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CONSTRUCTION OF A BREADBOARD ELECTRONICS SYSTEM FOR A LIGHT WEIGHT COLD CATHODE QUADRUPOLE MASS SPECTROMETER

By J. R. Roehrig

Prepared under Contract No. NAS1-5347 Task 11
NORTON RESEARCH CORPORATION
Cambridge, Massachusetts

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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CONSTRUCTION OF A BREADBOARD ELECTRONICS SYSTEM FOR A LIGHT WEIGHT COLD CATHODE QUADRUPOLE MASS SPECTROMETER

By J. R. Roehrig

Norton Research Corporation

SUMMARY

A light weight low power electronics system has been developed and constructed in breadboard form to operate a small cold cathode ion source quadrupole mass spectrometer. The system operates from 28 volts d.c. primary power with a mass range of 1 - 50 amu and a resolution of 1.2 amu in a pressure range of 10^{-8} to 10^{-4} Torr. The mass range may be scanned in five seconds or slower as required. The complete system weighs 4 lbs. 15 oz. and requires an average power of 11 watts.

INTRODUCTION

During 1967, Norton Research Corporation designed, fabricated and tested a miniature light-weight cold cathode source quadrupole mass spectrometer. This "in-house" work drew heavily on the results of Langley-sponsored research under NAS1-2691 wherein a cold cathode source was adapted to a commercial quadrupole spectrometer, and further drew on recent cold cathode source work performed in conjunction with the ALSEP program. The result was a 2 lb. 4 oz. unit which performed in accordance with design expectations and suggested various applications wherein light-weight, low-power, small size and cleanliness were paramount. However, mating miniature electronics had not been developed.

The work performed under this task order addresses itself to the development of breadboard miniature electronics, and the addition of an electron multiplier to the quadrupole unit described above. The breadboard electronics design goals are as follows:

Weight:	10 lbs.
Power:	10 watts
Mass Range:	2-50 amu
Resolution:	Constant Δm mode 2-50 amu Δm = 1.5 amu 10% valley between equal adjacent peaks.
Primary Power:	28 V.d.c.
Output:	0-5 V.d.c. analog

Dynamic Pressure Range: The mass spectrometer ion source shall operate in the total pressure range (N_2 equivalent) of between 10^{-8} Torr and 10^{-4} Torr or above.

Sweep Time: Full scan 2-50 amu shall be 5 sec. or less.

All of these specifications are reasonable goals for a first try breadboard model, yet are tight enough to create a challenge. The equipment which was developed to meet these criteria is described below. As will be shown, all of the specifications were met or exceeded, with the exception of the power budget which is 10% over the design goal.

THE BREADBOARD CCIS/QUADRUPOLE ANALYZER TUBE

The CCIS/Quadrupole Analyzer is shown in the accompanying exploded-view photograph, Figure 1. The complete unit, as shown, is 9 7/8 inches long and 1 3/8 inches in diameter. The total weight of the unit shown is only 2 lbs. 4 oz. (including magnets). The cold-cathode ion source elements, shown at the left, are nearly identical to ALSEP COLD CATHODE ION GAUGES being manufactured by NRC for the Southwest Center for Advanced Studies. The quadrupole analyzer is shown in the center of the picture and the Faraday cup ion collector is on the right. In its present form, the sensor does not employ an electron multiplier. The analyzer is operated by a commercial Ultek-EAI model 200 Quadrupole RF/DC Sweep Generator. This circuit permits coverage of the mass range from 1 to 102

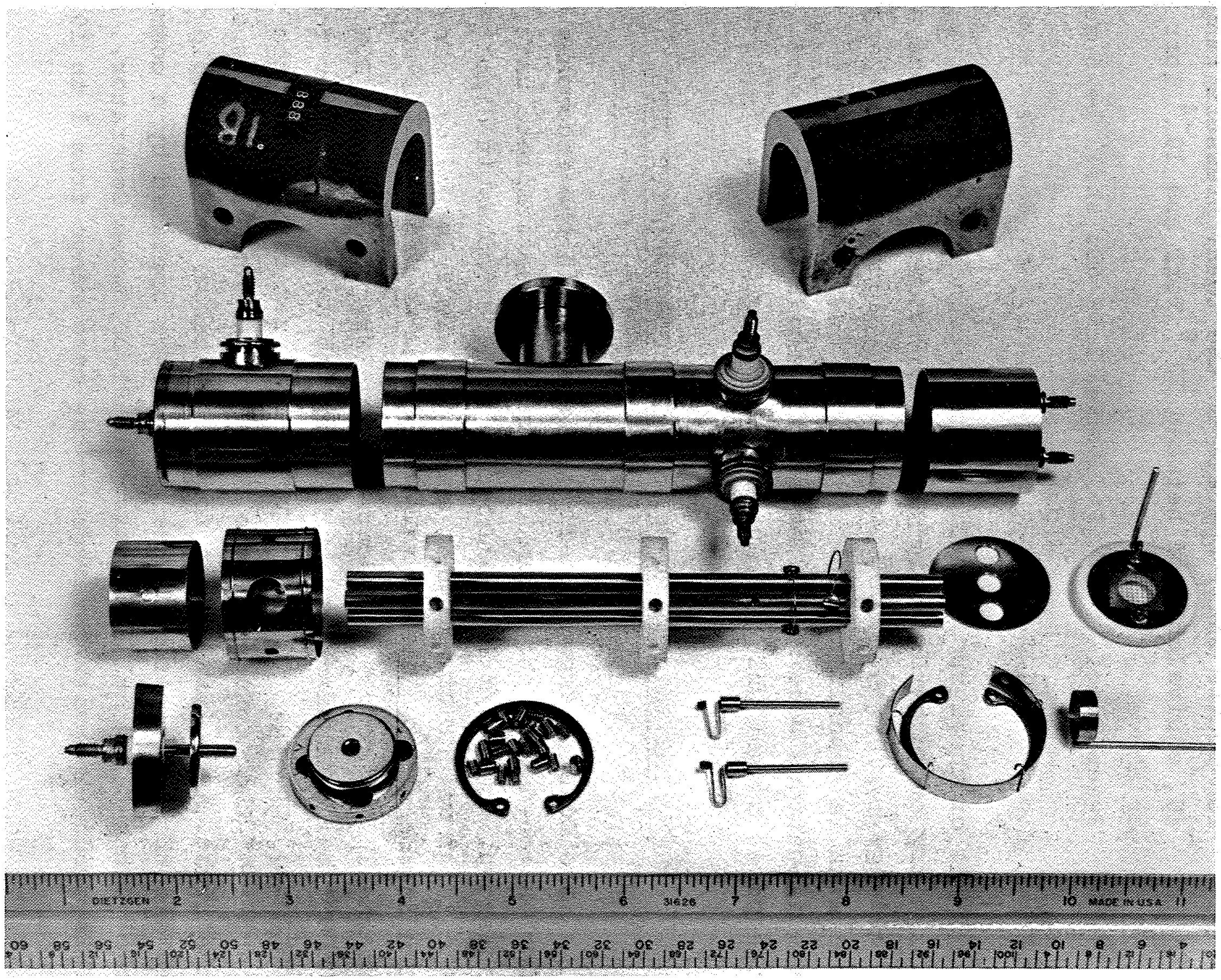

Figure 1. Exploded View of CCIS Quadrupole Flight Model Breadboard.

amu when operating the CCIS/Quadrupole analyzer.

Figure 2 shows the performance of the unit for a mixture of inert gases (He, Ne, Ar and Kr). The width of Ar^+ (mass 40) peak is about 1.2 amu at 5% of full peak height. Hence, the resolution for the 10% valley criterion is 1.2 amu. The electronics operate the analyzer in the so-called constant Δm (peak width constant) mode.

Figure 3 shows the performance of the spectrometer for higher masses. Krypton was introduced and its isotopes are clearly shown. It is to be noted that the valley between Kr^{82} and Kr^{83} is approximately 10% of the Kr^{84} peak height. This performance is identical to the much larger laboratory unit previously described.[1] A copy of this Figure is enclosed for comparison.

The sensitivity of the instrument (without an electron multiplier) is approximately 1.5×10^{-5} Amps/Torr for nitrogen (mass 28). The sensitivity for other gases has not been measured as yet. The nitrogen sensitivity is considerably lower than the value of 8.2×10^{-4} Amps/Torr obtained for the larger laboratory model (without multiplier) described in the aforementioned report. The reason for the reduction lies in the geometry of the quadrupole entrance aperture which is smaller and better collimated in the flight breadboard model than in the large laboratory unit.

A major modification of this unit was made under the requirements of Task 11. The Faraday cup and screen were

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1. See Fig. 11, of Final Report of Contract No. NAS1-2691, Task 8, sponsored by NASA-Langley Research Center.

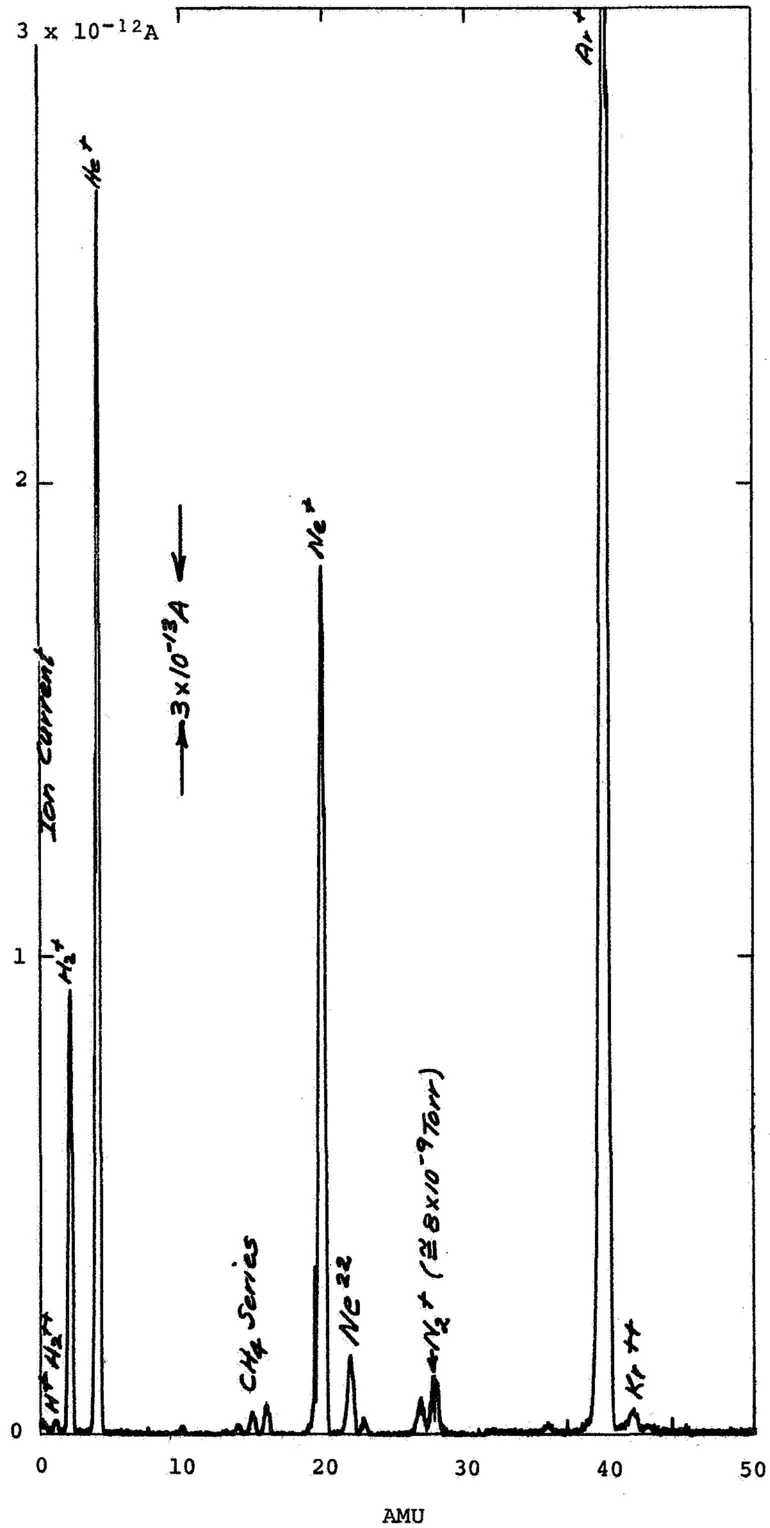


Figure 2.- Spectrum of a mixture of inert gases. CCIS quadrupole flight model breadboard.

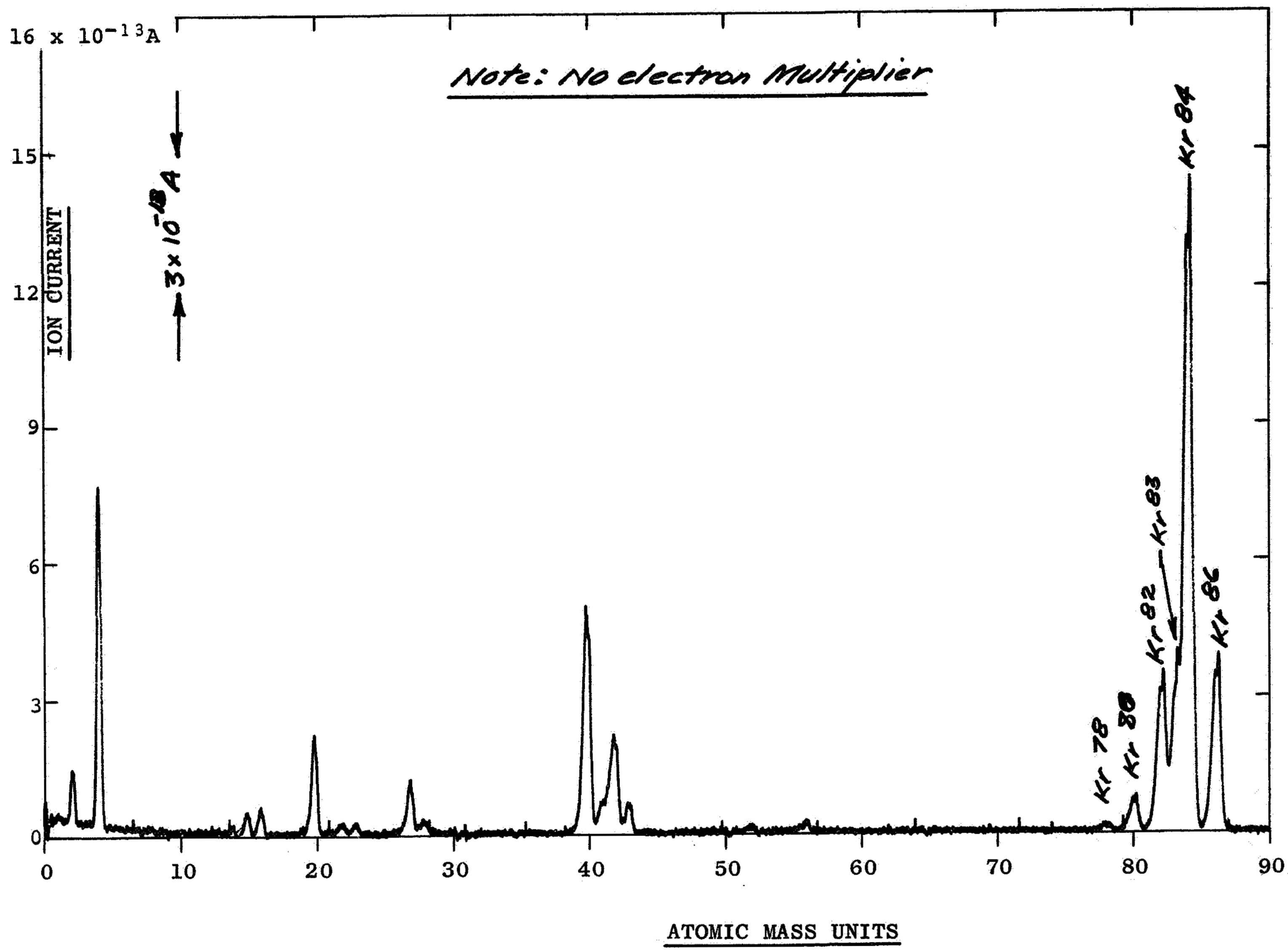


Figure 3.- Spectrum of Krypton. CCIS quadrupole flight model breadboard.

removed and an electron multiplier[2] was installed. The added amplification was necessary to provide operation at lower pressures. At this time a copper gasketed flange was added in order to permit future changes in the electron multiplier or collector arrangements. (This decision was based on information obtained under Task 8 which indicated a high photon background when using the electron multiplier. The results of the investigations on this problem under Task 16 may require changes in the electron multiplier which can be made at a later date.)

ELECTRONICS

The major effort of this task was the development of a lightweight electronics system to operate the flight-type quadrupole analyzer. A block diagram of the required functions is shown in Figure 4. Voltages supplied to the analyzer include: 2000 volts for the CCIS; 1200 volts for the electron multiplier; and variable rf and dc voltages to the quadrupole rods. The rf voltage at 6 MHz is swept from zero to 520 volts and the dc from zero to 80 volts. The ratio of the two voltages must be constant.

The primary control functions which provide the mass scan are incorporated in the sweep circuit and rf control amplifier. The data output from the electron multiplier is fed through a six decade logarithmic electrometer with a zero to five volt output for telemetry. All of the circuits operate from the 28V primary input power either directly or through the dc to dc

2. RCA Type C31019C.

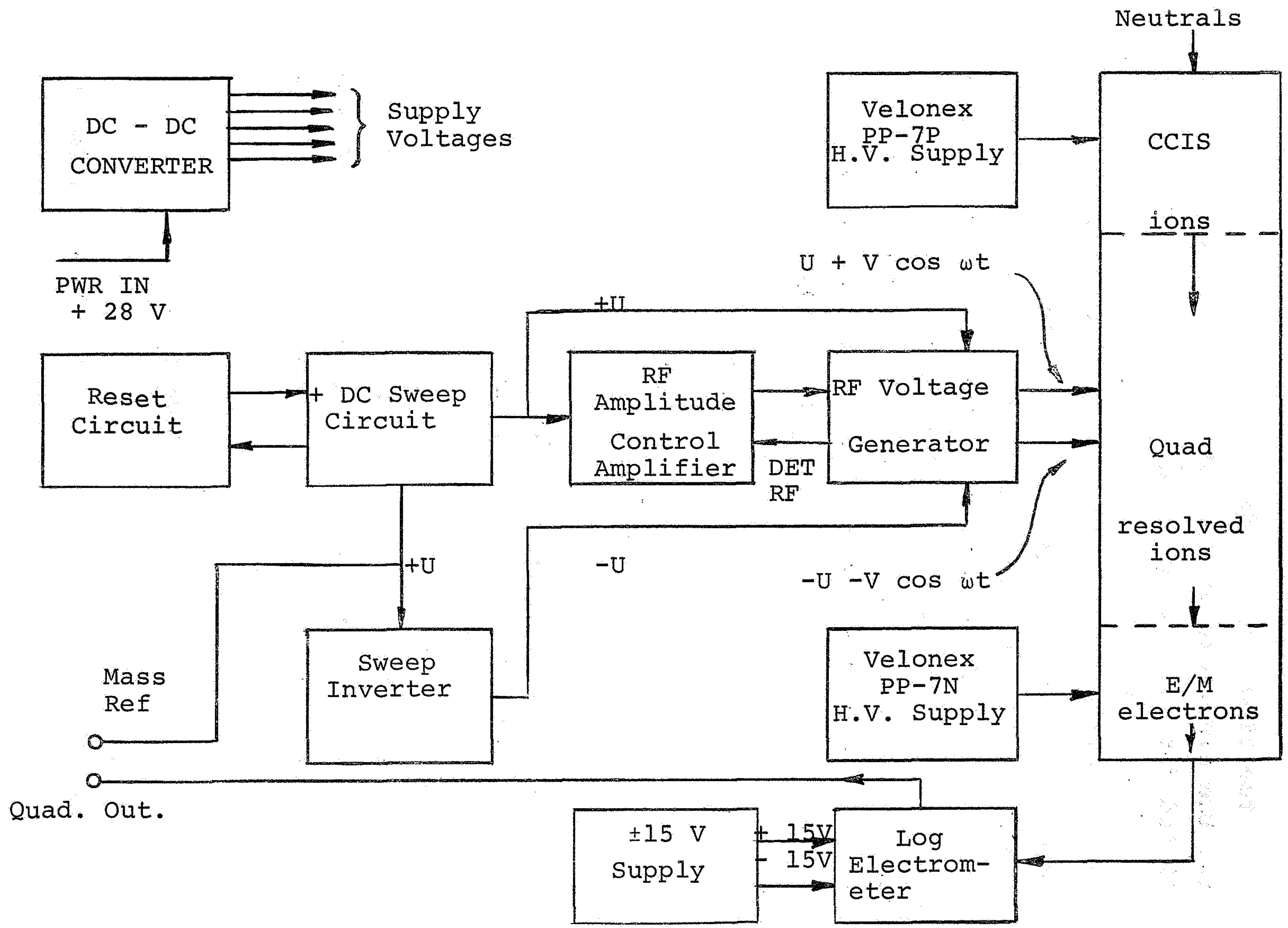


Figure 4. - Block Diagram Breadboard CCIS/Quad Electronics

converter.

Three of the blocks in the diagram, the high voltage supplies and the electrometer are not unique items. Commercial units qualified for space flight are available. New development of these items seemed redundant, therefore, it was anticipated at the inception of this program that these would be purchased and the major development be limited to the unique parts of the electronic system. The two H.V. power supplies are Velonex type PP-7 which have an adjustable regulated output and operate directly from the 28 volt primary power. The electrometer is a Keithley model 25107 with a model 60005 power supply which also operates directly from the main power. The specifications for these units appear in the appendix.

The circuit diagram of the remaining blocks is shown in Figure 5 and further described in the following paragraphs.

RF GENERATOR

The rf generator is a push pull Hartley oscillator whose amplitude may be modulated by a voltage supplied to the transistor bases to sweep the mass spectrum. The output tank circuit is a ferrite core transformer whose secondary winding is tuned to the operating frequency (6 MHz) by the quadrupole capacitance and two small balancing capacitors. With a collector supply of 70 volts, a peak rf voltage up to 550 volts will permit scanning to mass 50 or a little better.

RF AMPLITUDE CONTROL

In order to obtain a constant rf to dc voltage ratio, an

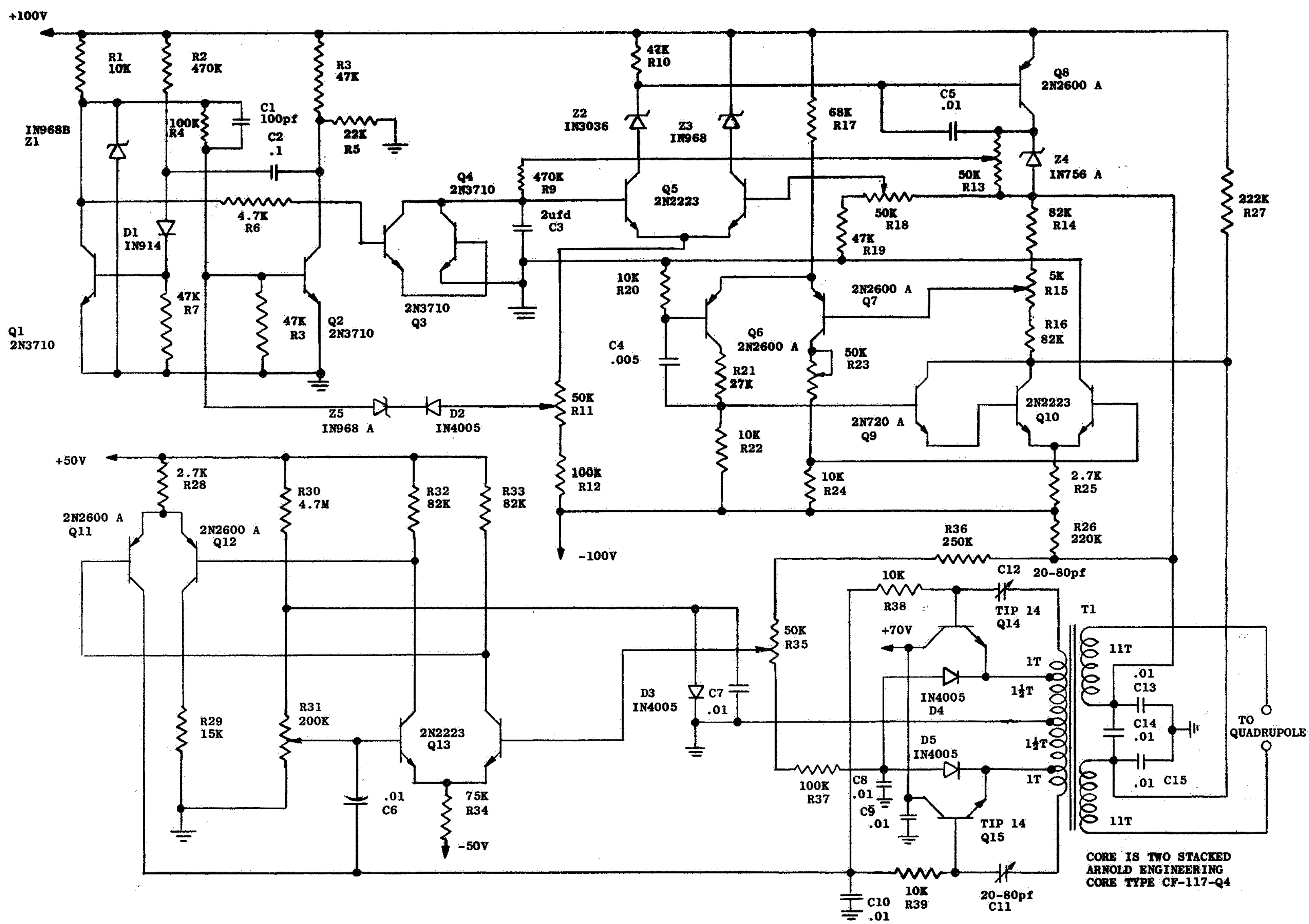


Figure 5. Schematic of Control Circuits and RF Generator.

amplified feedback loop controls the modulating voltage. The rf voltage is sampled at the oscillator transistor emitters by the two diodes. This voltage is compared to the dc sweep voltage through the voltage divider and a two stage amplifier provides the modulating voltage. The amplifier gain is sufficient to maintain the U/V ratio to 1.4%.

DC SWEEP CIRCUIT

Because the sweep rate is limited by the speed of response of the electrometer output amplifier, and because the peak width is proportional to mass number, the sweep generator is designed to provide a logarithmic sweep rather than linear. The lower mass numbers are then swept more slowly so that the electrometer can follow the narrower peaks. A true logarithmic sweep, however, scans the low mass numbers much too slowly when adjusted to scan the higher numbers properly. An adjustable linear voltage is added so that the scanning rate may be optimized for both ends of the spectrum.

The sweep voltage is developed by a differential input high gain amplifier with an RC positive feedback loop which generates the logarithmic sweep. The linear voltage is added into the feedback loop through Z5 and R13. The negative dc sweep voltage to provide the balanced output is developed by an inverting amplifier (Q6, Q7, Q9, and Q10). These voltages are connected to the rods at the center taps of the rf generator output transformer. A reset one-shot multivibrator triggered from the dc scan voltage discharges the sweep capacitor C3 to start the sweep at or near zero mass.

DC TO DC CONVERTER

The dc to dc converter supplies the voltages necessary to operate the foregoing electronic circuits. The schematic is shown in Figure 6. The two transistors operate as a square wave oscillator with the saturable core transformer at a frequency of approximately 600 hertz. The output windings of the transformer provide the necessary voltages for the circuit. Voltage regulation of four of these voltages is provided by a zener reference and pass transistor in each case. The +70 volts for the rf generator is not regulated. Although absolute measurements of the frequency stability were not made, the resolution over the spectrum does not indicate that this is a problem. The transformer wound for this model did not, however, have enough turns on this winding so that at the high mass numbers the U/V ratio does not remain constant. This can easily be corrected in later development.

The complete system is shown under test in the photograph of Figure 7. The analyzer tube is on the vacuum system pumped by an ion pump. The system pressure may be adjusted over the range of 10^{-9} to 10^{-3} Torr by admitting gas through a leak valve under the table top. The rf generator is strapped to the analyzer tube to permit very short leads to the quadrupole. The dc to dc converter is on the left and the other control circuit boards are to the right. The Keithley electrometer and one of the Velonex power supplies are in the foreground. The complete system weighs a little less than five pounds. (The aluminum chasses are only convenient mounting devices and are not included.)

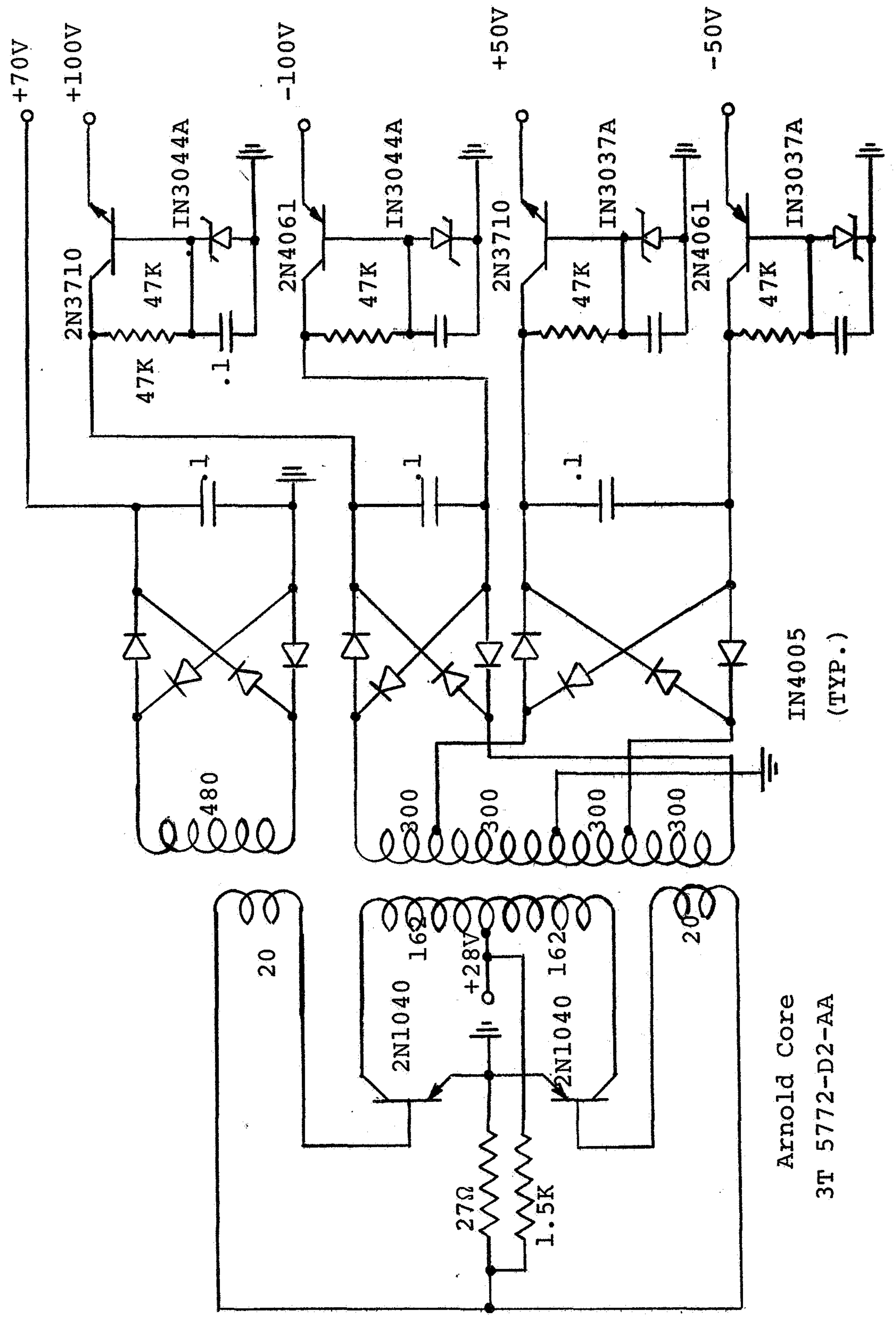
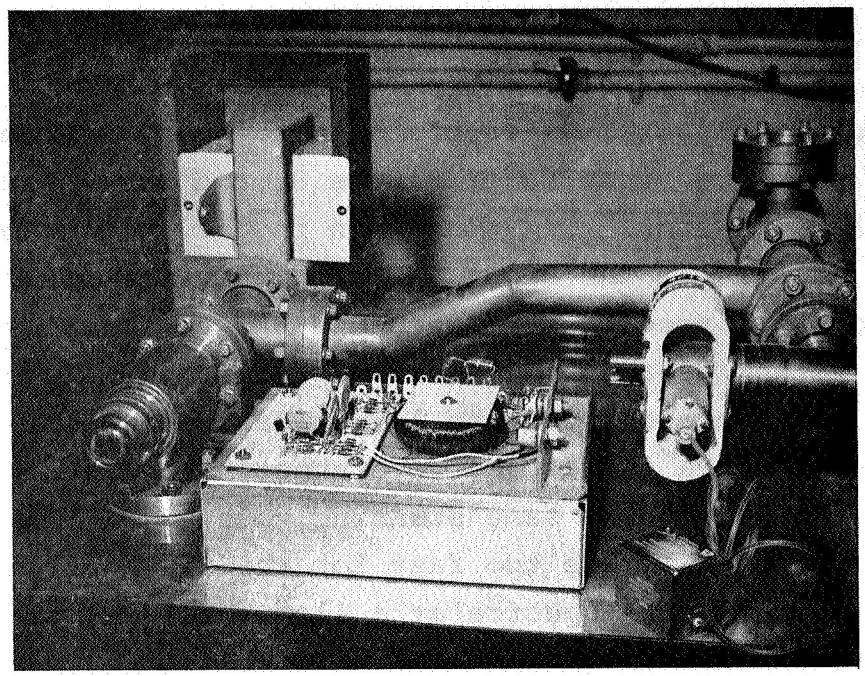


Figure 6. - Breadboard DC-DC Converter



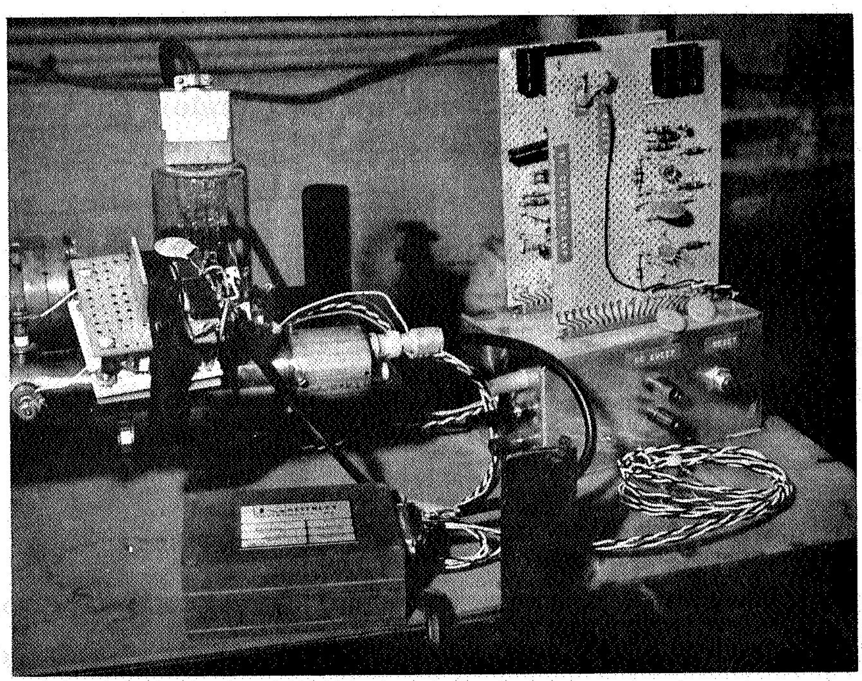


Figure 7. Breadboard System Under Test.

SYSTEM OPERATION

Operational characteristics of the breadboard system are shown in the slow scan spectra of Figure 8, and the 5 second scan photograph of Figure 9. (The scan in the photograph is reversed - 0 mass is at the right.) With only minor exceptions, the three slow scan spectra, one with the EAI electronics and two with the flight breadboard electronics, are equally good. The negative going trace after the large peaks on the breadboard automatic scan spectra is recorder overshoot. The sweep time could not be reduced to the same scanning rate as with the EAI electronics, and is a little too fast for the recorder to follow. The manual scan spectra at a slower rate eliminates the overshoot. The photograph also shows that this is not a system problem. As indicated in the discussion of the dc to dc converter the smaller and narrower argon peak is due to the change in U/V ratio increasing the resolution which reduces the sensitivity. This problem does not appear under fast scan conditions because there is enough stored energy in the dc to dc converter to maintain the rf generator voltage over the short duty cycle. The resolution is just over one amu for the mass 28 peak. (The logarithmic response is somewhat deceiving if one is used to the usual linear peak height spectra. The 10% peak point is down only 8.3 small divisions from the peak.)

POWER

A plot of the power profile for a single scan is shown in Figure 10. Because the rf voltage is maximum at the highest

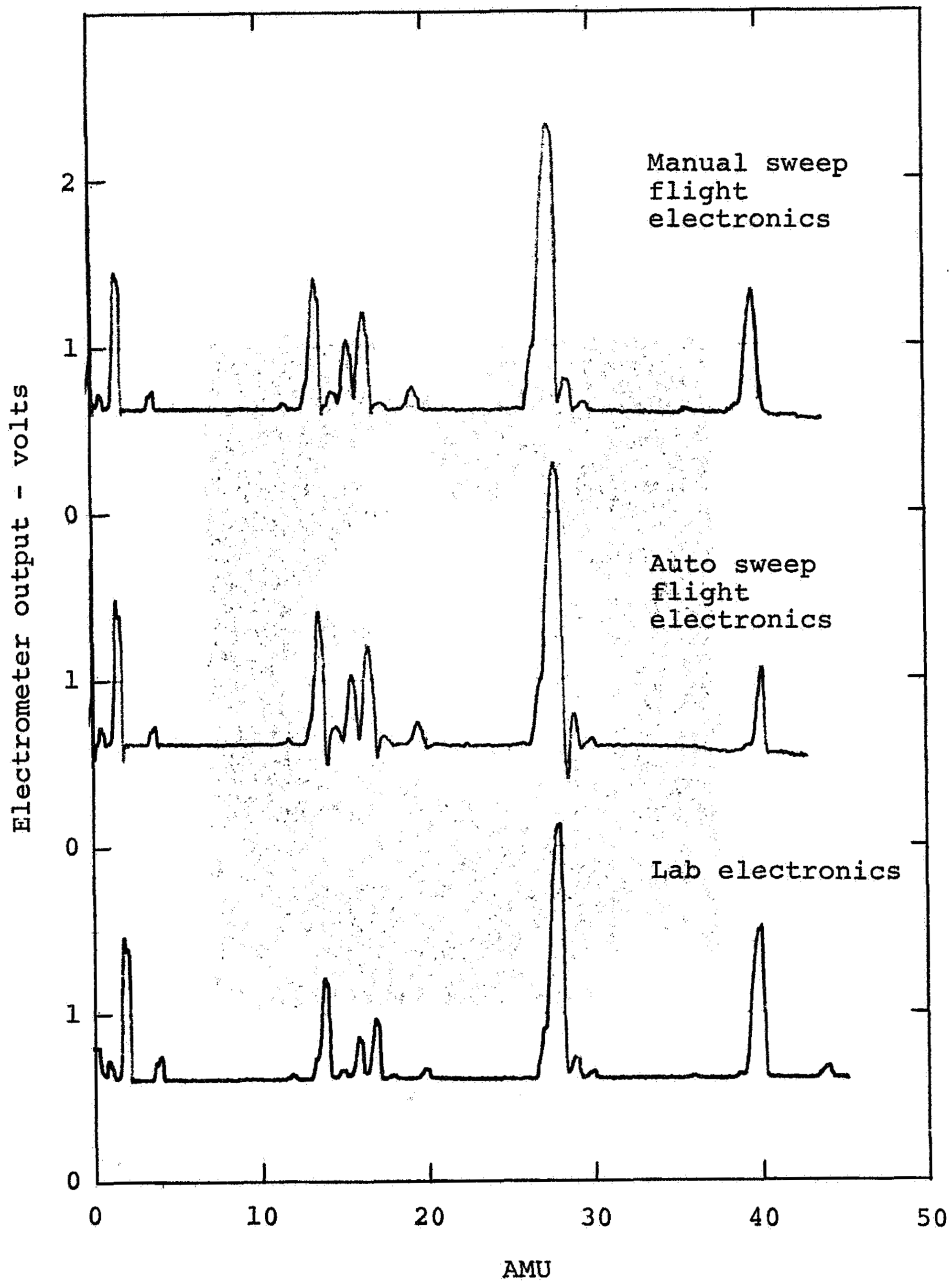


Figure 8.- Spectra using breadboard electronics
and lab electronics

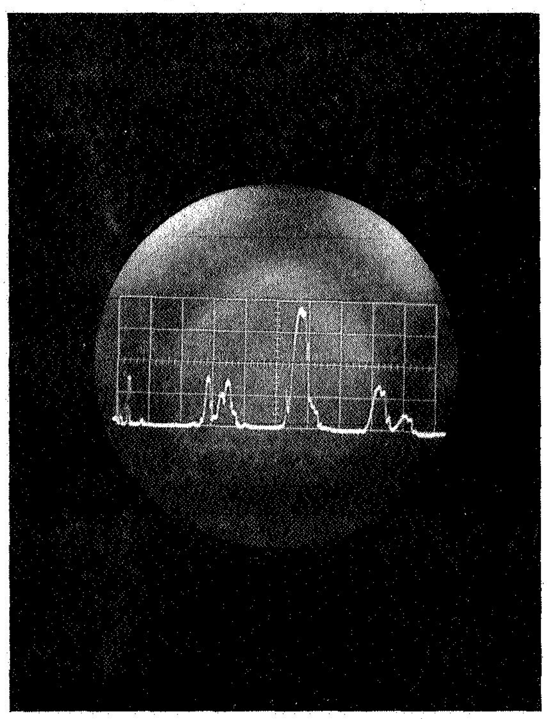


Figure 9. 5 Second Scan Photograph.

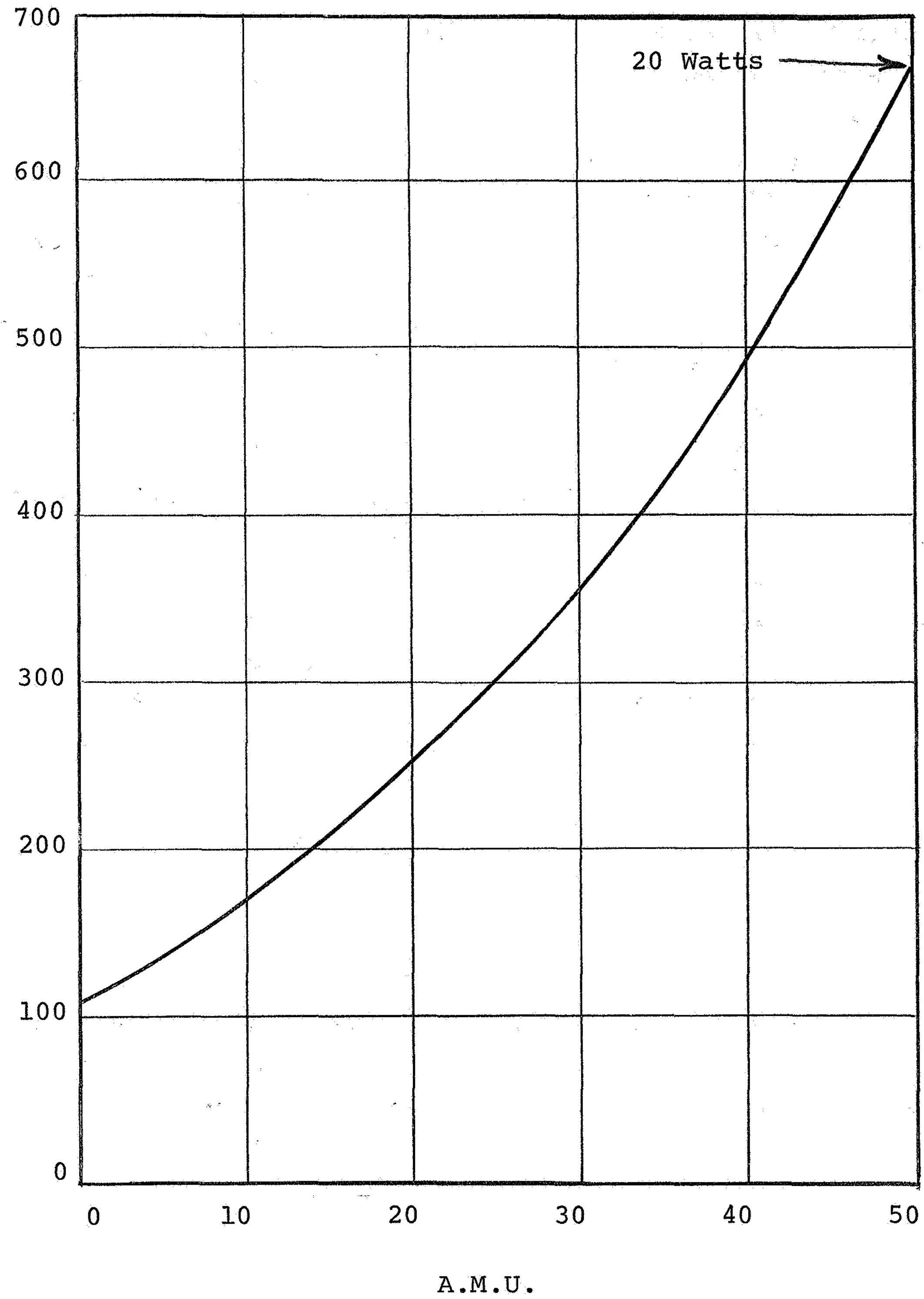


Figure 10. - Power consumption at 28 Volts input

mass number, the power increases as the scan proceeds to the higher numbers. Peak power at mass 50 is 20 watts and the average power is 11 watts. This is 10% over the design goal. Some improvement can be expected in building a prototype model and some trade-offs are available if the power requirements are too high for a specific mission. The dc to dc converter operates at 60% efficiency. This is low by usual standards. Increasing the wire size of the transformer windings to reduce the losses particularly in the high current 70V winding will help, and a single preregulator would probably eliminate the need for the four separate regulators which consume some power. In a final flight design, the dc to dc converter would be designed to supply all of the voltages required. The two high voltage supplies and the Keithley electrometer operate on separate converters in this model. Using a single converter would improve the overall efficiency. One obvious trade-off to reduce the power requirement is to reduce the operating frequency. This will also degrade the resolution but since the power is a function of $(\text{frequency})^5$ and resolution is a function of $(\text{frequency})^2$ the power will be reduced much faster than the resolution.

WEIGHT

While the total weight of the first breadboard model will provide a guideline for future missions, the requirements of a specific mission will affect the instrument weight. A breadboard model by nature is not a compact fully volume-integrated unit. The total weight of the various components of this system is 4 lbs. 15 ozs. including the spectrometer tube. Although some improvement can be expected in a fully integrated electronics package, the mechanical mountings and coverings will offset this improvement. In any case a figure of 5 lbs. is reasonable for planning purposes.

CONCLUSIONS AND SUMMARY

The development work on a light-weight mass spectrometer system described here and carried on under Contract NAS1-5347, Task 11, has resulted in a very respectable breadboard instrument. Although not designed for a specific mission, only minor changes would be necessary to meet the requirements of many types of missions. With the exception of the power budget which is 10% high, all of the design goals have been met or exceeded and the power requirements are subject to some improvement and trade-offs depending on mission requirements.

Typical specifications for the breadboard system are given in the following pages. A basic flyable mass spectrometer can be built with these characteristics but until the mission requirements are more fully defined, the final parameters cannot be determined.

TYPICAL SPECIFICATIONS

Power Supply

Input		
Voltage	28 Vdc	
Current	400 ma. Avg.	
Outputs		
+ DC Sweep	+ 100V dc	
Inverter	- 100V dc	
RF Control Amp	± 50V dc	
RF Generator	+ 70V dc	0-260ma
Anode HV Supply	+ 28V	10ma
E/M HV Supply	+ 28V	20ma
Keithly DC-DC Converter	+ 28V	12ma

Sweep Generator

Supply Voltages	+ 100Vdc	
	- 100Vdc	
Outputs	+ U 0- + 95Vdc	Sweep Ref
	- U 0- - 95Vdc	
	0 - 20Vdc	TO RESET CKT
Sweep Time	Variable 5 sec to 10 min	

RF Control Amplifier

Supply Voltages	+ 50Vdc	
	- 50Vdc	
Output	0 - 45V	RF Modulation Voltage

RF Generator

Supply Voltages	+ 70Vdc 0 - 260ma	
Outputs	0 - 50V	RF Amplitude Det
	+(U+V cos t)	U = 0 - 95V
	-(U+V cos t)	V = 0 - 560 Vac pk
		freq. 6 MHz.

Log Electrometer Amplifier

Supply Voltages	+ 15Vdc	1.8ma
	- 15Vdc	1.8ma
Range	10^{-11} to 10^{-5} ampere	
Output Resistance	1 K	
Response Speed	One millisec for a step change from 10^{-9} to 10^{-8} ampere	
Output Voltage	0 - 5Vdc	

Total weight for breadboard electronics 2 lb. 8 oz.

Quadrupole

r_o	2 mm
rod length	15 cm
d	.089 in
Capacitance	22.5 pf
Q	200
Magnet	845 G
Weight	2 lb. 8 oz.

APPENDIX

TO: Norton Research - NRC

KEITHLEY INSTRUMENTS, INC.
Quotation No. 22504

February 19, 1968

SOLID STATE LOGARITHMIC PICOAMMETER

MODEL 25007/25107

DESCRIPTION:	The Model 25007/25107 Picoammeter is an "all solid-state" DC current amplifier capable of measuring currents as small as 10^{-11} amperes with a dynamic range of about 4 to 7 decades. Temperature compensation circuit will be installed using nominal values. Testing to be done at 25°C only, consequently, no assurance can be given for the degree of compensation which will result.
RANGE:	As selected by customer. 10^{-11} to 10^{-5} ampere range.
POLARITY OF INPUT:	Negative for Model 25107.
TRANSFER FUNCTION:	Each unit will be individually calibrated at temperatures selected by customer. The calibration data will be accurate to 0.3% of readings. Testing to be done at 25°C only and data will be furnished.
OUTPUT RESISTANCE:	Less than 1K. A specific value can be furnished if desirable.
CALIBRATION POINTS:	NONE
OUTPUT CLIPPERS:	NONE

OUTPUT NOISE:	Dependent on response speed and input shunting capacity. Typically about 10 mv peak-to-peak.
RESPONSE SPEED:	Adjusted to the requirements of the customer. One millisecond for step change from 10^{-9}A to 10^{-8} ampere.
POWER REQUIRED:	+15V at 1.8 ma -15V at 1.8 ma The voltage value is not critical but must be stable. The degree of regulation required depends upon the desired readout stability. If the (+) and (-) vary together the regulation may be less critical. A regulation of 0.05% for line load and temperature would fulfill the most stringent requirement and often a much less exotic power would be sufficient.
CONNECTOR:	Usually a "D" series connector with a coaxial insert for the input connection (type DBM-17W 2P). Other types can usually be furnished.
CASE:	Magnesium with a chromate conversion coating, black, conductive.
WEIGHT:	120 grams. Nominal
SIZE AND MOUNTING:	See drawing 22074A.
OPTIONS:	1. No potting 2. Output voltage 0 to 5 volts DC controlled for current range selected. Output voltage may exceed above values for input currents beyond selected range.

TO: Norton Research, NRC
DATE: February 19, 1968
QUOTATION NO.: 22504

KEITHLEY INSTRUMENTS, INC.

POWER SUPPLY - MODEL 60005

The model 60005 power supply is a DC to DC converter featuring light weight, good efficiency, and well regulated outputs.

The Model 60005 operates from a 28 volt power source that is common to most aircraft and aerospace vehicles. Total output power of 300 milliwatts is available at 3 pins of the connector; +15 volts, -15 volts, and common. The common is isolated from the case with provision for internal connection when required. Short circuit protection and reverse polarity protection are provided.

The power supply is furnished in our standard case of machined magnesium with a chromate conversion coating.

Modification of electrical characteristics and mechanical configuration can be supplied upon request.

SPECIFICATIONS - MODEL 60005

INPUT

Volts: 28 ± 5 volts DC
Current: 27 ma nominal full load.
7 ma nominal no load.
Reverse polarity protection.

ENVIRONMENTAL

Temperature: To be tested at 25°C only.
Vibration: No potting required.

EFFICIENCY: 40% at rated conditions.

OUTPUT

Volts: ± 15 volts
Current: 10 ma full load
Short circuit protection with current limiting to 20 ma.

REGULATION:

Load: .03%
Line: .03%

MECHANICAL

Size and Mounting Dimensions: see drawing 2074A

TO: Norton Research, NRC
DATE: February 19, 1968
QUOTATION NO.: 22504

KEITHLEY INSTRUMENTS, INC.

ISOLATION: Input to output greater than 10^9 ohms.

WEIGHT: 115 grams Nominal

FREQUENCY: 15 KHZ Nominal

CONNECTOR: DEM-9P

OPERATING INSTRUCTIONS

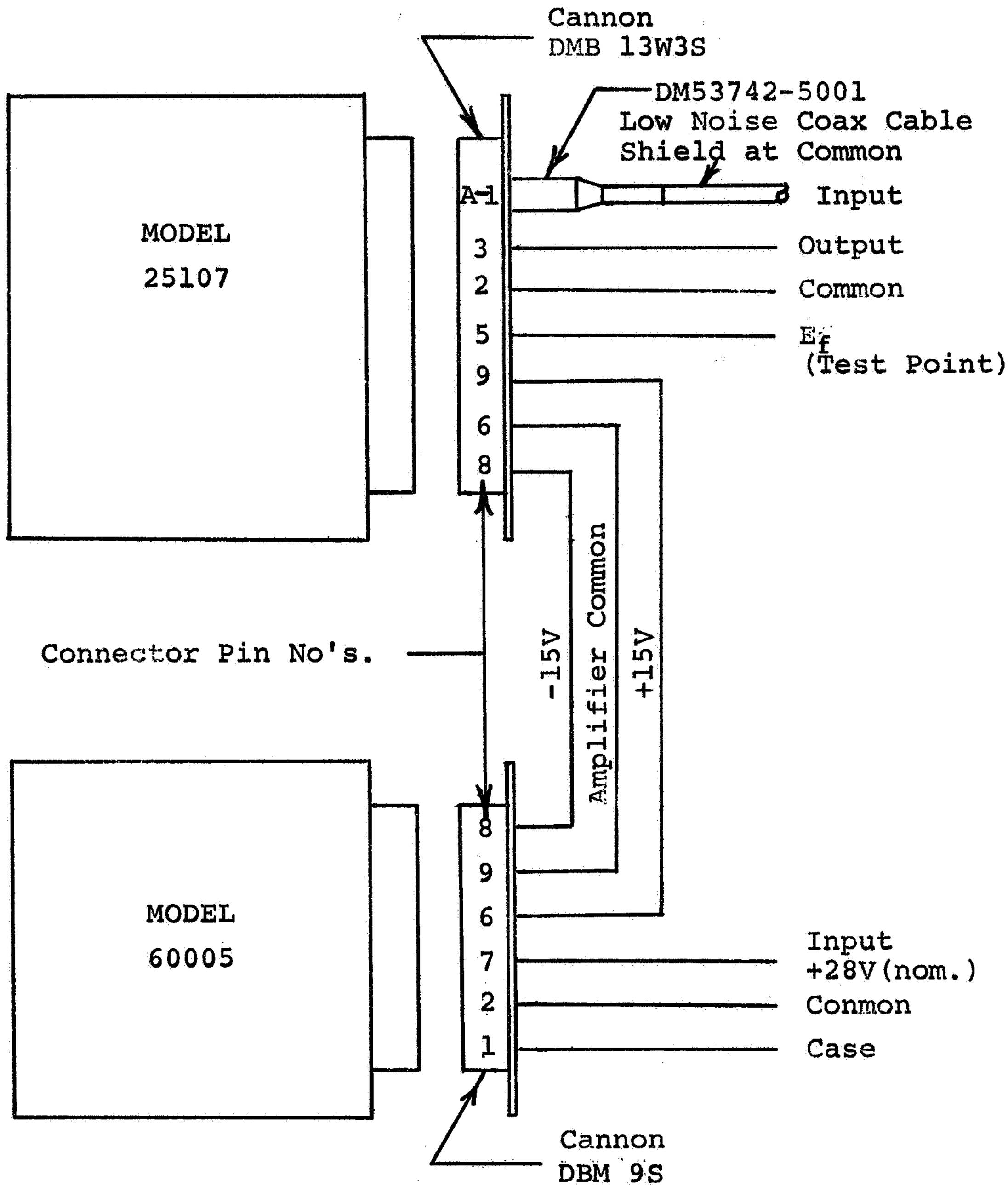
See Figure 1 and Drawing #20274A for wiring instructions and mounting dimensions.

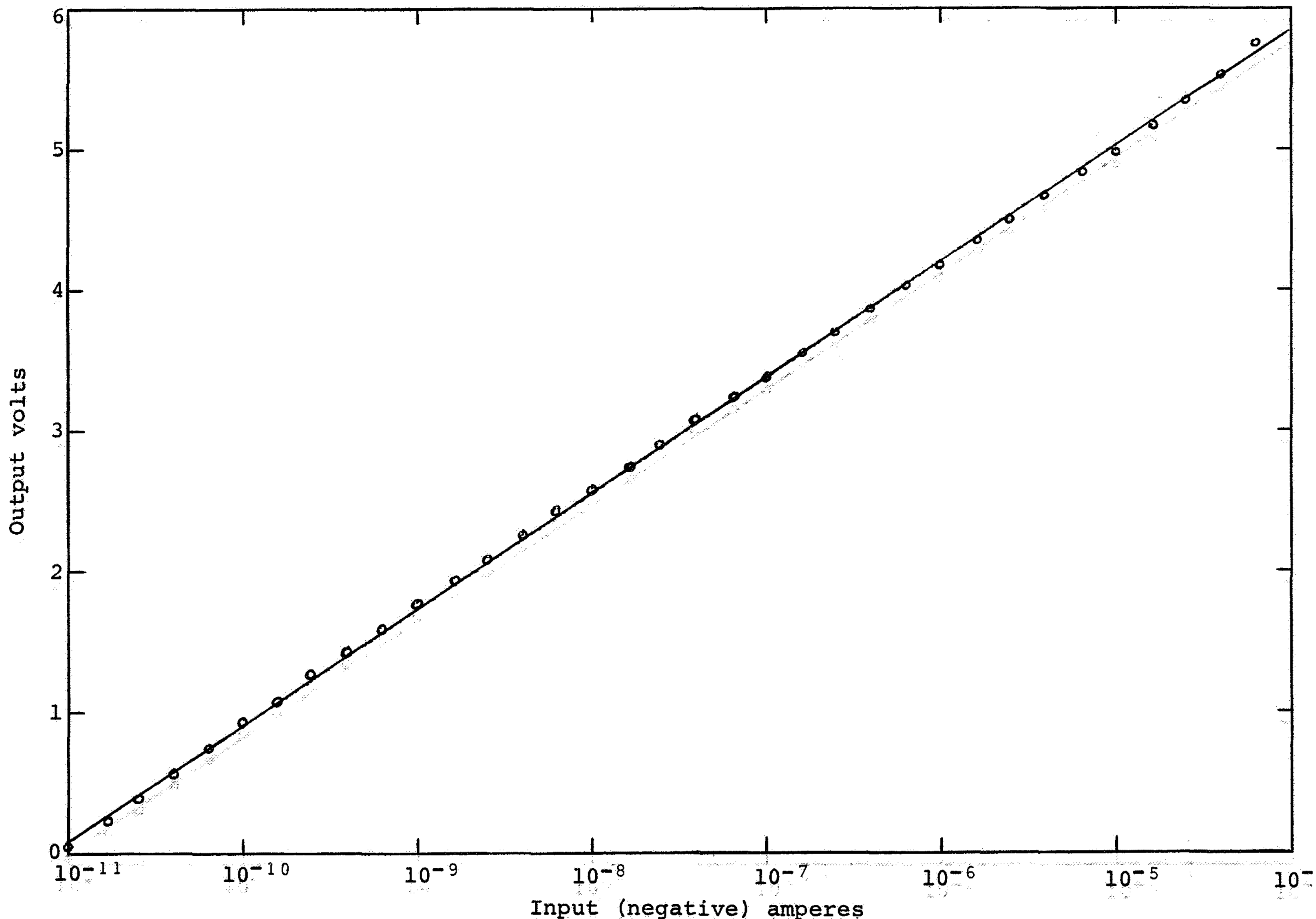
Model 25107 case is internally connected to amplifier common.

Model 60005 case input common and output common are not connected internally and may be wired externally in any arrangement desired.

Zero balance adjustment procedure is as follows:

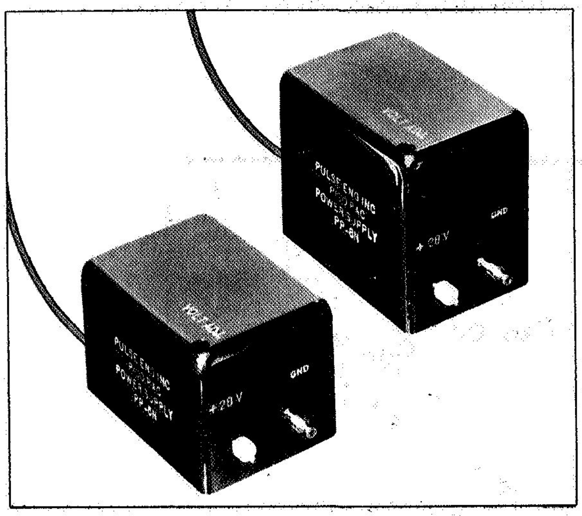
1. Short input (A-1 center conductor) to output (pin 3).
2. Short feedback (pin 5) to common (pin 2).
3. Observe output (pin 3) with an oscilloscope to make sure the amplifier is not oscillating; if it is, a large capacitor (C > 1 mfd) from input to common will stop the oscillation.
4. Observe output with a millivoltmeter and adjust balance trimpot until the output voltage is less than ± 1 millivolt.
5. Don't forget to remove the short from feedback.


Cannon
DMB 13W3S
DM53742-5001
Low Noise Coax Cable
Shield at Common
MODEL
25107
A-1
3
2
5
9
6
8
Input
Output
Common
Ef
(Test Point)
Connector Pin No's.
-15V
Amplifier Common
+15V
MODEL
60005
8
9
6
7
2
1
Input
+28V(nom.)
Conmon
Case
Cannon
DBM 9S



CALIBRATION
MODEL 25107 S/N 404 25°C DATE 5/2/68

PICO-PAC ADJUSTABLE POWER SUPPLIES
1/4 WATT 28 V DC INPUT



- ENCAPSULATED UNITS DESIGNED FOR SPACE ENVIRONMENTS
- VERY LOW RIPPLE
- EXCELLENT REGULATION
- COMPLETE VOLTAGE COVERAGE FROM 400-4000 VOLTS
- 28 VOLT DC INPUT

For the laboratory or for the designer of space flight radiation - measurement systems, Pico-Pacs are a flexible family of pre-tested and flight-proven HV power supplies solving a broad range of problems at a saving in time and expense. They are designed to power: photomultipliers, Geiger-Muller tubes, ionization gauges, solid state detectors, channeltrons, silicon diode detectors, and many kindred high voltage low-current devices.

Each unit is *adjustable* over its range making it possible to take advantage of the optimum output of the particular sensing element—or to use the power supply with several different devices. This feature alone gives each unit optimum flexibility as a system component, and makes design and testing of special power supplies completely unnecessary. These units contain reverse-polarity protection, should the input power connection be incorrect.

Check the individual specifications shown, and order by part number the unit that meets your requirements. Polarity is indicated by adding the letter N or P to the item ordered.

UNIT	VOLTAGE RANGE IN VOLTS	WEIGHT* MAX GRAMS	SINGLE ** PRICE
PP-5	400-750	110	$270
PP-6	750-1300	110	$280
PP-7	1150-2000	140	$335
PP-8	1500-2600	140	$355
PP-9	2300-4000	160	$395

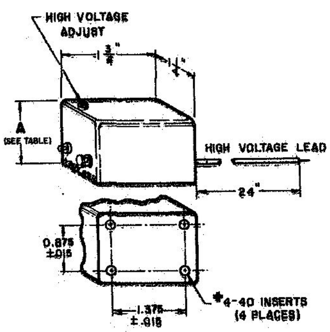
Negative and Positive HV output polarities are available on any model. Specify polarity by adding dash letter P or N. *Example:* PP-5-N or PP-5-P.

*excluding high-voltage lead.

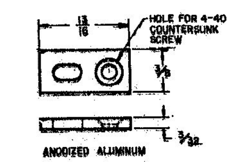
**F.O.B. Santa Clara, California.

SPECIFICATIONS, All Models

1. *Input:* 28 volts DC nominal; ground negative on input.
2. *Line Regulation:* < ± 0.4% (24-32V).
3. *Load Regulation:* (50 to 250 MW output) < ± 1.5%.
4. *Ripple:* < 0.007% peak to peak.
5. *Output Power:* 250 MW maximum.
6. *Input Current:* Figure 1 (See other side).
7. *Temperature Drift:* < ± 1% (—30°C to +71°C).
8. *Dynamic Regulation:* Equivalent power supply source impedance < 100KΩ at 1KHz to < 1KΩ at 0.5 MHz
9. *Environmental:* See other side.
10. *Noise induced into 28V power line:* < 15mv across 1 ohm impedance.



UNIT	"A" DIMENSION
PP-5	1-1/8"
PP-6	1-1/8"
PP-7	1-1/2"
PP-8	1-1/2"
PP-9	1-3/4"



ANODIZED ALUMINUM MOUNTING BRACKET 4 SUPPLIED

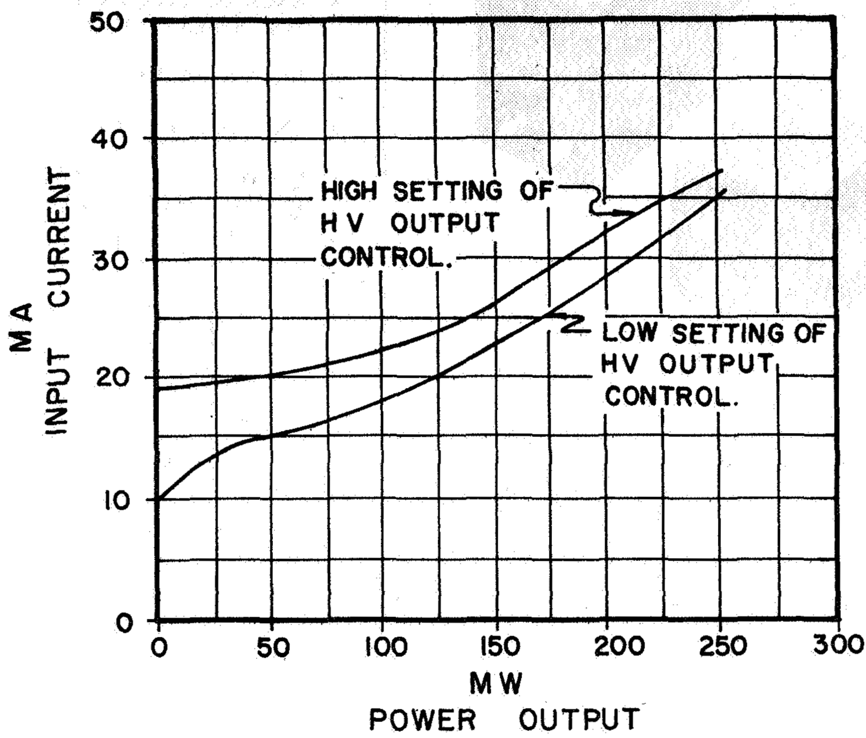
Data and Prices Subject to Change Without Notice. 9/67
Available in non-magnetic gold finish at $15.00 additional.

velonex
division of Pulse Engineering, inc.

velonex division of pulse engineering, inc./560 robert ave., santa clara, california 95050/(408)244-7370/twx 910-338-0114

FIG. 1

Typical Input Current Requirements from 28 volt DC Supply at + 25°C.



ENVIRONMENTAL DATA

Pico Pacs have been designed and tested to meet or exceed the environmental conditions indicated below:

Altitude—Operational from sea level to 200,000 ft. (exposure to reduced pressure $>$ 30 min.);

Acceleration* — 120 g for 30 seconds - any axis

Mechanical Shock*—80 g, 15 milliseconds - any axis

Thermal Shock* — -54°C to + 65°C to -54°C, each in less than 5 minutes

Sinusoidal Vibration* — 5-28Hz: 0.55 inch double amplitude
28-3000 Hz: ± 20 g
} 2 octaves/minute - any axis

Random Vibration* — 0.1 g^2/Hz, 3σ, 20-2000 Hz, 90 seconds, any axis

Stability — Drift less than ±0.1% per day after 2 hours of operation

*Units energized following, but not during, tests.

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