at a lower frequency, the mass range can be extended to a higher AMU range to include barium. This is indeed anticipated in future LASSII ionospheric modification experiments where barium releases are planned.