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MEASUREMENTS OF MAGNETIC FIELDS PRODUCED BY A 30 kWe CLASS ARCJET POWER CONDITIONING UNIT

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Final Report

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FOREWORD

This final report was submitted by the OLAC PL/RKAS Branch, at the Phillips Laboratory, Edwards AFB CA 93524-7190. OLAC PL Project Manager was Chris Andrews

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the DD Form 298.

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13. ABSTRACT *(Maximum 200 words)*
The magnetic fields produced by a 30 kWe class Arcjet Power Conditioning Unit were measured using a Gauss meter and an axial magnetic field probe. These tests were conducted at Rocket Research Company in Redmond WA from 11-12 Jun 1992 using a 30 kWe class Arcjet Power Conditioning Unit (PCU), and associated hardware. The PCU is an engineering model designed by Pacific Electrodynamics for the Electric Propulsion Experiment (ESEX) to be flown on the Advanced Research and Global Observation Satellite (ARGOS). Measurements were recorded at various locations around the PCU at ambient conditions and at power levels of 26, 20, 10, and 6.5 kWe. The results indicate the magnetic field presence is at a level, considering the "worst case" scenario of the test, well below any that would result in damaging effects to the spacecraft or to any other experiment.

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INTRODUCTION

The success of the Advanced Research and Global Navigation Satellite (ARGOS) is highly dependent on the ability to predict interactions between each of the experiments. The Electric Propulsion Space Experiment (ESEX) is one of only two operative experiments in the second phase of ARGOS operation and, therefore, is a dominant factor in determing the success of the ARGOS mission. The most critical concern during the operation of ESEX is the effect of radiated Electromagnetic Interference (EMI) from the arcjet, and the potentially large magnetic field generated by the Power Conditioning Unit (PCU).

The radiated EMI from the arcjet is due to high current levels and a largely unobstructed view, electromagnetically, of the arc. Although there is potential for significant EMI effects, tests performed from 27 - 30 JUL 92 indicate these effects are substantially less than originally predicted. These data are now being reduced and final results are expected in the near future.

The PCU for the 30 kWe class arcjet is used to assure that the power to the arcjet is kept constant by controlling the input current level. The configuration (Figure 1) tested in these experiments is an on - going design produced by Pacific Electrodynamics (PED). PED is acting with Rocket Research Company (RRC) as subcontractors of TRW on contract number F04611 - 90 - C - 0005, "26 kWe Arcjet ATTD." *The design is comparable with that in* Reference 3 with the only change being the addition of three inductors as shown in Figure 2.

The tests were conducted on 11 - 12 JUN 92 at Rocket Research Company in Redmond, Washington. The tests involved using a gauss meter to determine the magnetic fields (B-fields) produced from different portions of the PCU under several operating conditions. The parameters studied include various power level effects, probe location, and arcjet startup trends. The data acquired in these tests provide a "worst-case" baseline on which to map B-field trends around the PCU. This is due to several geometric differences in the test model PCU compared with the flight unit.

EXPERIMENTAL APPARATUS

Facility and Arcjet

This experiment was conducted at the electric propulsion facility at Rocket Research Company in Redmond, Washington. This facility has already been described in detail in Reference 1 and little was altered in these tests except for the addition of the PCU. The arcjet used was a standard RRC modified arcjet with the cathode gap set to 0.200 in. rather than the more common 0.240 in. The reader is again referred to Reference 1 for further information regarding the RRC modifications to the arcjet.

Power Conditioning Unit

The PCU is a PED design and has an input voltage ranging from 160 Vdc to 180 Vdc for the 30 kWe level and maintained efficiencies of approximately 97% (Ref. 3). The unit used for these tests is essentially equivalent to the flight unit with a few exceptions. This PCU lacked some of the shielding and insulative properties that the flight unit will have, making it much "nosier" than the spacecraft unit. There are some possible modifications to the starter circuit hardware which have yet to be determined (Ref. 4).

Additional PCU Inductors

The addition of three inductors to the PCU was accomplished to block an excessive voltage spike. These three inductors were wound by Mr. Bob Kay at PED and are 7.3, 9.0, and 9.1 milliHenrys respectively (Figure 2). The reason for different inductances was solely due to differences in core permeability. The cores are high quality ferrite material with a permeability on the order of 5000. Once the inductors are saturated, which occurs almost immediately upon arcjet initiation, the core becomes irrelevant to the production of B-fields, and the inductor acts as a free space inductor. Appendix B contains more information about the inductors themselves and contains the calculations for determining their B-field contribution.

Gauss Meter

The actual B-field measurements were acquired with a gauss meter and its associated hardware. A standard F.W. Bell model 4048 Gauss/Tesla Meter was used along with a probe extension cable, a zero gauss chamber for calibration, and an axial B-field probe. Appendix A has a listing of this equipment along with associated serial or model numbers. Other experimental apparatus consisted only of standard tools and measuring devices used to align and affix the probe in the desired location.

EXPERIMENTAL PROCEDURES

The procedure for obtaining these measurements was not particularly complex. The probe was either affixed or supported at certain locations around the PCU, and the reading was taken from the Gauss meter. The locations were kept common between data runs to facilitate data collection and to observe trends in the B-field strength at different power conditions.

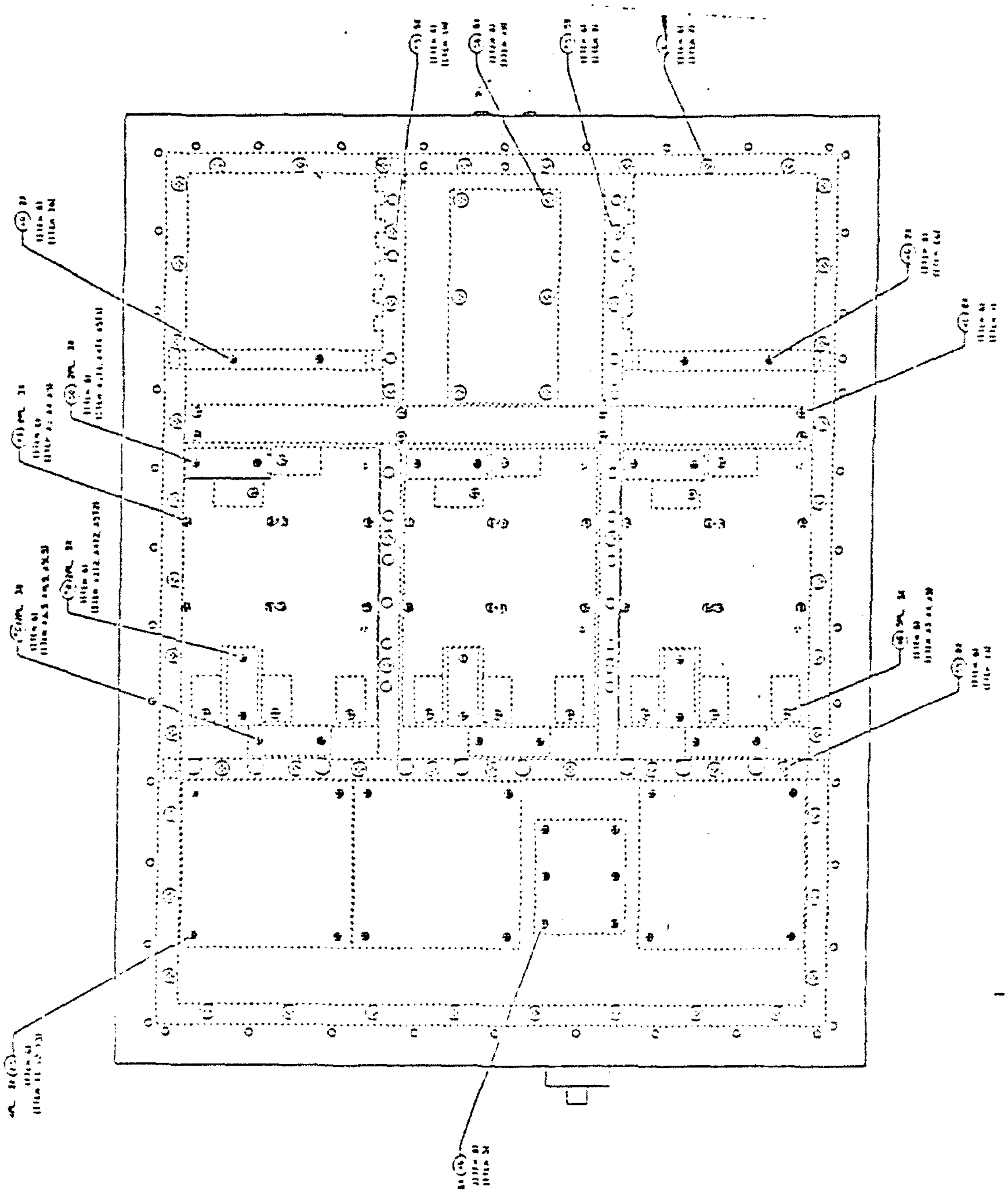

Figure 1
Basic PCU Layout

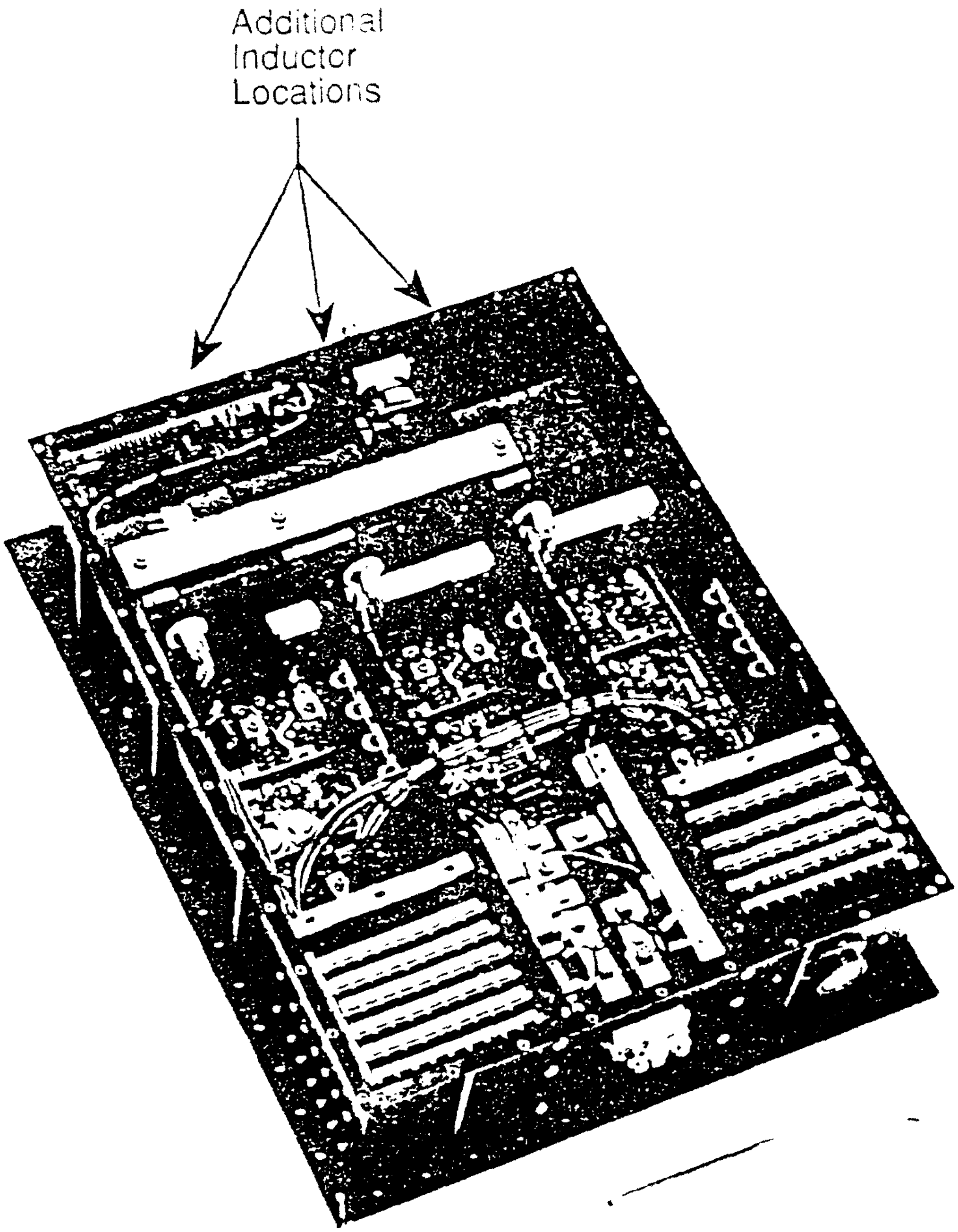

Figure 2
PCU Interior Architecture

Figures 3 and 4 illustrate the general probe locations for all of the power conditions tested. Figures 5 and 6 illustrate the general probe orientation for each of the measurements. The gauss meter was calibrated at the beginning and the end of the entire experiment, and several times throughout to assure the probe readings were accurate.

B-field Strength Prior to Arcjet Operation

For the case of the arcjet being inoperative, the experimental procedure was based on obtaining a "point and read" measurement. The locations for the measurements were decided based on accessibility, the potential for high B-field strength, and the desire to expedite measurement acquisition. The Plexiglas cover was unfastened to provide access to the interior architecture and to provide a location to affix the probe when measuring above the PCU. The experimenter's hand was removed from the probe, the reading allowed to settle, and the value recorded. The probe was then moved to the next location - either by sliding the Plexiglas cover or repositioning the probe entirely.

B-field Strength During Arcjet Operation

When the arcjet was running, the procedure was similar to the inoperative procedures with the *only difference* caused by certain safety considerations. A second piece of Plexiglas was added to cover the exposed portion of the PCU, and the experimenters had to remain a certain distance away from the PCU while it was operating. The only problem this presented was determining a method for reading the display on the Gauss meter.

The probe was secured in the same manner as above, either affixed to the Plexiglas cover or supported outside the Plexiglas box using some convenient item. The Gauss meter was placed on a table which allowed viewing from a distance of approximately four feet. The B-field strength was monitored and recorded while the arcjet was started and the power ramped up to 26 kWe. The power was then shut down allowing access to the PCU for probe repositioning.

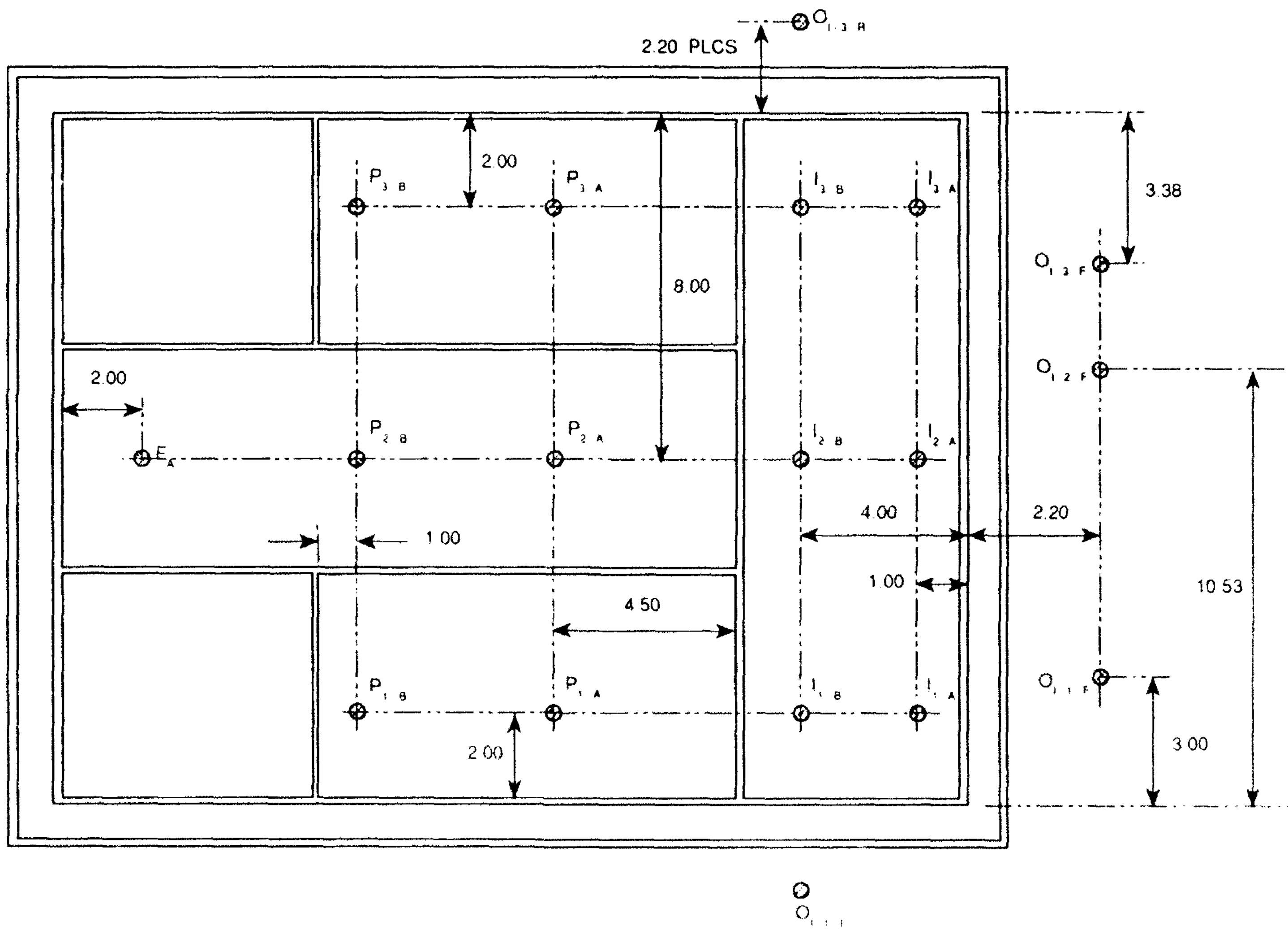

Figure 3
Top View of PCU Housing and General Probe Location

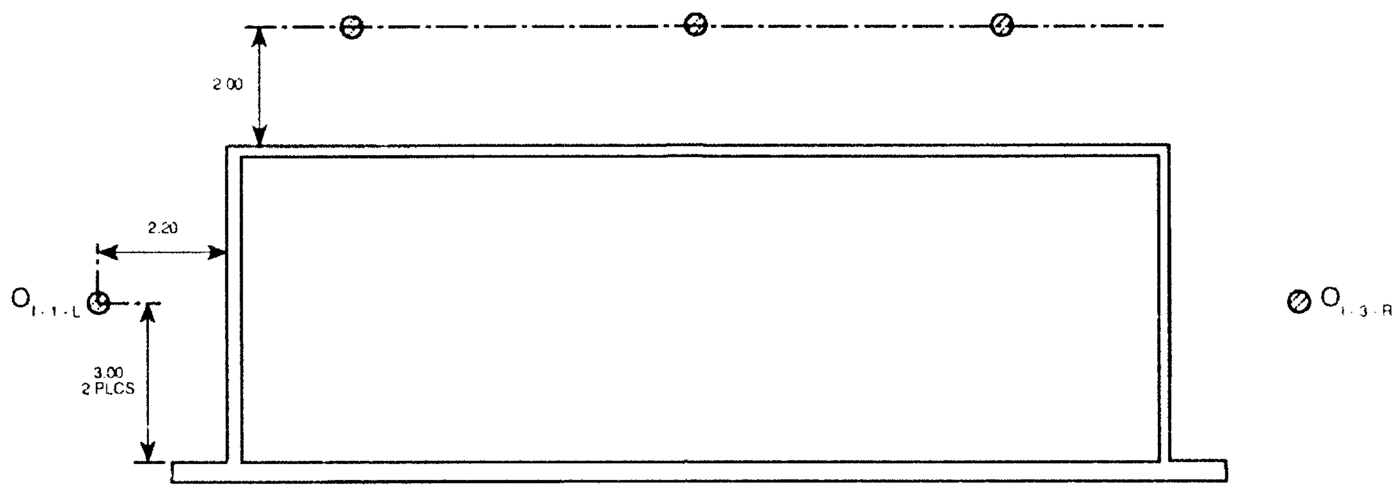

Figure 4
Front View of PCU Housing and General Probe Location

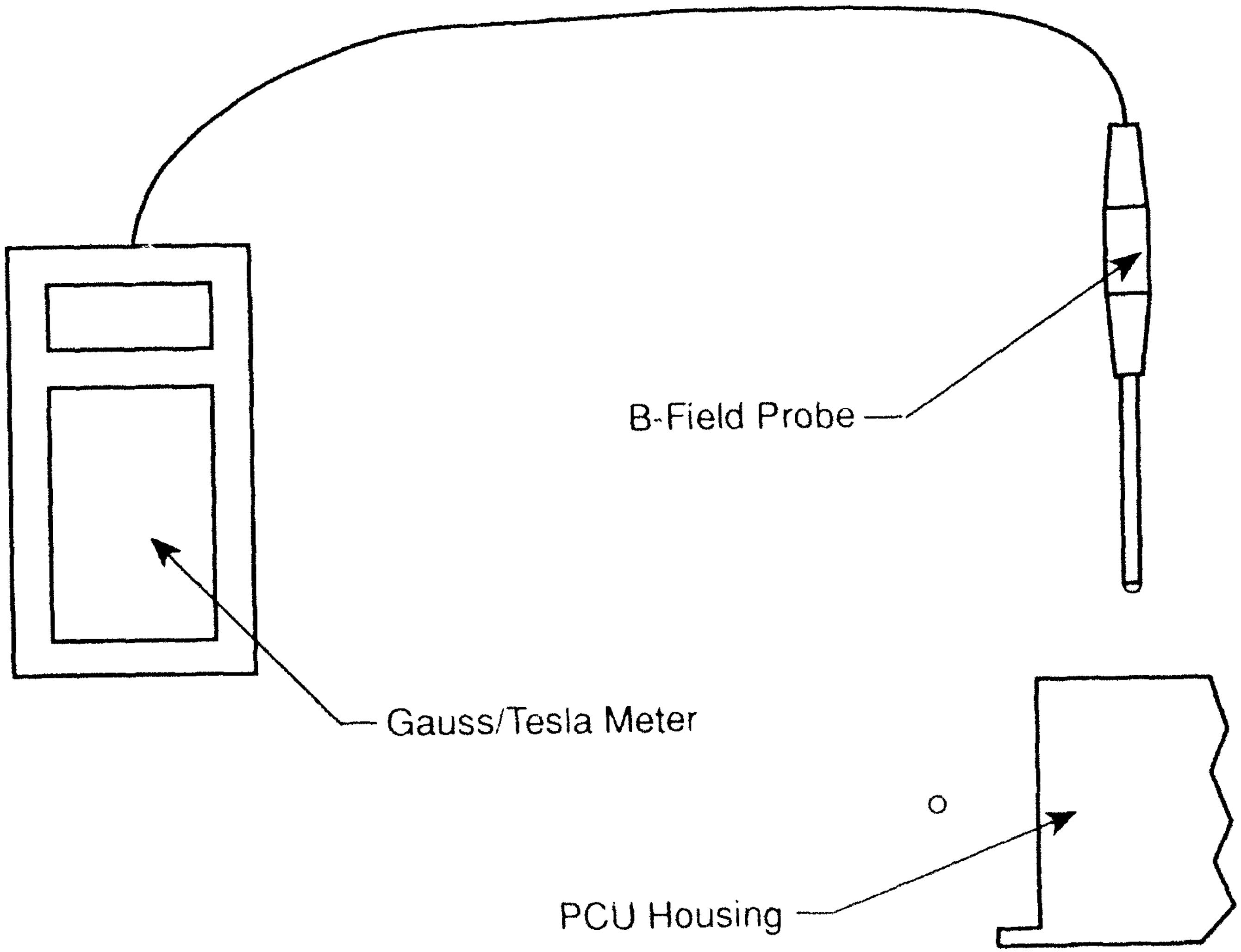

Figure 5
General Measurement Technique for B-Field Strength Above the PCU

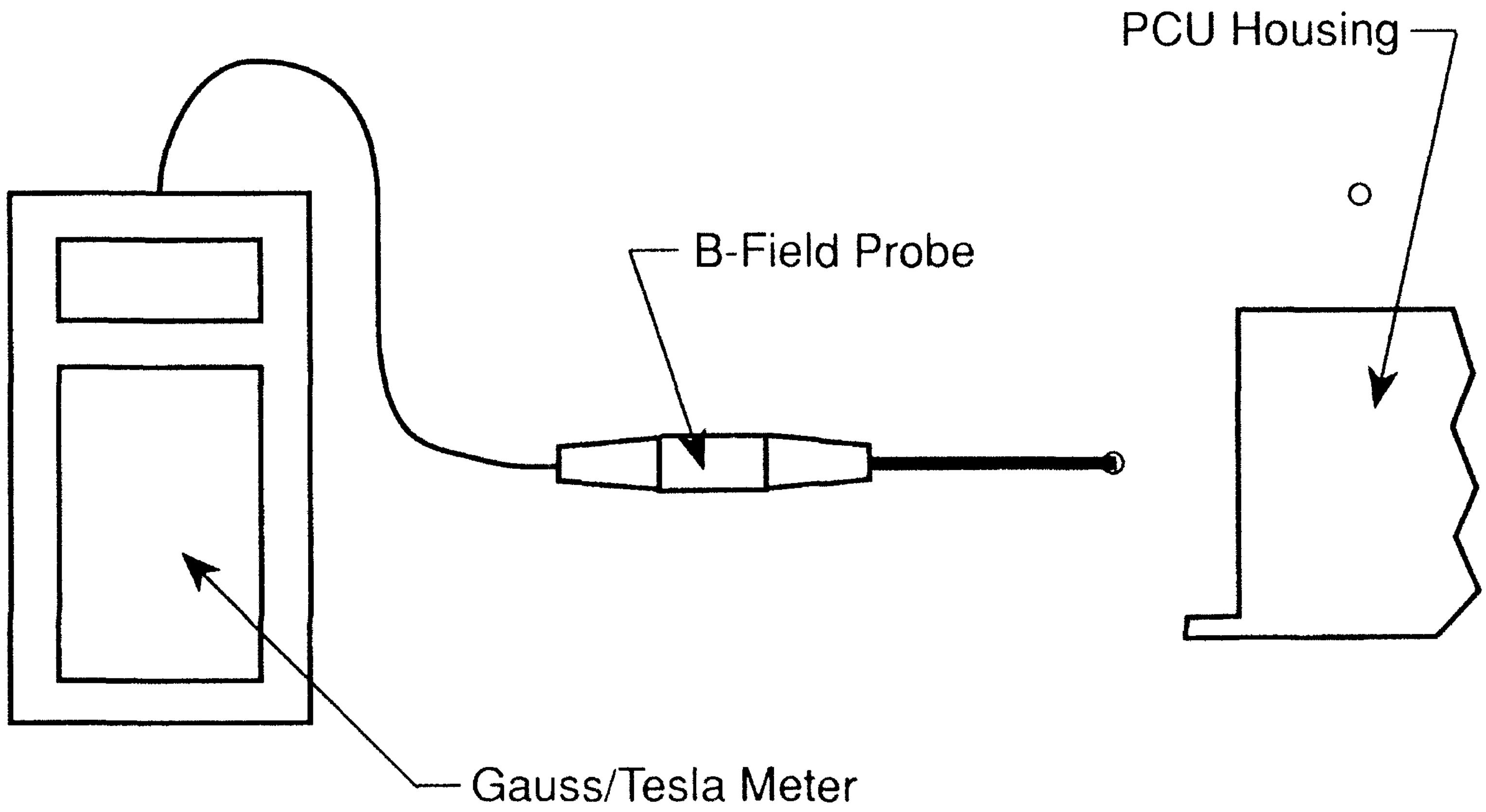

Figure 6
General Measurement Technique for B-Field Strength Around the PCU

DATA REDUCTION AND RESULTS

The B-field strength is summarized in Table 1. Negative signs occurred in the actual data values which are not shown in this table. This is caused by the meter and is indicative of the direction of the field produced - into the probe or away from the probe. The negative sign means the north magnetic field moves away from the axial probe tip, parallel to the probe axis. Figures 7 - 10 show B-field contour maps at the two extremes of testing, power off and at 26 kWe, illustrating the highest B-field strength versus the initial conditions.

Table 1. B-field Strength Under Various Operating Conditions

Position (See Figure 3)	B-Field Strength (Gauss)	
	0 kWe	26 kWe
I_{1-A}	0.2	1.0
I_{1-B}	0.2	4.2
I_{2-A}	0.2	1.9
I_{2-B}	0 2	1.8
I_{3-A}	0.2	0.6
I_{3-B}	0.9	1.4
P_{1-A}	0.1	0.9
P_{1-B}	0.2	1.0
P_{2-A}	0.2	0.7
P_{2-B}	0.1	0.6
P_{3-A}	0.2	0.8
P_{3-B}	0.2	0.8
F_A	0.1	0.6
O_{I-1-L}	0.5	1.7
O_{I-1-F}	0.4	1.6
O_{I-2-F}	0.2	33.3
O_{I-3-F}	0.2	27.4
O_{I-3-R}	0.1	0.6

Data Reduction

The contour maps shown in Figure 7 - 10 were constructed to graphically illustrate trends and B-field gradients. The procedure consisted of plotting the data points and then interpolating between them. The estimates of the iso-Gauss lines are liberally constructed, but seem to represent a viable map of the area. Caution was taken to avoid relying on any single data point, and the lines were constrained to remain continuous. The lines were also constructed to force higher field strength closer to the PCU, except in cases where strong local fields were expected to be present - as in the case of the inductors. Although all of the points are considered valid data, these maps should be used only for trends due to the inherent errors contained in this, and any, interpolation.

Results

All of the data in Table 1 follow trends expected at the outset of the experiment. The most obvious of these trends is increasing field strength for increasing power levels. O_{I-3-F} did have a higher field strength at startup than the points over the power electronics, but were comparable to the measurements in front of the other inductors.

Figure 7 shows the top view of the PCU prior to the start of the arcjet. As can be seen, most of the measurements are near ambient conditions as was expected. The exceptions to this are the high points located in the lower right corner of Figure 7 and the area around I_{3-B}, both of which are in close proximity to the unshielded inductors. Although there was no power applied to the PCU at the time, it is likely there was some residual current in the inductors, producing a small magnetic field. Again, this scenario is "worst - case" due to the lack of insulation on this PCU which will be present in the flight hardware. Figure 8 reiterates the conditions shown in the top view with the gradient from I_{3-B} to ambient conditions very evident on the right. The high point around the lower right corner in Figure 7 can also be seen as a high point on the left side of Figure 8, as well as its gradient to ambient conditions.

Figure 9 shows the top view of the PCU during operation of the arcjet at 26 kWe. The readings increased as expected, with an increase in power level, with the exception occurring in the immediate vicinity of the second and third inductors. A portion of these high readings can be attributed to the inductors which contribute approximately 8.5 Gauss each at 26 kWe (see Appendix B). The major portion of these high readings, however, can be attributed directly to the construction of the PCU. Both of these measurements were recorded in close proximity to the output power cables (Figure 1). The development unit

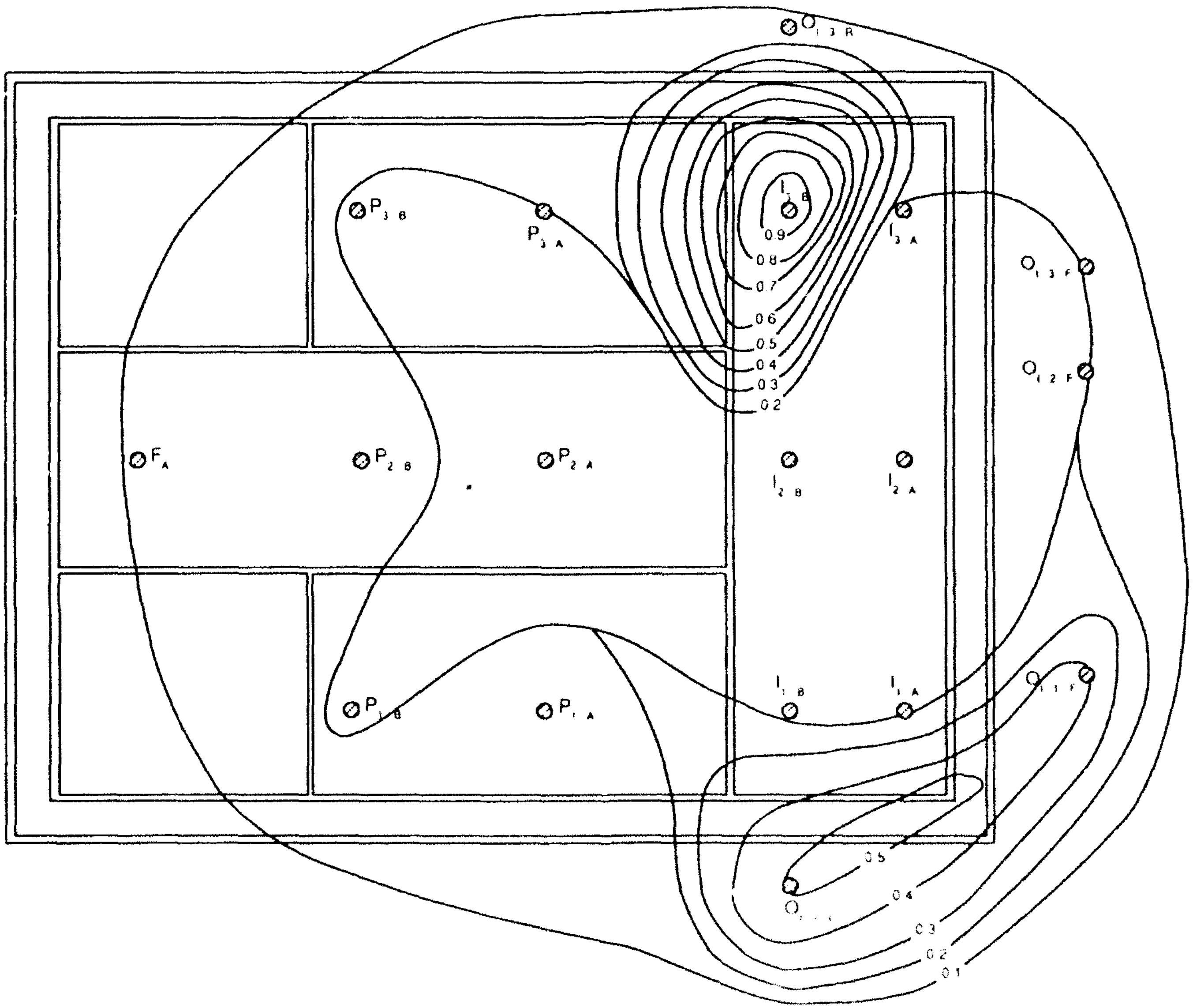

Figure 7
Top View of B-Field Measurements Prior to Arcjet Operation

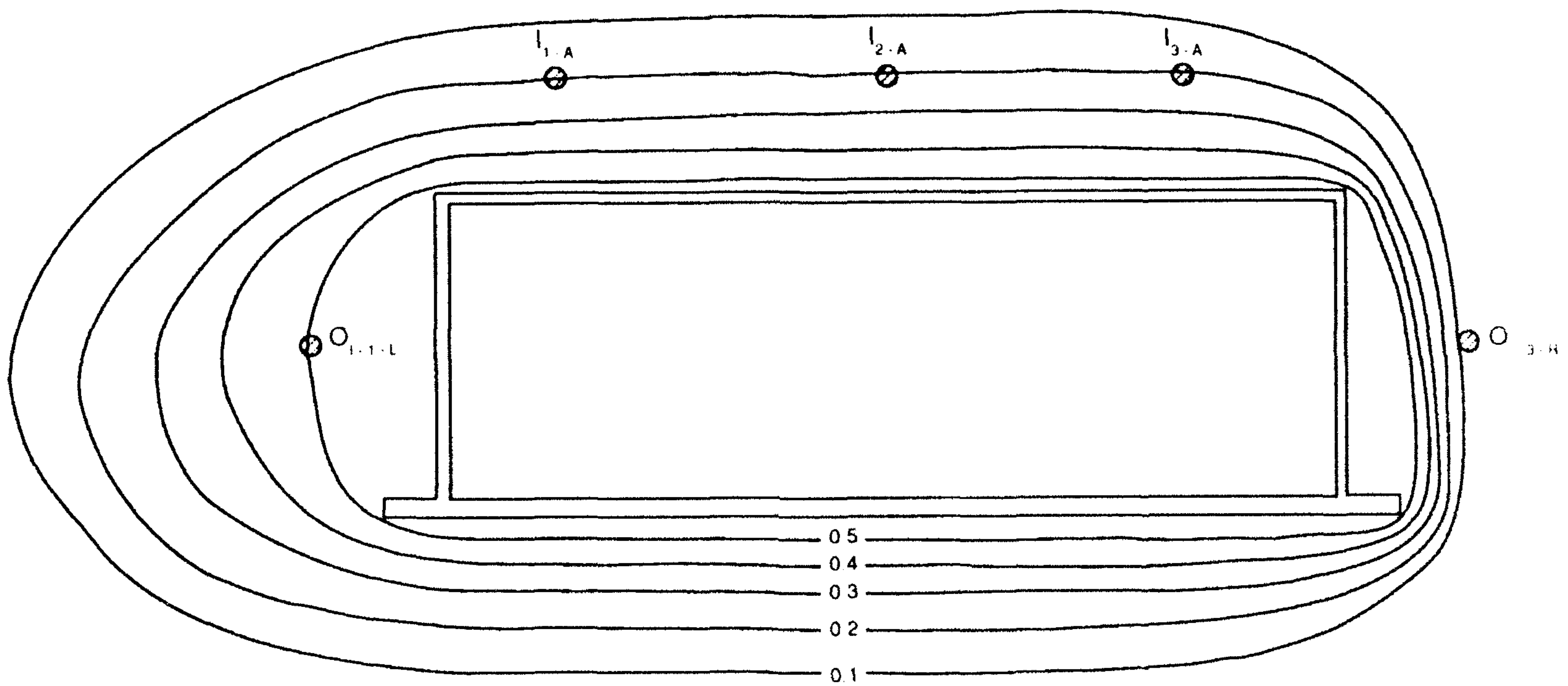

Figure 8
Front View of B-Field Measurements Prior to Arcjet Operation

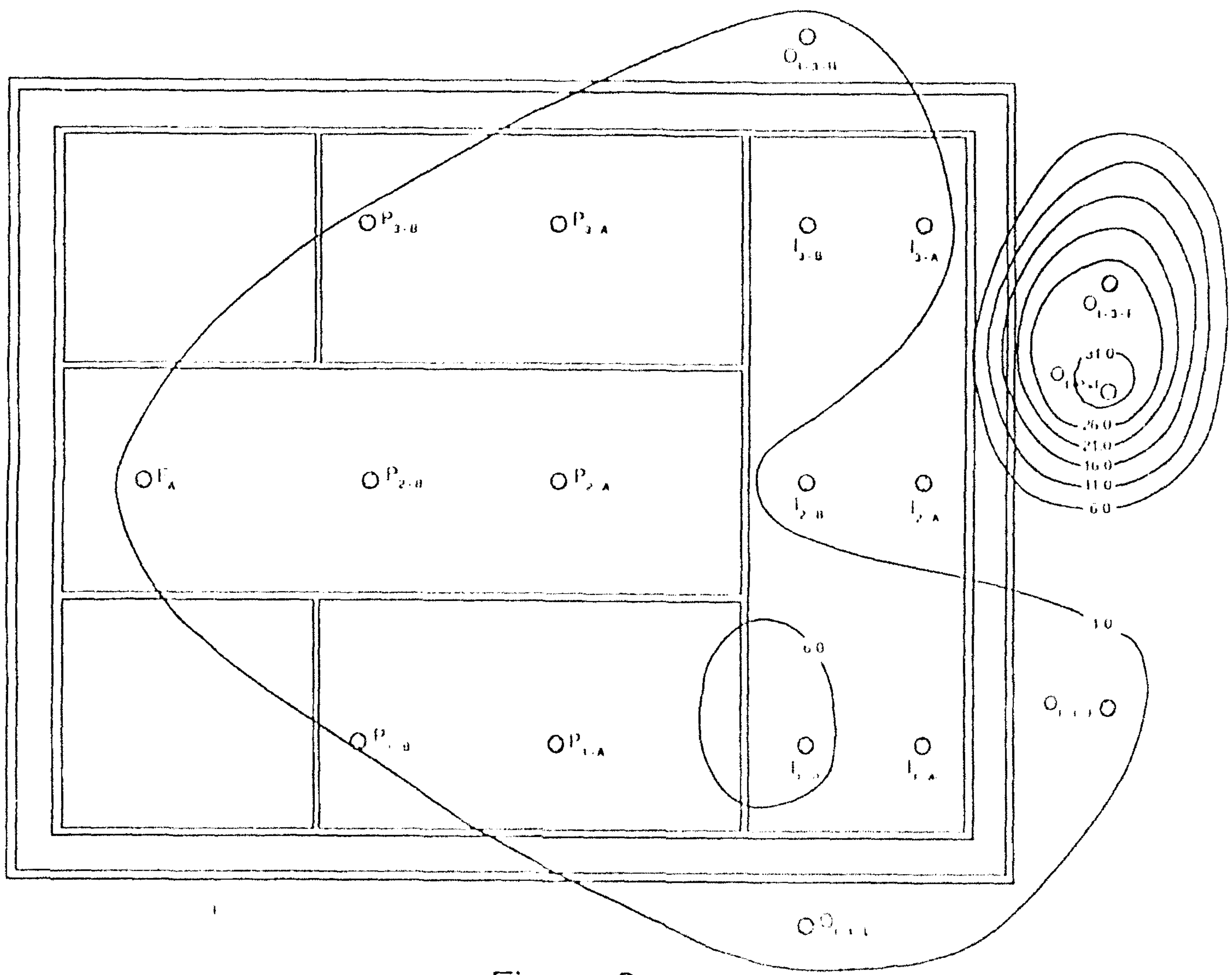

Figure 9
Top View of B-Field Measurements During Arcjet Operation

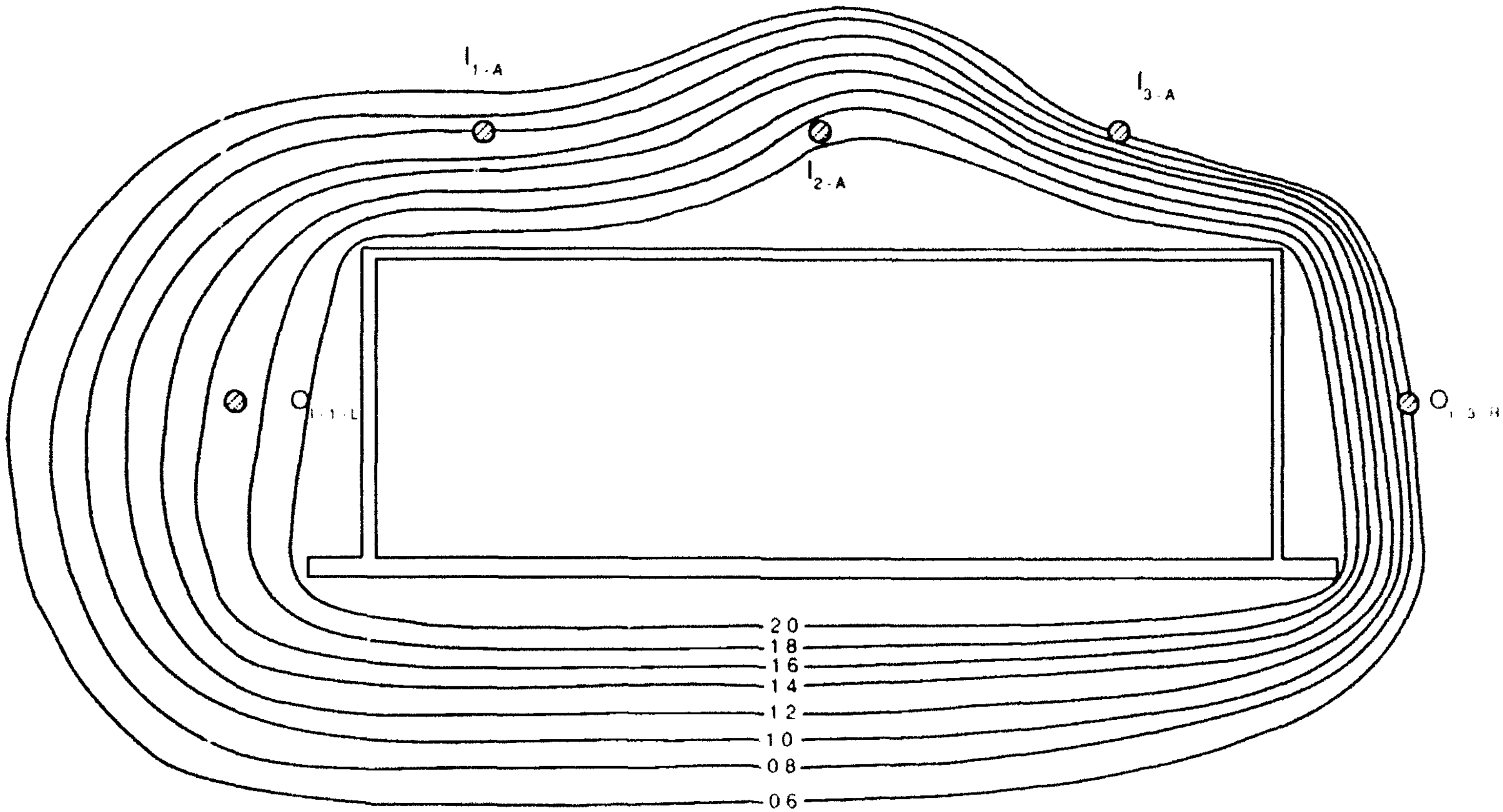

Figure 10
Front View of B-Field Measurements During Arcjet Operation

differs largely from the flight unit in this area, due to plans for heavy shielding of the PCU output to minimize interference from the large current levels. These large current levels produce the large B-fields measured in this experiment. By shielding the output cable, the high B-fields shown in Figure 9 will be eliminated. Figure 10 shows the front view of the PCU during operation and verifies the correspondence between power level and B-field strength seen above.

The presence of these large magnetic fields, although initially disconcerting, must be put into the perspective of the "worst - case" scenario of these tests. The three inductors are unshielded, uninsulated, and are not mounted in accordance with an effort to reduce disturbances. The power cables now serving as output from the development model PCU will be replaced by a heavily shielded cable, with the intent of minimizing electrical interference. In addition to the lack of interference protection, since the PCU is still in the design stages, the need for these inductors has not yet been determined. Regardless of the need for these inductors in the flight unit, there will be much done in order to minimize the disturbing effects of all the hardware in the PCU.

CONCLUSIONS

In general, the experiment verified the expectations of the experimenters regarding the strength of the B-fields around the PCU. The results from this experiment are "worst-case" values, and the flight unit emissions are expected to be much less. The presence of the three inductors in this design and the lack of adequate shielding around the output cable contribute significantly to the data collected. Regardless of the possible addition of the inductors, the B-fields produced by the flight unit will be significantly less due to additional shielding and insulation. This additional shielding includes internal and external insulation, as well as the existence of considerable ESEX hardware between the PCU and the remainder of the ARGOS flight vehicle. The experimenters feel confident the magnetic fields produced by the PCU will not affect the performance of any experiment, or on the overall mission of ARGOS itself.

REFERENCES

1. Andrews, J. C., Telephone Interview, 5 AUG 92.

2. Bowman, E. C., Personal Interview, 3 AUG 92.

3. Cassady, R. J., P. G. Lichon, and D. Q. King, "Arcjet Endurance Test Program," Final Report for Air Force Phillips Laboratory, AL-TR-90-069.

4. Cassady, R. J., Telephone Interview, 5 - 19 AUG 92.

5. Sanks, T. M., "Measuring Radiated Electromagnetic Emissions From a High Power Arcjet Thruster," Revision: Draft, 30 APR 92.

6. Rocket Research Company, TRW, DSI, ETS, Inc. "Arcjet ATTD Quarterly Status Review," Review Handout, 31 MAR 92.

7. Wong, S-P, E. J. Britt, K. McCracken, "30 kWe Class High Efficiency Arcjet Power Conditioner - Volume I," Final Report for Air Force Phillips Laboratory, AFAL-TR-88-049.

8. Kay, B., Telephone Interview, 12 AUG 92.

9. Buchsbaum, W. H., "Buchsbaum's Complete Handbook of Practical Electronic Reference Data," Second Edition, Prentice - Hall, 1978.

APPENDIX A

The following is a list of equipment used to acquire the strength of magnetic fields in the vicinity of the 30 kWe call arcjet PCU.

Table A.1 - Gauss Meter and Supporting Equipment List

Manufacturer	Item Name	Model Number	Serial Number	Other
F.W. Bell	Gauss/Tesla Meter	4048	N/A	N/A
F.W. Bell	Probe Extension Cable	X-4048-003	N/A	N/A
F.W. Bell	Axial B-field Probe	A-4048-002	0070241	Calibration # 1536
F.W. Bell	Zero Gauss Chamber	YA-111	N/A	N/A

APPENDIX B

This appendix contains additional data on the inductors added to this development unit PCU and the magnetic fields they produce.

Inductor (mH)	Current (Amps)	Inner Diam. (inches)	Outer Diam. (inches)	Mean Radius (inches)	No. of Turns	Permeability (Tesla m/A)	B-Field (Tesla)	B-Field (Gauss)
7.3	65	2	3	1.25	20	1.2566E-06	0.000208	2.08
	100	2	3	1.25	20	1.2566E-06	0.00032	3.2
	102	2	3	1.25	20	1.2566E-06	0.000326	3.264
	265	2	3	1.25	20	1.2566E-06	0.000848	8.48
9	65	2	3	1.25	20	1.2566E-06	0.000208	2.08
	100	2	3	1.25	20	1.2566E-06	0.00032	3.2
	102	2	3	1.25	20	1.2566E-06	0.000326	3.264
	265	2	3	1.25	20	1.2566E-06	0.000848	8.48
9.1	65	2	3	1.25	20	1.2566E-06	0.000208	2.08
	100	2	3	1.25	20	1.2566E-06	0.00032	3.2
	102	2	3	1.25	20	1.2566E-06	0.000326	3.264
	265	2	3	1.25	20	1.2566E-06	0.000848	8.48

**** B-fields are the same for each inductor.
Since the inductor is saturated, the permeability of the core is irrelevant and the inductor becomes a free space inductor. Since the no. of turns are all equal, the B-fields are equal.