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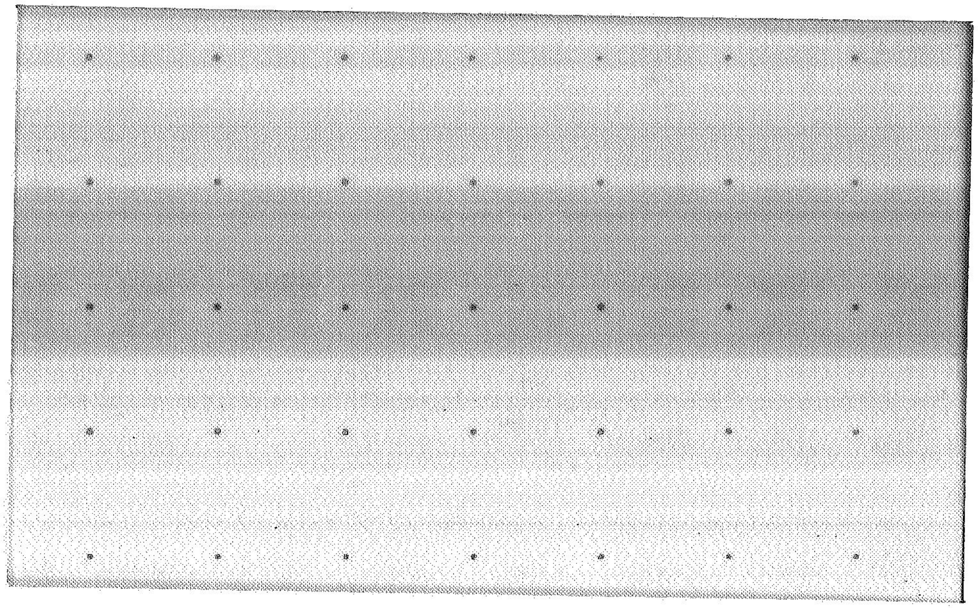


EOS

Final Report

PRESSURE SWITCH FOR DETECTION OF THRUSTER OPERATION OF LUNAR EXCURSION MODULE REACTION CONTROL SYSTEM

Prepared for
National Aeronautics and Space Administration
Manned Space Flight Center
Houston, Texas
Attention: Mr. R. R. Richard

Contract NAS9-6409

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ELECTRO-OPTICAL SYSTEMS, INC. - PASADENA, CALIFORNIA
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PRESSURE SWITCH FOR DETECTION OF THRUSTER OPERATION OF LUNAR EXCURSION MODULE REACTION CONTROL SYSTEM

by

J. Delmonte

ABSTRACT

Information is presented on the construction of rugged, low pressure threshold, miniature electronic pressure switches designed to withstand RCS combustion pressures and associated severe environmental conditions.

Test data are presented to verify high speed of response, high overload protection, and stability during vibratory accelerations. Minor design improvements are proposed.

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CONTENTS

ILLUSTRATIONS

SUMMARY

Model 101038-0003 pressure switch transducer is described as a device which produces a switching output as the pressure increases above the design threshold.

The basic pressure sensor structure is that of an absolute analog transducer. The sensor consists of a gaged cantilever beam that is deflected by a diaphragm-force rod system when the latter senses a pressure from the RCS combustion chamber.

In order to provide the extremely high overpressure protection required by the LEM RCS application, the outer diaphragm is supported by a rugged mechanical stop. In operation the diaphragm is displaced so that it hits the stop at 1.5 times the threshold pressure of the switch. Ability to withstand high shock loads as well as very large static overpressures without shift in the threshold has been emphasized by optimizing the stability of the threshold point. Nonlinearity of the transducer and sensitivity changes with temperature variations can be accommodated since only one point in the pressure sensing spectrum must remain stable within practical tolerances. The requirements of this program were to provide a threshold switch signal at 23 psia ±3 psi such that:

		Output (volts)
Pressure < threshold	=	$14 < E_o < 28$
Pressure > threshold	=	$+0.5 < E_o < +2.5$

Results of the verification and acceptance tests indicate that the basic design goals have been met.

SECTION 1

INTRODUCTION

1.1 PROJECT IDENTIFICATION

The NASA Manned Spacecraft Center, Houston, Texas, requires a rugged, reliable, miniature, lightweight pressure switch transducer capable of switching on and off at a precise pressure under extremely severe environmental conditions. This transducer would detect the operation of reaction control system thruster engines on the Lunar Excursion Module (LEM).

On contract NAS9-6409, Electro Optical Systems, Inc., has developed such a transducer, Model 101038-0003, and has shipped four 23 psia pressure switches that meet the design goal specifications with certain specific (but normally controllable) exceptions.

1.2 DETAILED DESCRIPTION OF THE RCS PRESSURE SWITCH INSTRUMENTATION

Figures 1 and 2 illustrate the RCS pressure switch, Model 101038-0003. Figure 3, representing drawing 101038-0003, Revision C, gives the overall size and mounting dimensions plus pertinent electrical interface information. The top assembly drawing is shown in Fig. 4. Details of the pressure sensor mounting thread and the pressure seal O-ring groove are shown in Fig. 5, print number 204146-0001. The Teflon O-ring itself is described in Fig. 6. The RCS engine chamber port and the first proposed pressure sensor installation sketch are to be seen in Figs. 7 and 8. The latter concept remained firm except for the substitution of 9/16" wrench flats for torquing the pressure sensor into the AN port, in place of spanner wrench holes.

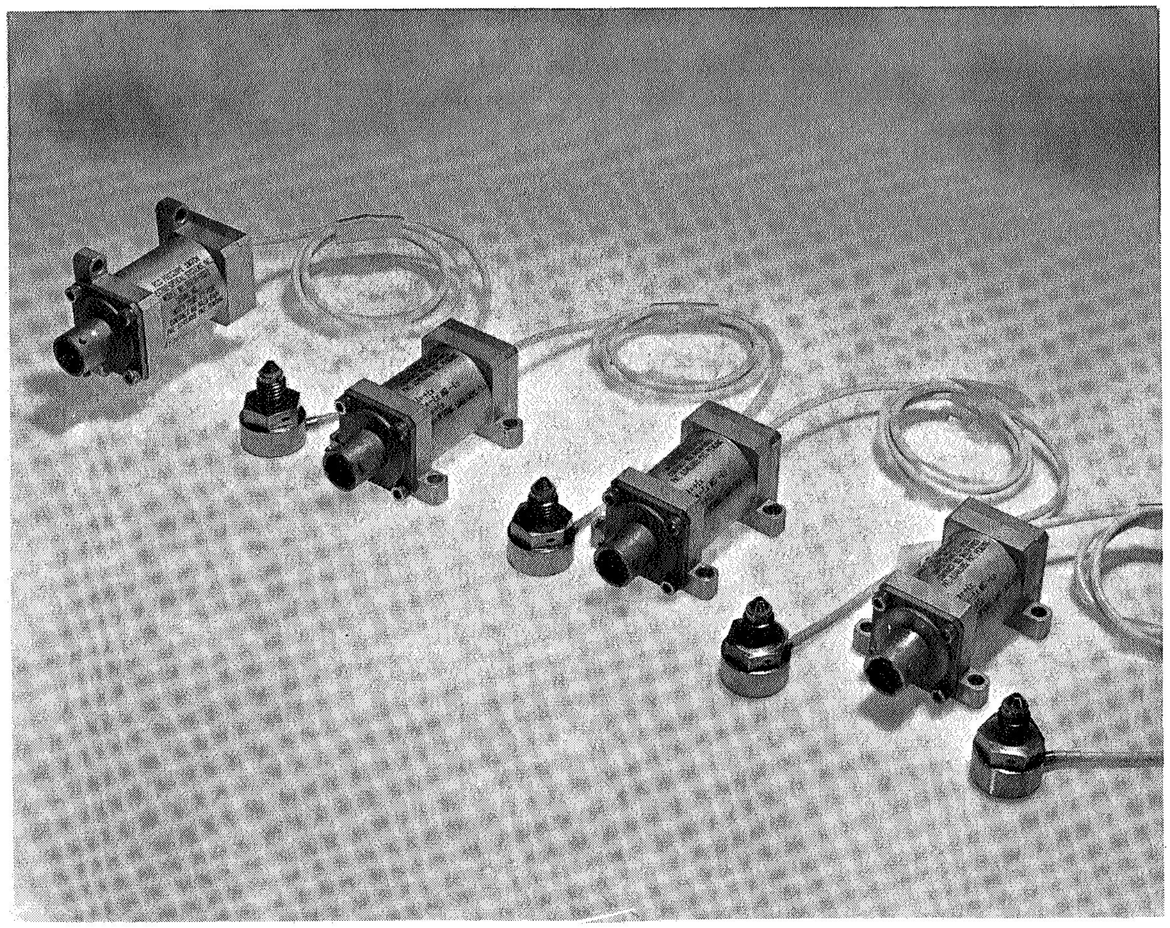

Figure 1. Photograph of Four RCS Pressure Switches

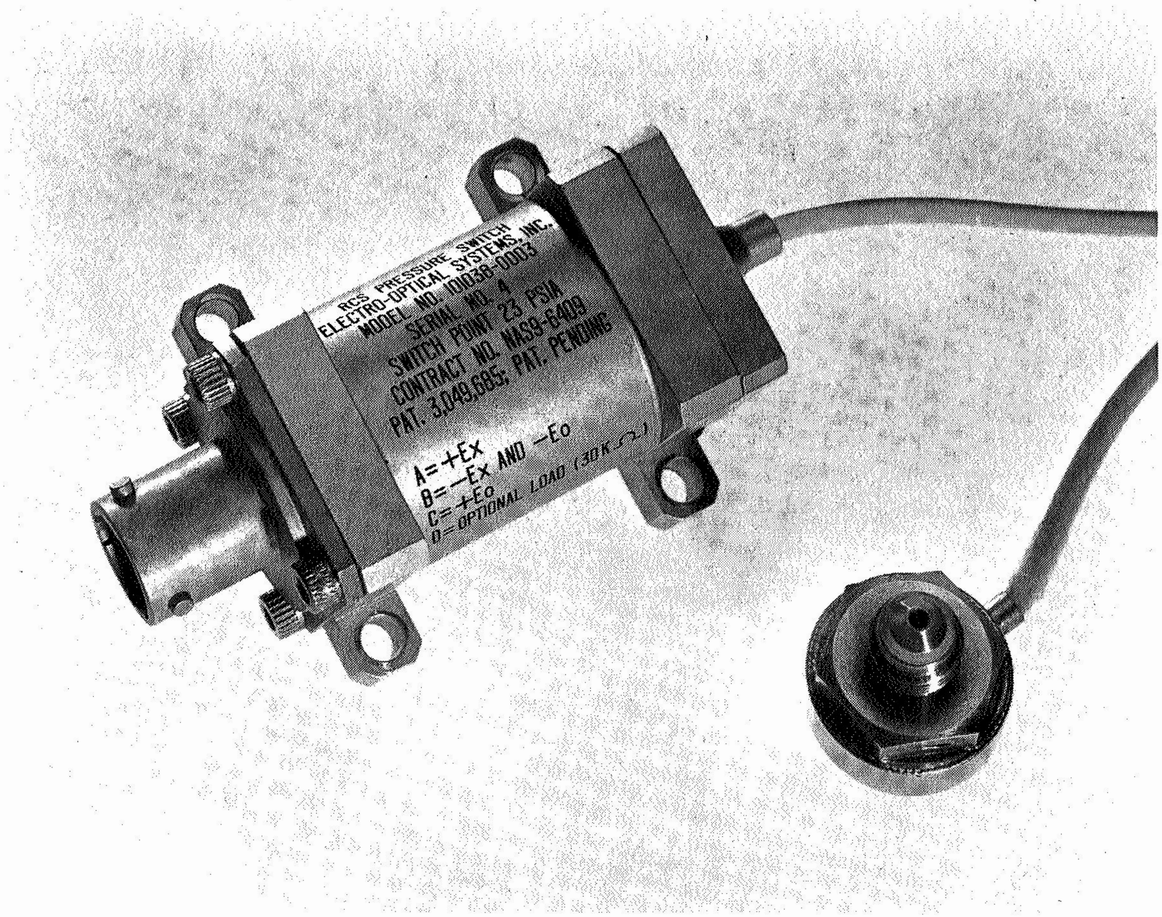

Figure 2. Photograph of RCS Pressure Switch S/N4, Model 101038-0003

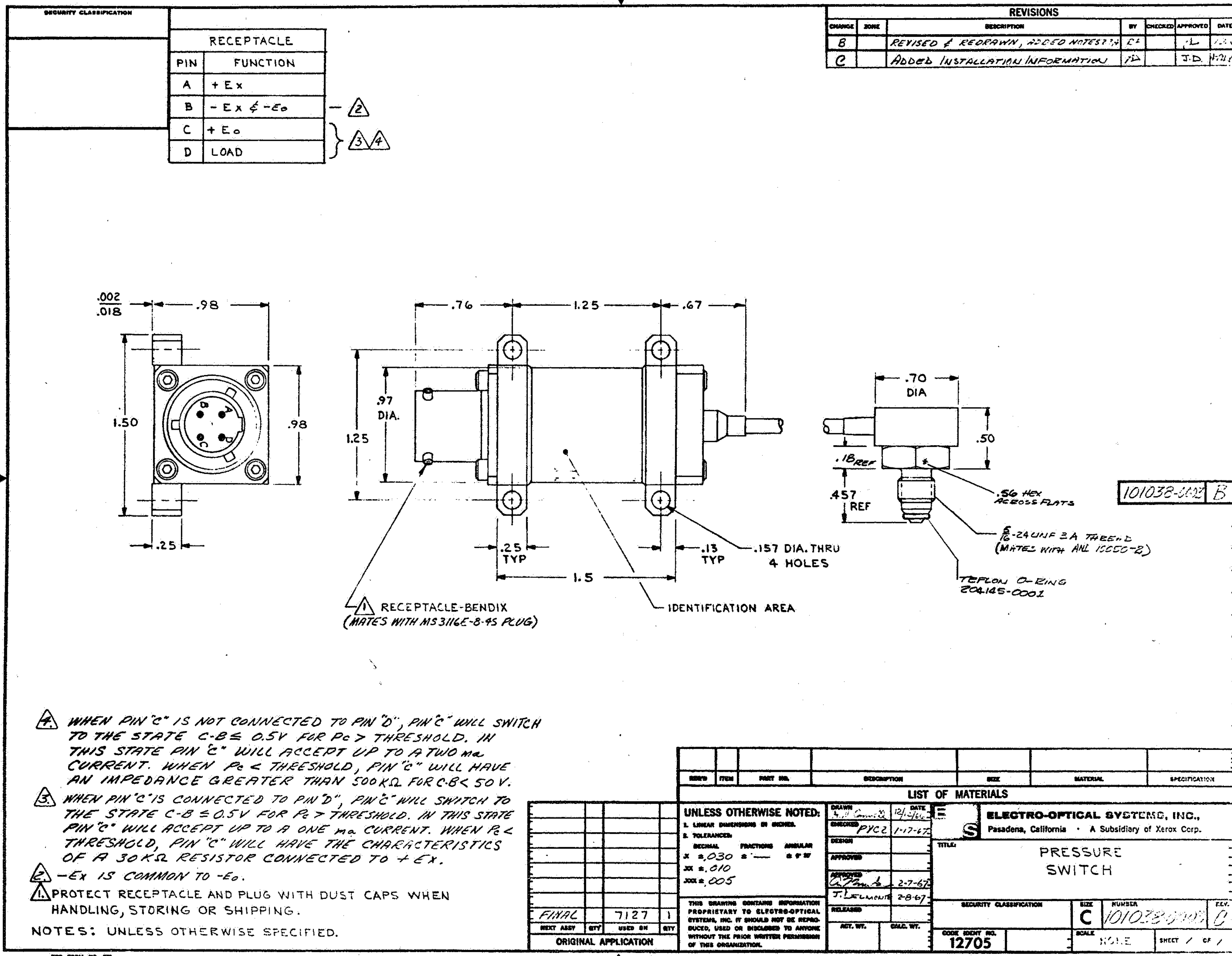

Figure 3. Overall Size, Mounting Dimensions, and Pertinent Electrical Interface Information for the RCS Pressure Switch

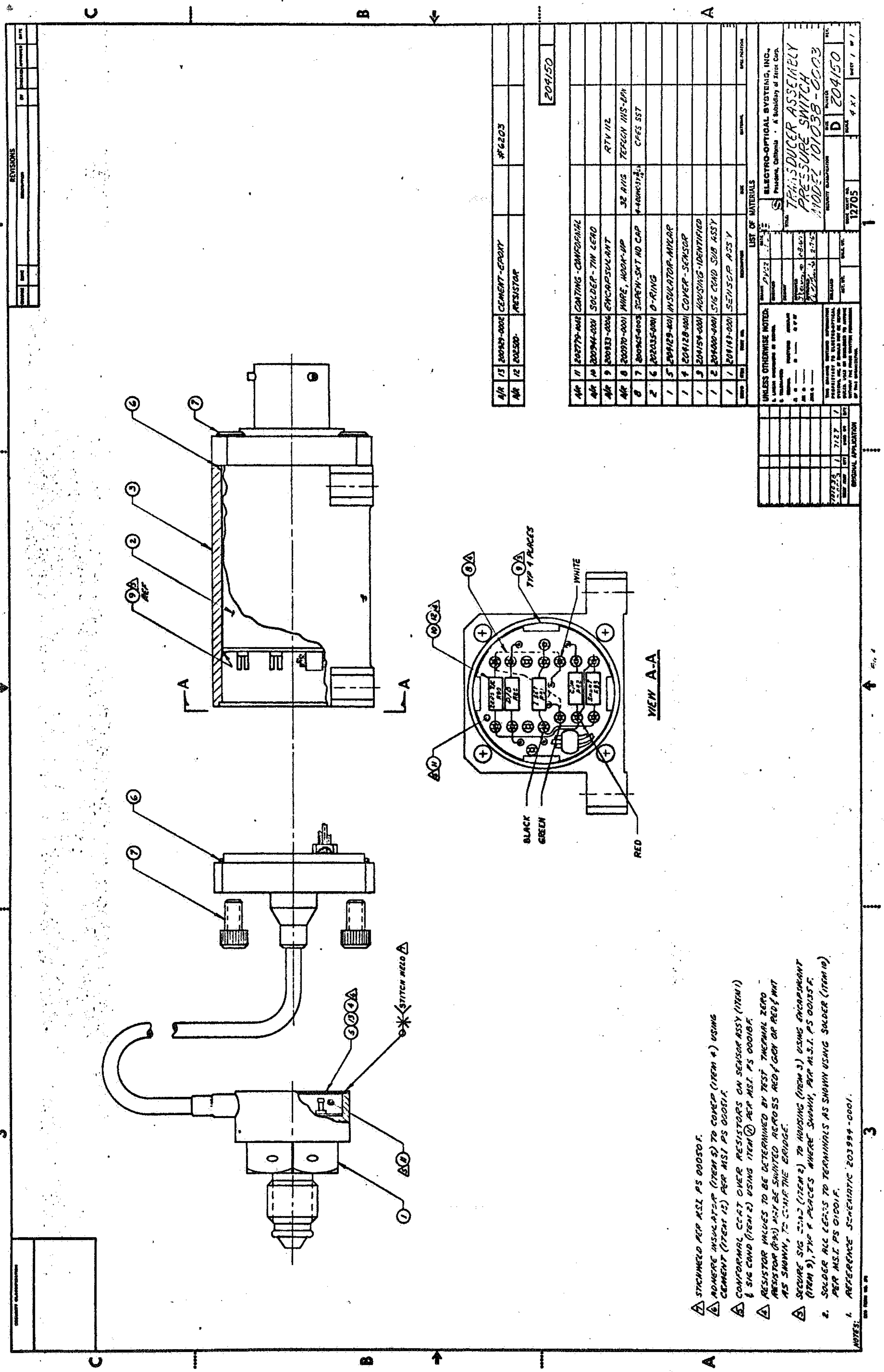

Figure 4. Top Assembly Drawing

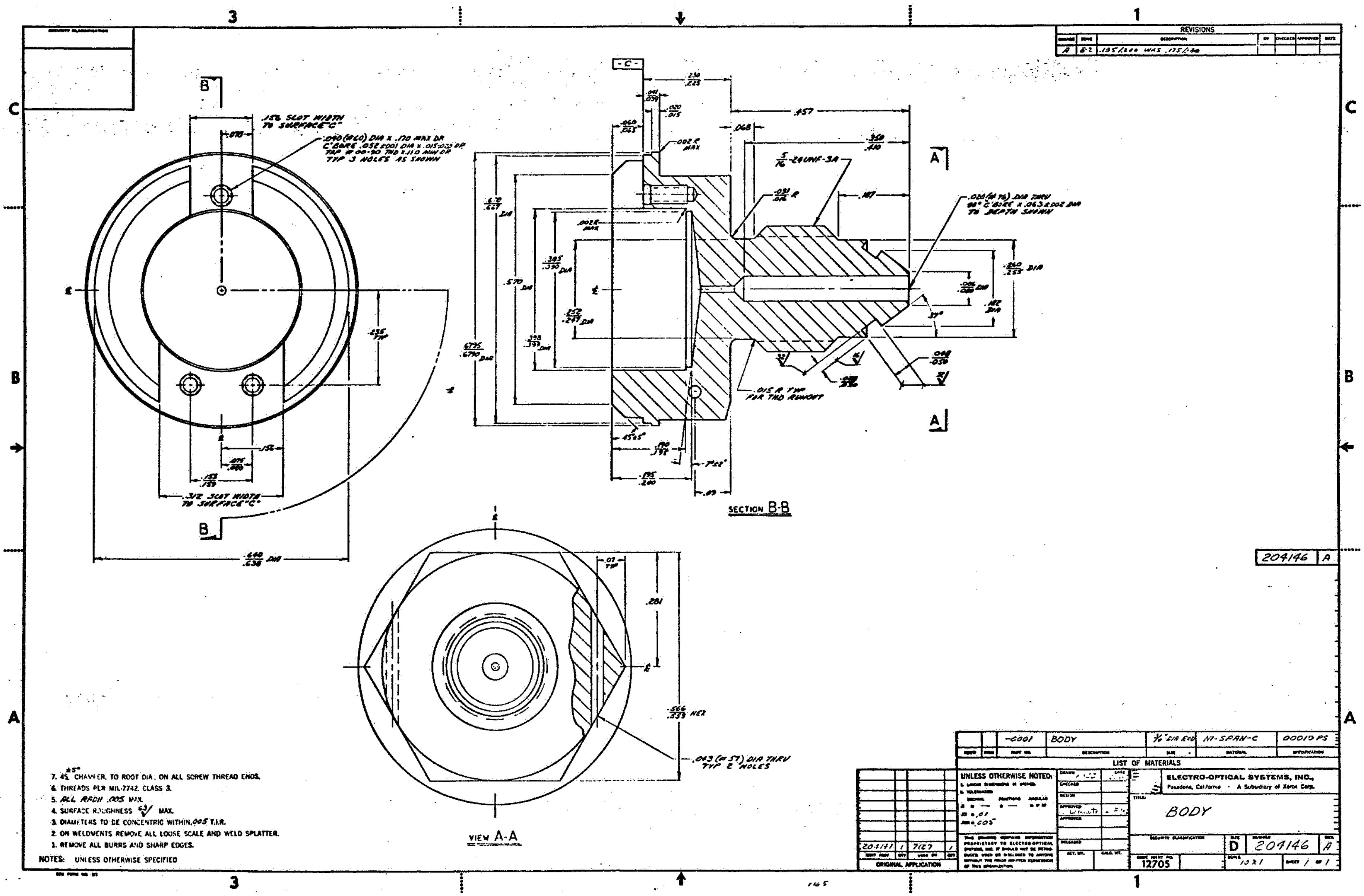

Figure 5. Details of the Pressure Sensor Mounting Thread and the Pressure Seal O-Ring Groove for the RCS Pressure Switch

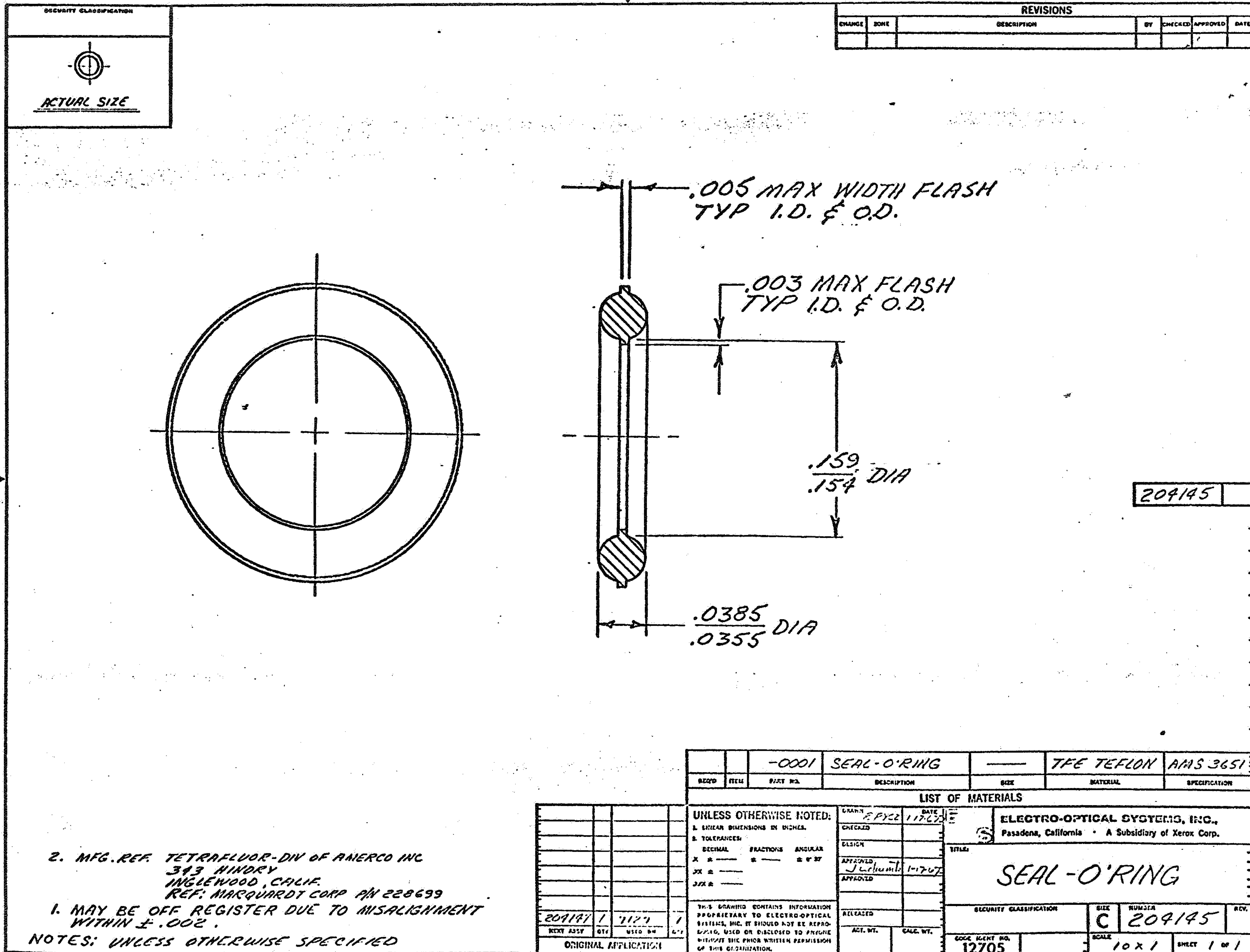

Figure 6. Teflon O-Ring Seal for the RCS Pressure Switch

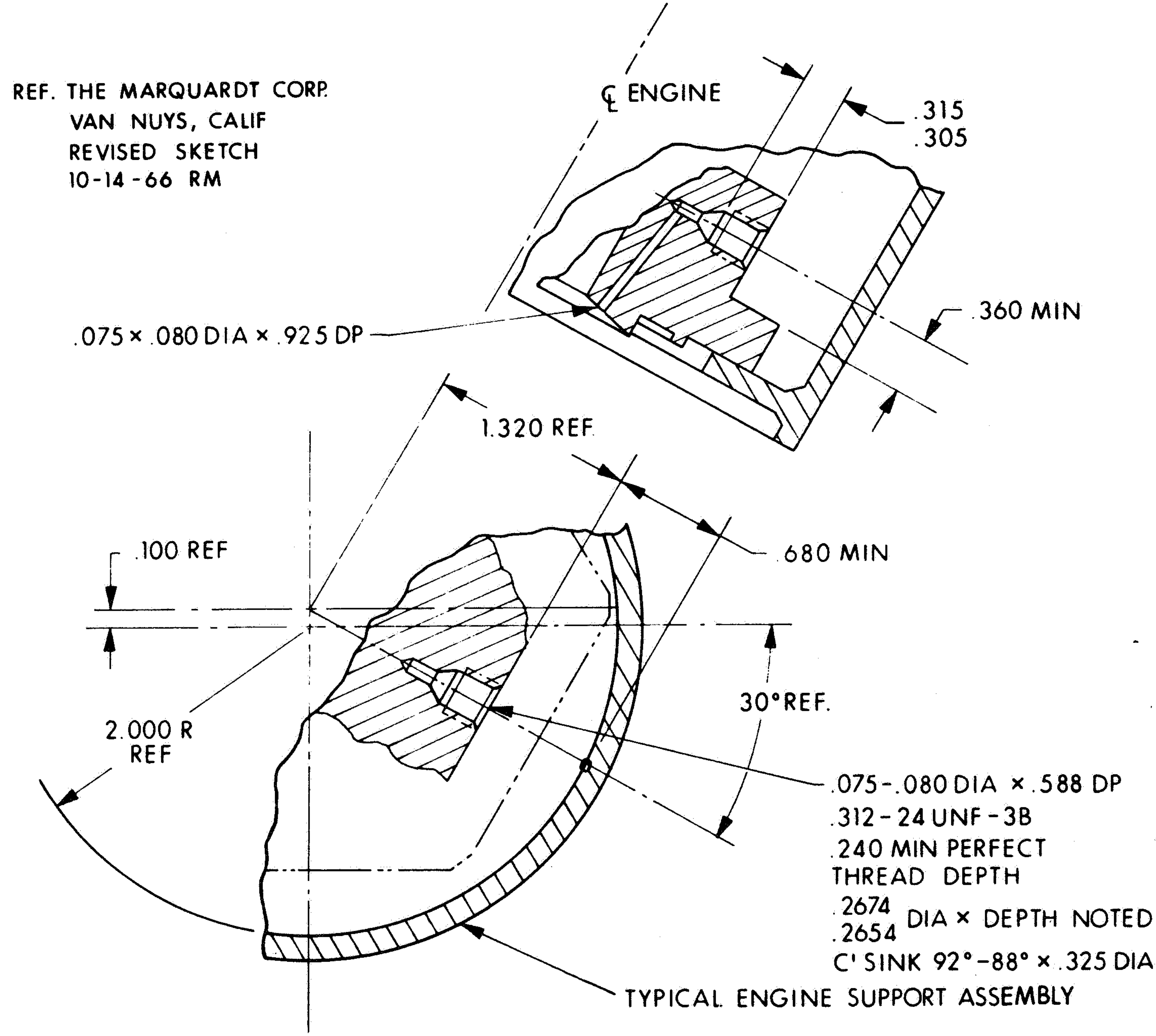

Figure 7. LEM Instrumentation Envelope 228687 Engine Chamber Pressure Port

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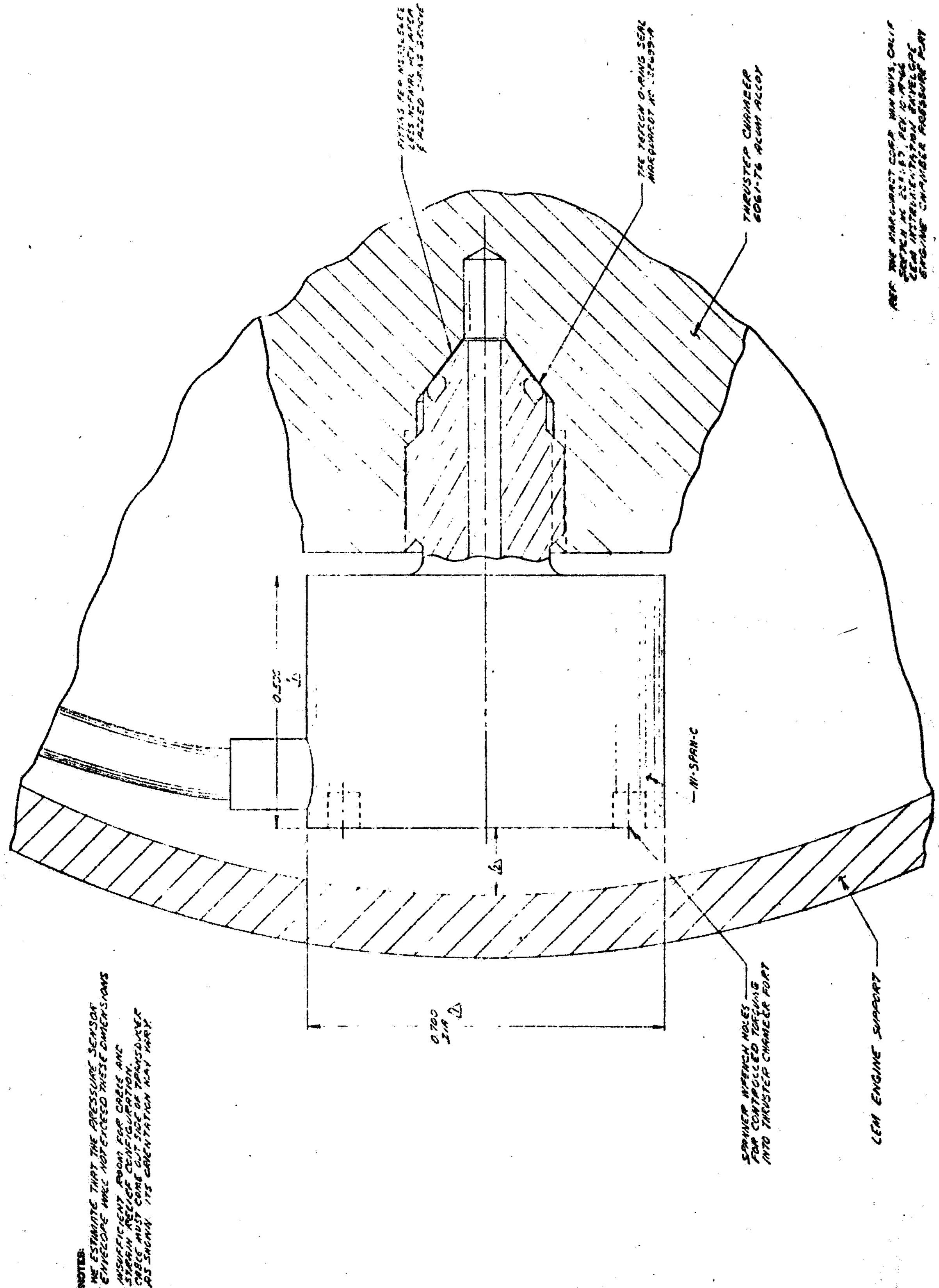

Figure 8. Proposed Pressure Sensor Installation Details

SECTION 2

TECHNICAL REVIEW OF PROJECT BY PHASES

2.1 PHASE I, FEASIBILITY PHASE

The first phase of this 23 psia pressure switch project started in August, 1966, and was completed shortly after the design review conducted at EOS on December 5 and 6.

The primary "sensor" which converts pressure into an electrical signal consists of four silicon strain gages bonded to a cantilever beam. Pressure summing is accomplished by a low spring rate, convoluted diaphragm made from Ni-Span C stripstock. The diaphragm, in turn, is stitch-welded to a massive mechanical stop capable of resisting the maximum applied pressure (25,000 psi). Displacement of the outer diaphragm from its "stop" is done through a force-rod and helper-spring mechanism: see Fig. 9 (204147). Once the proper position has been determined, with due consideration to the effects of the trapped reference pressure and the desired "stop" pressure, the primary sensor is attached by brazing its pivot tube to a force rod which is directly linked to the outer diaphragm.

Both flat and convoluted diaphragms were investigated during Phase I. The performance of the convoluted diaphragm was superior in terms of less hysteresis and better repeatability. High temperature cement systems and several strain gage designs were reviewed during the first phase effort.

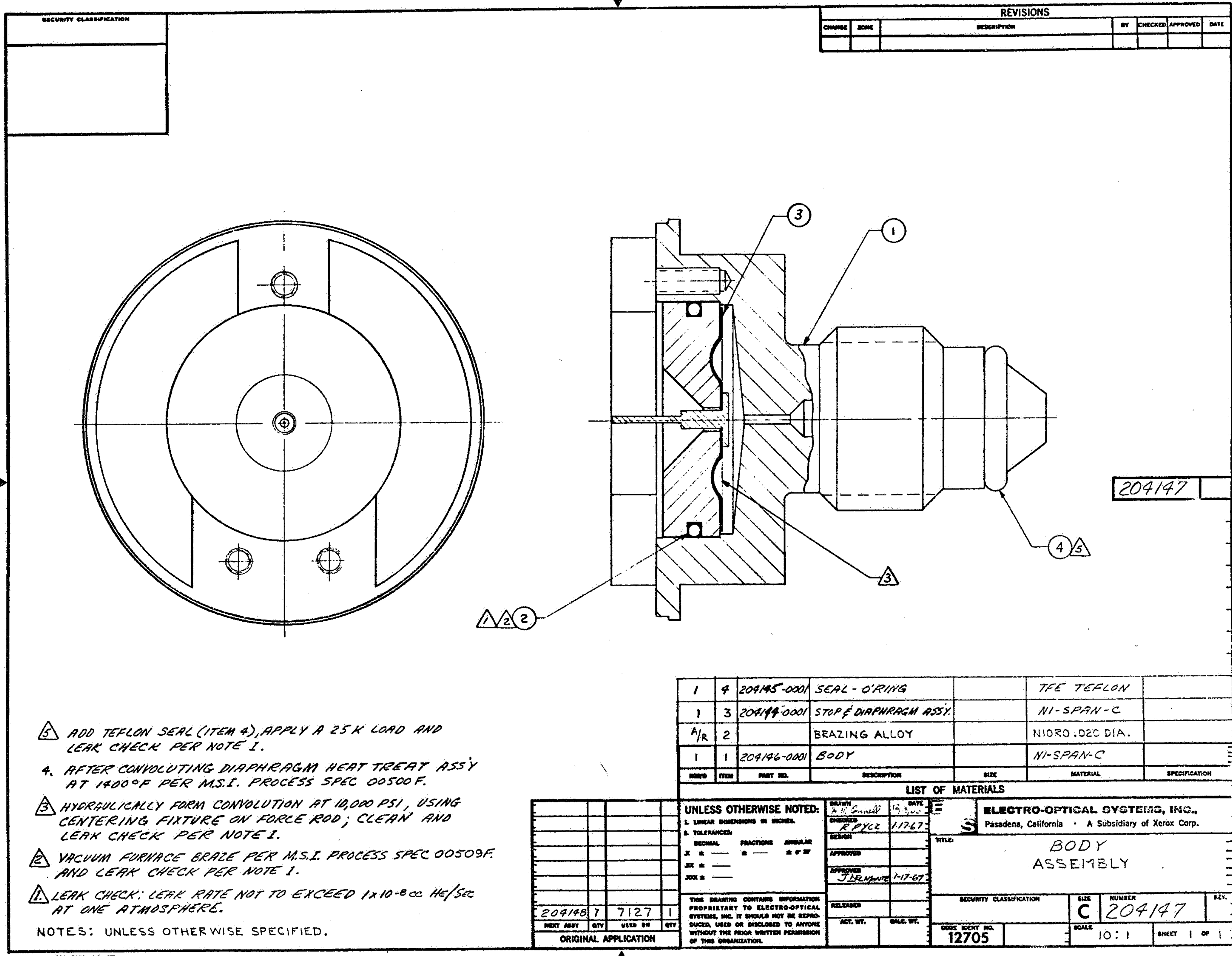

Figure 9. Body Assembly, RCS Pressure Switch

Concurrently, the electronic switch effort centered about the proven MSI "RC07" signal conditioner design. Preliminary external modifications worked well, and as a result, internal modifications were designed, breadboarded, tested, and evaluated. The signal conditioner of the RCS pressure switch converts the output of the strain gage bridge to an output voltage which switches sharply when the pressure rises above a predetermined threshold.

The block diagram of Fig. 10 shows the basic circuit structure of the modified "RC07" signal conditioner. The key elements of this unit and their functions are as follows:

a. Regulator

A preregulator is used to eliminate most effects of change in excitation potential on the converter output voltage. The isolated circuits are inherently immune to supply changes, and the overall performance of the instrument is outstanding in this regard. The regulator draws approximately 5 mA constant current from the excitation source and is operable with excitation voltages ranging from 20V to 70V.

b. Amplifier

A differential amplifier is used for conditioning the signal from the transducer bridge. This amplifier has three direct coupled stages with an open-loop gain of greater than 10,000. In the analog transducer, negative feedback is used to reduce the gain of the amplifier to approximately 20, giving the circuit great inherent stability.

c. Output Switch

Dual transistor output stage to isolate the differential amplifier from output loading and to provide the required output characteristics.

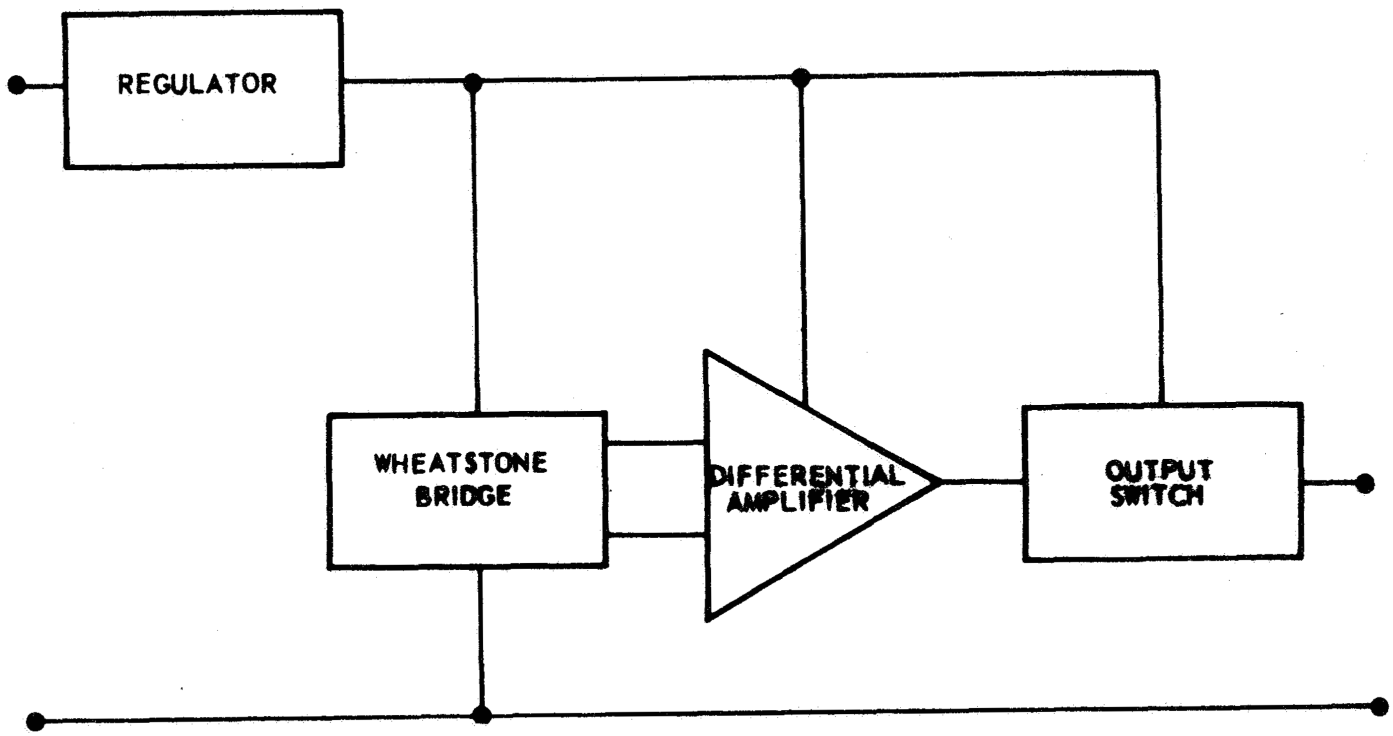

Figure 10. Block Diagram of RC07 Signal Conditioners

In order to obtain a switching output signal rather than an analog voltage from the standard RC07 signal conditioner, the output of the amplifier is connected to the input through a resistor network. This provides controlled positive feedback in the amplifier circuit, producing the required switching action. The positive feedback tends to drive the amplifier output to the low level clamp (-0.6V) when the amplifier input is negative, and into the high level clamp (+6V) when the input is positive. The principal advantages of this approach are the following:

a. Only minor modifications to the basic RC07 signal conditioner are required; the resistors can be added externally.

b. The switching is abrupt and positive. The hysteresis (dead band) can be set as required by the resistor network.

c. Fast switching (<1 msec) is possible if an output capacitor in the standard signal conditioner is eliminated or reduced in value.

d. The switch point is at zero input voltage. This minimizes effects of temperature and line changes on sensitivity. Only the zero stability of the sensor is important. The sensor zero is set at the desired threshold.

For the Model 101038-0003 RCS pressure switch, Fig. 11, drawing 880720, represents the interfaces of the developed signal conditioner. It is to be noted that all of the switching electronics worked entirely without fault throughout all of the verification and acceptance tests.

2.2 PHASE II, VERIFICATION PHASE

The second phase was entered into shortly after Mr. George Zivley's visit to EOS in early December during which time the preliminary pressure switches were demonstrated on both the oscilloscope and Moseley X-Y plotter. Verification and final acceptance test plans were also discussed and tentatively approved by Mr. Zivley. A request to deliver one complete mockup and working pressure switch to prototype dimensions

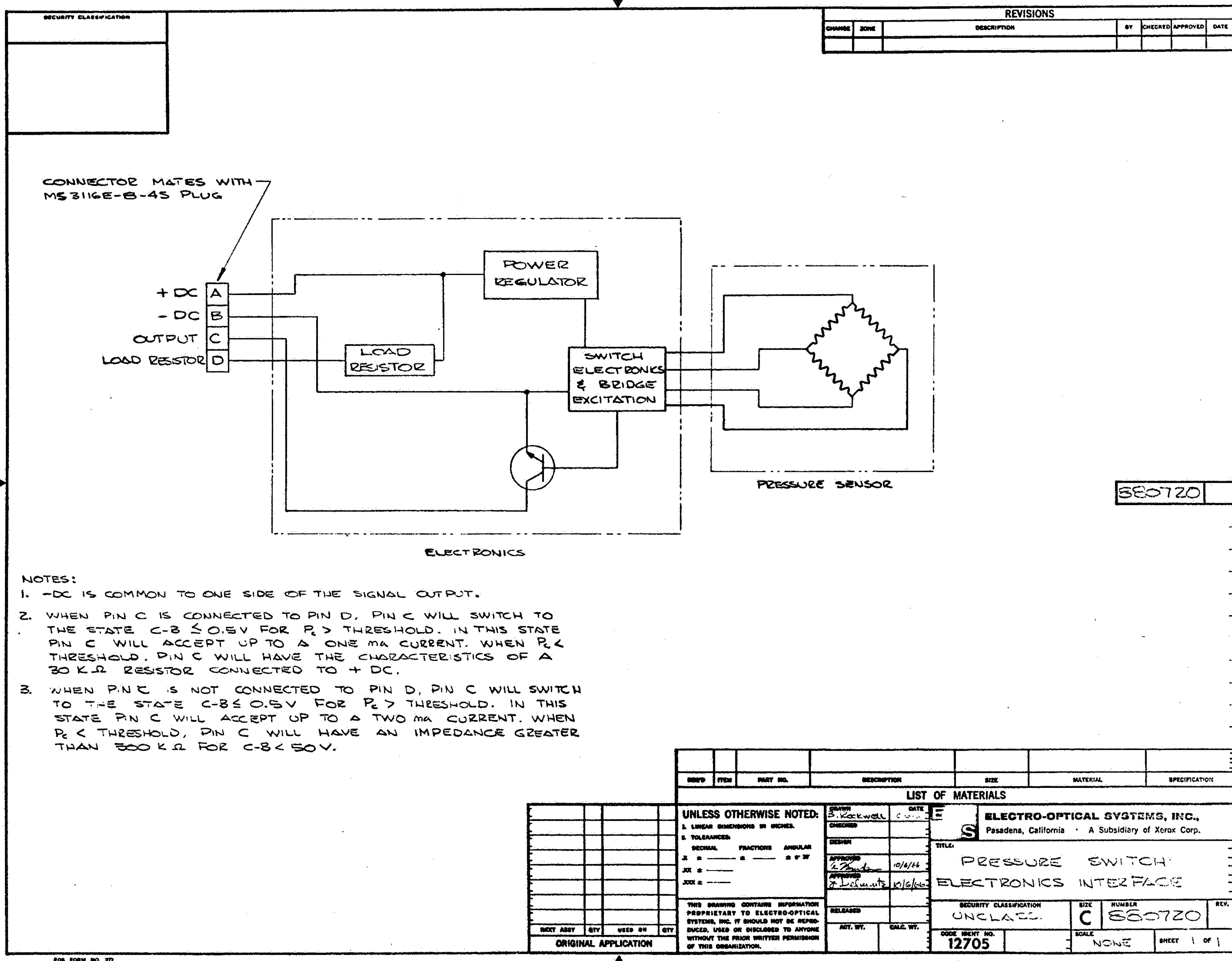

Figure 11. Electronics Interface, RCS Pressure Switch

in mid-February 1967 was acknowledged and acted upon. This unit (pre-prototype S/N 5) had been subjected to 25,000 psi with its gaged beam in final position and had survived this stringent test very well.

Verification and acceptance testing of four prototype pressure switch transducers was begun by the end of March and tests were completed early in April.

The basic pressure switch test apparatus used for verification and acceptance tests is diagrammed in Fig. 12. A Moseley X-Y plotter, with dual fixed and unchanged gain adjusts for all the tests and for all the pressure switches, was used to record switching behavior.

Since all four switches were made to identical manufacturing specifications, it was relatively easy to initially balance their respective bridge outputs to zero at 23 psia. Y axis motion on the Mosely was controlled by inputs from the pressure switch under test with its ON-OFF signal. The X axis test pressure signal was supplied by an EID laboratory supplied and calibrated absolute pressure transducer. Both the switch and the EID transducer were supplied equal pressure stimuli simulataneously. The pressure was monitored by T. I. equipment consisting of a calibrated quartz Bourdon tube plus digital readout servo-nulling equipment. This is one of the pressure standards of the EID Laboratory.

Controlled overpressure of 5000 psi was exerted by the calibrated Amthor dead weight tester hydraulic system. Lower overpressures to the pressure switch were introduced from the high pressure nitrogen gas source, regulator, and gage system.

Controlled temperatures for the pressure sensor and for the signal conditioner were obtained from a pair of Delta Design ovens and their automatic temperature controllers.

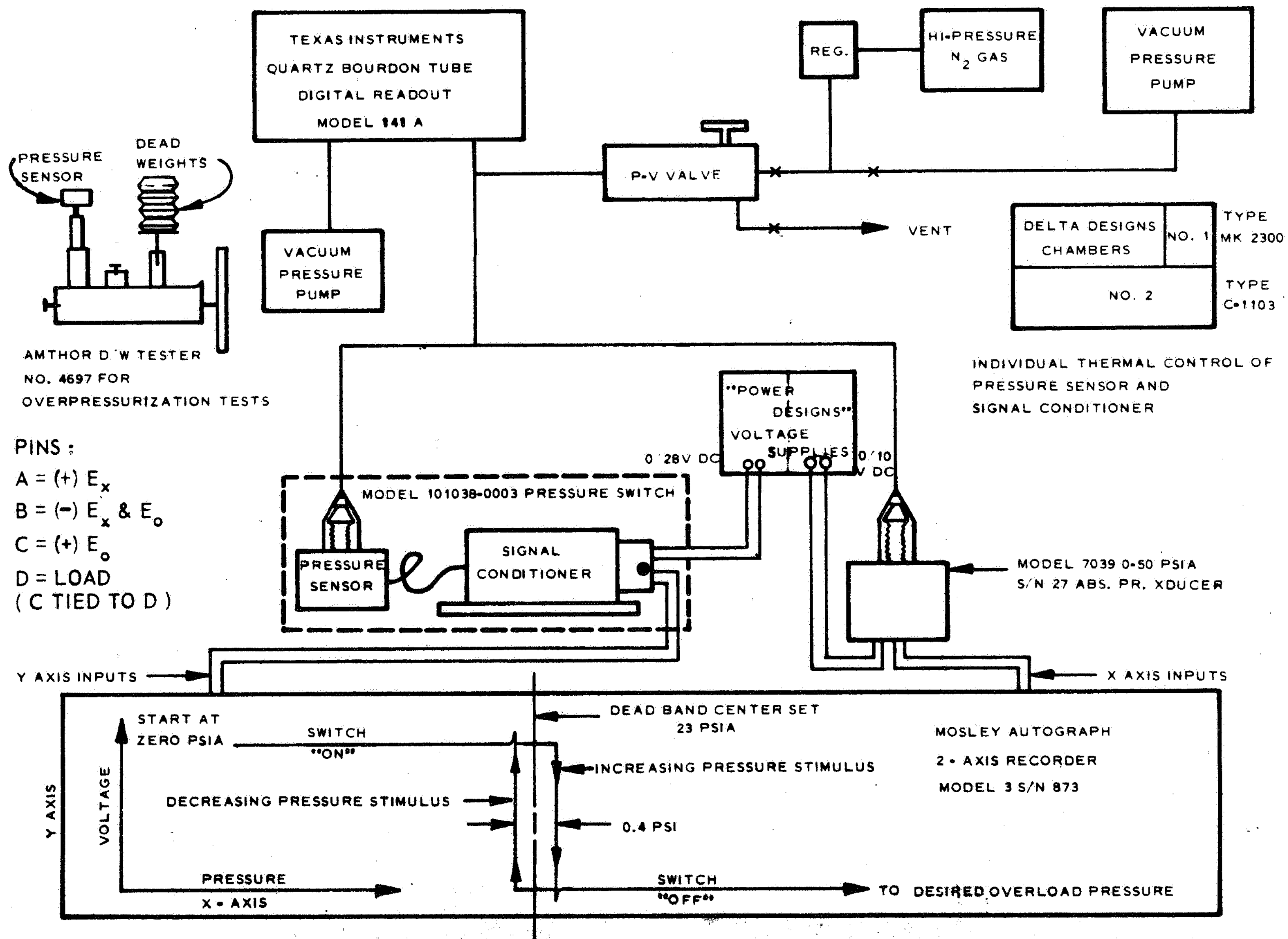

Figure 12. Diagram of Basic Pressure Switch Test Setup

SECTION 3

PERFORMANCE GOALS OF MODEL 101038-0003 PRESSURE SWITCH

a. Pressure switch point. As agreed upon, all deliverable prototypes were made to one switch-point range: 23 psia ±3 psi. All delivered units conform to this basic requirement.

b. Survival and maintenance and pressure integrity at 25,000 psi. All deliverable prototypes were subjected to hydraulic static pressures of 25,000 psi then cleaned and helium leak-tested. All units successfully passed this test.

c. Limits were to remain within switch pressure tolerance (±3 psi) after steady state thermal environmental changes plus overload pressure conditioning.

Thermal range: Pressure sensor $+30^{\circ}F$ to $+350^{\circ}F$
Signal Conditioner $-65^{\circ}F$ to $+160^{\circ}F$

See Tables: 1 (S/N 1), 2 (S/N 2), 3 (S/N 3), and 4 (S/N 4) at the end of this section.

d. Units must survive and be within switching specification after 10 cycles at 5000 psi, pressure switch to be at room temperature.

(1) All units demonstrated their capability to pass this test on the second attempt. The second test was necessary because we had failed to condition the set of the diaphragm while in the "absolute" mode of operation, but had done so while the pressure sensor was in the "gage" mode. The slight amount of new forming that occurred was enough to change the diaphragm's apparent spring rate, and hence the amount of deflection required of the composite system to achieve the 23 psia output switching position (i.e., the bridge output going to zero volts output).

Once the diaphragm had been properly formed the 5000 psi overload had little or no effect on the switch point drift, and as explained in the following paragraph, we were able to rebalance the electrical output of the silicon sensor bridge so that the switch point would again occur at 23 psia.

(2) Rebalance of the bridge was required on three of the four units. If, in effect, we had had a five wire system leading from the pressure sensor to the signal conditioner, electrical rebalance of the bridge would have been very easily accomplished by the insertion of a new switch point balance resistor (Evanohm quality).

What we had was a stitch-welded cover on the pressure sensor and four wires (a completed) bridge, leading from it. Rebalancing could only be accomplished by paralleling one of the 500Ω, silicon bridge arms.

S/N 1 required 25 kΩ in parallel with one bridge arm.
S/N 2 required 7 kΩ in parallel with one bridge arm.
S/N 4 required 4.6 kΩ in parallel with one bridge arm.

(3) Upon reacquisition of the proper switch point, namely 23 psia, we now traded off our previous excellent bridge thermal environmental balance. Figures A-2-8 and 9; and A-4-8 and 9 are now grossly different from Figs. A-2-7 and A-4-7 (see Appendix A). Keep in mind that: (a) the inserted paralleling (shunting) resistors are located in the signal conditioner which provides the mechanism (an accessible terminal board plate) for making corrections, but which does not see the same temperatures as the pressure sensor; and (b) paralleling a silicon strain gage sensor element with an Evanohm element produces a correction where the resistance change with temperature is significantly different than that of the sensors themselves.

(4) In summary, a design that would permit the change of the switch point balance resistor within the pressure sensor housing itself would have been the most desirable solution to the dilemma presented in Subsection 3.4.1. A second choice would be provision of a five-wire system from an open-bridge network between the pressure sensor and the signal conditioner with the ability to make balance (switch-point) corrections in the associated signal conditioner terminal board.

e. To survive and remain within specification after:

(1) 100,000 cycles of 500% pressure overload
(2) Pressure sensor at > 300°F
(3) Signal conditioner at 77°F
(4) (A bonus): vibrational g-load of 20 g, peak-to-peak

(All conditions being applied simultaneously.)

The selected pressure switch, S/N 4, was mounted in the cylinder head of an O&R 1-hp, 2-cycle, 6000 rpm engine. It survived and remained within specification after > 100,000 pressure-temperature cycles.

In Appendix E, Figs. E-1-1 and E-1-2 show the required modification to the O&R engine cylinder head. The modification included ports for the pressure sensor, a flush mounted, water cooled pressure transducer, and two thermocouples, one of which read the cylinder head temperature and the other of which protruded into the high compression-clearance zone of the piston-cylinder head assembly. Previous to this particular verification test, several runs were made to ascertain the actual test pressures and temperatures. The engine ran close to 6000 rpm; a total run of 18 minutes was made with S/N 4 mounted in its pressure port. At the conclusion of the run, the switch-point characteristics were determined again. No shift had occurred. See Figs. E-2-1 and E-2-2 in Appendix E.

Figure E-1-3 (also Appendix E) shows oscilloscope traces of the actual pressure cycle occurring per revolution in the O&R engine. Chromel-alumel thermocouples were used to record temperatures and their outputs were read on a Moseley Autograph Model 680 strip chart recorder.

f. The switch must operate within specification while subjected to pulsed (350%) overload pressure and (1) sinusoidal vibration and (2) random vibration. S/N 4 was selected and a continuous trace of its output was monitored. No deviations from the norm were experienced under the 3 axes investigation. (Both pressure sensor and signal conditioner were mounted on the same M-B shaker tooling fixture.) Appendix D gives the test requirements, the test setup, and the accumulated data sheets.

g. Survival and response to shock wave impulse were also demonstrated by S/N 4. A byproduct was the capture of the speed of response of the combined pressure sensor, its Helmholtz cavity, and the switching speed of the electronics. Their combined response was about 500 microseconds; that is, it would take less than 500 microseconds for the switch to go from 0 psia to 23 psia and switch from ON to OFF state under a large shock wave impulse. See Figs. F-1, F-2 and F-3 of Appendix F.

All of these tests, (a) through (g), were witnessed by an EOS project engineer, a QC inspector and a DCAS representative.

TABLE 1

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS,
MODEL 101038-0003 PRESSURE SWITCH S/N 1

A. Temperature Runs: Temperature, steady state

Pressure Sensor (^oF)	Signal Conditioner (^oF)	Switch Point (psia)
+30	- 65	23.90
77	+160	23.0
77	- 65	23.10
30	77	23.90
200	77	21.40
350	77	22.0
350	160	22.0

Results: All points within switching error band.
Above runs completed 29 March 1967.
See charts in Appendix A, Figs. A-1-1 through A-1-7.
Test setup, Fig. 12.

B. Multiple Overpressure Cycling at 5000 psi: Amthor Dead Weight Tester Equipment

Results: Switch point shift to 19 psia.
No significant recovery occurred after approximately 2 hours.
Above tests completed 29 March 1967.
See chart in Appendix B, Fig. B-1-1.

Recalibration of Switch Point: 25,000Ω introduced as a shunt across one leg of the silicon bridge which also included the original balance resistor and Balco thermal compensation resistor, which had produced the excellent results of (A) above.

Results: Switch point brought back to 23 psia.

Retest of Multiple Overpressure Cycling at 5000 psi:

Results: No significant change of switch point occurred.
Above tests and recalibration completed 30 March 1967.
See chart in Appendix B, Fig. B-1-2.

TABLE 1

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS, MODEL 101038-0003 PRESSURE SWITCH S/N 1 (contd)

C. Retest of Pressure Switch at Selected Thermal Environment Extremes:

This test was required because of the nature of the 30 March recalibration and its effect upon thermal drift of the switch point.

Results: S/N 1 is still within the ±3 psi switching error band.
Above tests completed 1 April 1967.
See charts in Appendix A, Figs. A-1-8, A-1-9.

D. Effect of Variations in Supply Voltage Upon the Switch Point:

Results: No significant switch change occurs with variation in supply voltage from 37 to 22V dc.
Above test completed 3 April 1967.
See chart in Appendix C, Fig. C-1-1.

TABLE 2

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS, MODEL 101038-0003 PRESSURE SWITCH S/N 2

A. Temperature Runs: Temperature, steady state

Pressure Sensor (^{o}F)	Signal Conditioner (^{o}F)	Switch Result (psia)
+30	- 65	21.75
77	+160	21.60
77	- 65	21.60
30	77	22.90
200	77	21.10
350	77	21.25
350	160	20.75

Results: All points within switching error band.
Above runs completed 29 March 1967.
See charts in Appendix A, Figs. A-2-1 through A-2-7.
Test setup, Fig. 12.

B. Multiple Overpressure Cycling at 5000 psi: Amthor Dead Weight Tester Equipment

Results: Switch point shift to 10 psia.
Above test completed 29 March 1967.
See chart in Appendix B, Fig. B-2-1.

Recalibration of Switch Point: 7,000Ω introduced as a shunt across one leg of the closed silicon bridge which also included the original balance resistor and Balco thermal compensation resistor which had produced the excellent results of (A) above.

Result: Switch point brought back to 22 psia.

Retest of Multiple Overpressure Cycling at 5000 psi:

Result: No significant change of switch point occurred.
Test completed 30 March 1967.
See chart in Appendix B, Fig. B-2-2.

TABLE 2

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS,
MODEL 101038-0003 PRESSURE SWITCH S/N 2 (contd)

C. Retest of Pressure Switch at Selected Thermal Environment Extremes:

This test was required to document the effect of the recalibration upon the thermal drift of the switch point.

Results: S/N 2 now switches ON-OFF at 36 psia while stabilized at +350°F; the influence of the signal conditioner upon the drift is minimal (approximately 1 psia).
Above tests completed 3 April 1967.
See charts in Appendix A, Figs. A-2-8 and A-2-9.

D. Effect of Variation in Supply Voltage Upon Switch Point:

Results: No significant switch point change occurs during change in supply voltage between 37 and 22V dc.
Above test completed 3 April 1967.
See charts in Appendix C, Fig. C-2-1.

TABLE 3

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS, MODEL 101038-0003 PRESSURE SWITCH S/N 3

A. Temperature Runs: Temperature, steady state

Sensor Pressure (^{o}F)	Signal Conditioner (^{o}F)	Switch Point (psia)
+30	- 65	24.50
77	+160	24.13
77	- 65	24.25
30	77	24.75
200	77	23.13
350	77	22.60
350	+160	22.60

Results: All points within switching error band.
Above runs completed 29 March 1967.
See charts in Appendix A, Figs. A-3-1 through A-3-7.
Test setup, Fig. 12.

B. Multiple Overpressure Cycling at 5000 psi: Amthor Dead Weight Tester Equipment

Results: Slight shift of switch point, no recalibration required.
Above tests completed 30 March 1967.
See charts in Appendix B, Fig. B-3-1.

C. Retest of Pressure Switch at Selected Thermal Environment Extremes:

Not required

D. Effect of Variation in Supply Voltage Upon Switch Point:

Results: No significant change in switch point.
Above tests completed 3 April 1967.
See charts in Appendix C, Fig. C-3-1.

TABLE 4

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS, MODEL 101038-0003 PRESSURE SWITCH S/N 4

A. Temperature Runs: Temperature, steady state

Sensor Pressure (°F)	Signal Conditioner (°F)	Switch Point (psia)
30	- 65	22.90
77	+160	21.13
77	- 65	21.40
30	77	23.0
200	77	19.75
350	77	20.50
350	160	19.0

Results: A more precise set on the 23 psia switch point would have brought all points within the ±3 psi tolerance.
Above runs completed 29 March 1967.
See charts in Appendix A, Figs. A-4-1 through A-4-7.
Test setup, Fig. 12.

B. Multiple Overpressure Cycling at 5000 psi: Amthor Dead Weight Tester Equipment

Results: Switch point moved outside of +0 psia to +60 psia range of the X-Y plotter due to reforming of the outer diaphragm by overpressurizing in the absolute pressure mode of operation.
See chart in Appendix B, Fig. B-4-1.

Recalibration of Switch Point: A 4,600Ω resistor introduced as a shunt across one leg of the silicon bridge was required to correct the shift in the switch point.

Results: Switch point brought back to 22 psia.

Retest of Multiple Overpressurization at 5000 psi:

Results: No significant change in the switch point.
Test completed 30 March 1967.
See chart in Appendix B, Fig. B-4-2.

TABLE 4

SEQUENTIAL VERIFICATION AND ACCEPTANCE TEST RESULTS
MODEL 101038-0003 PRESSURE SWITCH S/N 4 (contd)

C. Effect of Variations in Supply Voltage Upon Switch Point:

Results: No significant change in switch point occurs between 22 and 37V dc.
Above test completed 3 April 1967.
See chart in Appendix C, Fig. C-4-1.

D. Effect of Sine and Random Vibration Upon Switch Point:

Results: Continuous monitoring of the output ON-OFF signals and of the pressure monitoring transducer showed no abnormal or spurious signals from the pressure switch during the vibration environment tests.
Above test completed 31 March 1967. See Appendix D.
Test G-loading requirement: Section D-1.
Test setup, Section D-2.
Test data sheets, Section D-3.

E. Effects of 100,000 cycles of 5X Switching Pressure and Exposure to High Temperature Gases:

Results: No significant change in pressure switch point performance occurred.
Above tests completed 31 March 1967.
See Appendix E test setup, Figs. E-1-1 through E-1-3,
Data sheets, Figs. E-2-1 and E-2-2.

F. Effect of Shock Wave Pressure Pulses:

Results: No significant change in switch point characteristics of the multiple shock wave pressure impulses.
Response time to achieve 23 psia pressure output is less than 500 microseconds.
Above tests completed 31 March 1967.
See Appendix F, test setup, Fig. F-1,
"Response" data, Fig. F-2,
Chart, Fig. F-3.

G. Retest of Pressure Switch at Selected Thermal Environment Extremes:

This test was required because of the nature of the recalibration required on 30 March 1967 and its effect upon thermal drift of the switch point.

Results: S/N 4 now will switch at 42.5 psia at the extreme thermal environments.
Above tests completed 3 April 1967.
See charts in Appendix A, Figs. A-4-8 and A-4-9.

SECTION 4

ACCEPTANCE TEST PLAN AT EOS

The acceptance test plan conducted at EOS was broken down into the following reviewed items:

a. Weight and dimensions of the signal conditioner and pressure sensor
b. Connector type, pin wiring
c. Workmanship
d. Identification markings of the product
e. Threshold pressure for Type I
f. Overpressure rejection for Type I
g. Sensitivity of switch point to variations in supply voltage
h. Transducer switching output signal
i. Transducer output impedance
j. Transducer response time
k. Transducer insulation resistance
l. Transducer isolation resistance
m. Threshold variation with temperature
n. Threshold shift due to 500% static overload

Appendix G includes the summary results of the acceptance tests and supporting documents.

SECTION 5

ANALYSIS OF MEASUREMENT ERROR % DEVIATION FROM 23 PSIA

Test		% Deviation From 23 psia S/N 1	S/N 2	S/N 3	S/N 4	Error, Squared S/N 1	S/N 2	S/N 3	S/N 4
5.1.	Temperature, plus overload*	-7.0	-9.8	+7.6	-17.4	49	100	58	300
5.2.	Gross static overload**	-1.1	-4.8	-9.8	- 3.4	1.2	23	100	11.5
5.3.	Variations in supply voltage***	--- < 1/4 psi ---				--- < 1/4 psi ---			
5.4.	Verification tests, one sample only								
	Acceleration effects				< 1/4 psi				—
	Repetitive cycling				< 1/4 psi				—
	Shock wave pressure pulses				< 1/4 psi				—
	Algebraic Sum =	-8.1	-14.6	-2.2	-20.8				
	Sum of the squares =					50.2	123	158	311.5
	Square root of the sum of the squares					7.1	11.1	12.6	17.6
	In terms of psi =					1.6	2.6	2.9	4.1

Design goal - ±13% of 23 psia or ±3 psi

Note:
1. Chart reading error is estimated at 1/4 psi (±1/8) simply because of the backlash in the drawing mechanism of the Moseley recorder.
2. After all tests and shipment from EOS to NASA, Houston, and back again, the units are within the original error band.

---

*Worst case percentage deviation from 23 psia as determined by the averaged center of the dead band. See Appendix A, charts A-1, A-2, A-3, A-4; all 1 through 7, only

**Data from 5000 psi loading (or 21,700% overload); Appendix B, charts B-1 through B-4, pretest calibration point is to be taken as 23 psia

***Data from Appendix C, charts C-1 through C-4

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SECTION 6

PROGRAM ORGANIZATION AND ACKNOWLEDGMENTS

This project required the harmonious meshing of talents and capabilities from the Transducer and Controls Division of Electro-Optical Systems (formerly a wholly owned subsidiary, Micro-Systems, Inc.) and the Engineering Instrument Department of the Measurement Systems Division of EOS.

Figure 13 shows the line organization of this project. Particular mention and acknowledgment are due to Messrs. Earl Rogers, David Bargen, and Joseph Sanchez for their help and guidance in the early formative stages of this contract. Mr. Hans Christen was most helpful in the Phase I mechanical design and test areas.

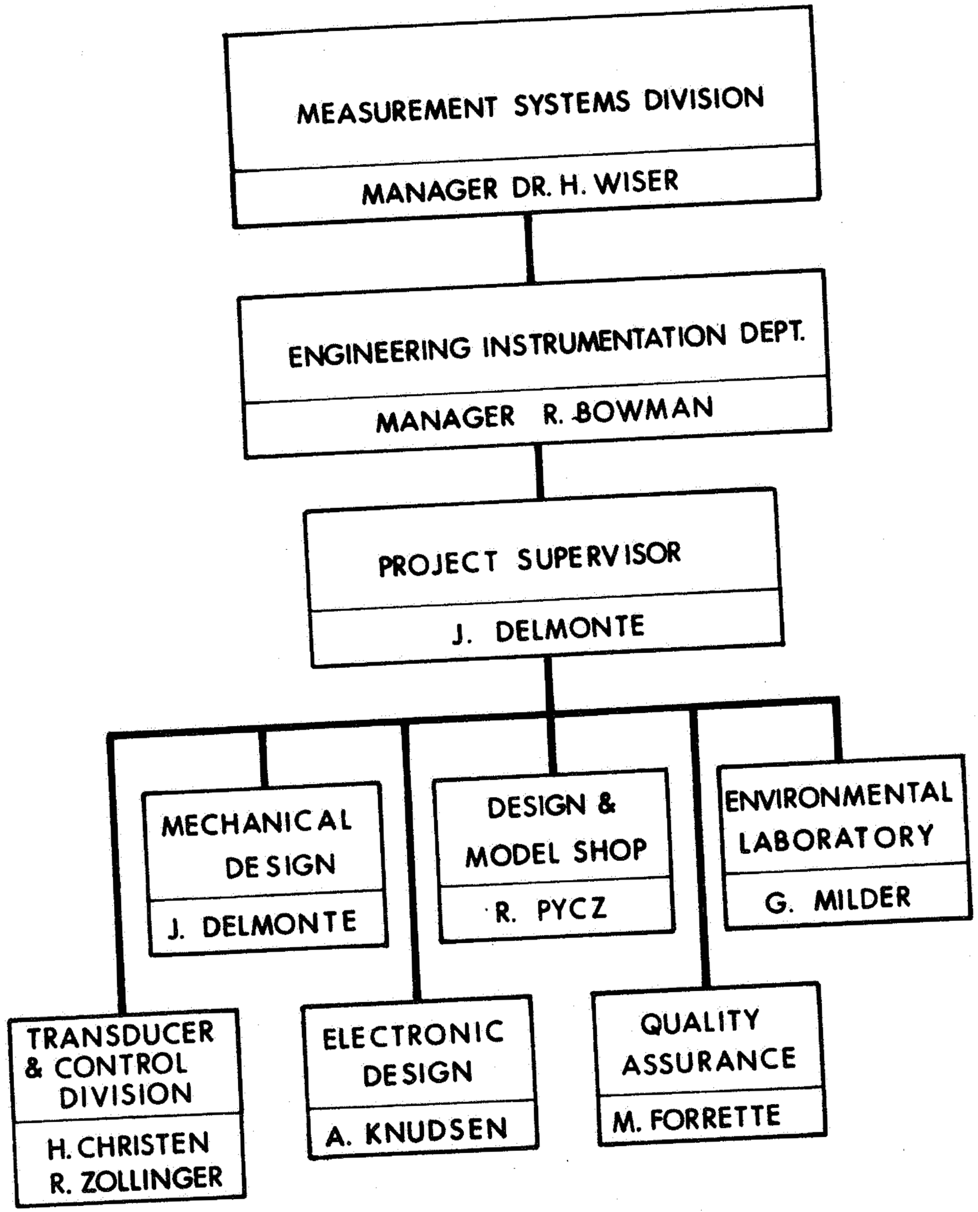

Figure 13. Program Organization

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

From the performance of RCS pressure switch S/N 4, one would expect all the delivered units to perform equally well under extreme overload, sinusoidal and random vibrational loads, shock pressure impulses, multiple rapid pressure cycles, and varying supply voltages. All should exhibit excellent response time.

In the specification area involving thermal stability, two units, Nos. 2 and 4, will be "out" at the high temperature end of the pressure sensor spectrum (from 165^{o}F to 350^{o}F). However, the results of the first series of thermal verification tests indicate that no state-of-the-art problems are faced in reaching the desired design goal. Pressure sensor units can be made to span +30^{o}F to 350^{o}F within a ±3 psi switch point tolerance. Problems raised by units Nos. 2 and 4 are reviewed in the next subsection, 7.2.

Because of similarities between the RCS pressure switch design and related LEM qualified instruments, and based upon considered engineering judgement and experience, EOS believes that many tests need not be repeated on this specific hardware development program. This would apply in the following areas:

a. Fungus resistance
b. No hazardous gas output
c. Salt fog damage
d. Nondamage in explosive atmosphere

e. Fluid compatibility

f. No dissimilar metals

g. Performance, irrespective of operating position

h. No metal deterioration

i. Use of anodized aluminum

j. Use of corrosion-resistant steel

k. No surface wear problems

l. Rubber parts per ANA bulletin 438

m. No critical materials

n. Proper screw threads

o. Proper locking methods

p. Interchangeability of parts

q. Maintainability characteristics

r. Expected service life

s. Expected storage life

t. Performance of the signal conditioner in all operating characteristics and effects of environment other than the following which are related to the switching operation

(1) Output signal voltage

(2) Threshold shift due to temperature

(3) Switching speed

7.2 RECOMMENDATIONS

a. The problems raised by units Nos. 2 and 4 which are evidenced now by excessive switch point drift with temperature result from the cover design of the pressure sensor. Closure for verification and acceptance testing was "to print" which meant being spot-welded. Thus, the only way to adjust for a small switch point set was through removing the cover plate of the electronics which exposed the terminal board interface of the bridge and the electronics and shunting the proper leg of the closed bridge brought over by a 4-wire cable.

Proposed Future Modification

(1) Provide for a removable cover to the pressure sensor, which would expose the Evanohm balance resistor of the strain gage bridge when removed.

A small change in the value of the latter would not affect the thermal compensation since the total bridge draws only 2.65 mA current.

or

(2) Retain the present cover design and provide for a 5-wire cable from the pressure sensor to the signal conditioner thus leaving the bridge "open", and locate the bridge balance resistor on the signal conditioner's accessible terminal board for final adjustment as required.

Even though the signal conditioner does not necessarily "see" the same temperature as the pressure sensor, the Evanohm temperature coefficient of resistance is extremely small, and its 1% maximum variation will cause only a small shift in the switch point.

b. Improvement could also be made in the interconnect cable between the pressure sensor and the signal conditioner and cable termination means.

The present 4-conductor cable with its stranded conductors, shielding, and outer jacket of Teflon material, is too stiff in relation to the physical size of the pressure sensor termination. It should either be lengthened (doubling its present length) or the lay of the wires be made flat instead of bundled.

The first recommendation would significantly reduce the strain on the outer jacket as the pressure sensor is torqued into its pressure port and thus reduce its tendency to creep out from the termination tube at the pressure sensor.

SECTION 8

ITEMS DELIVERED

- Four Type I RCS pressure switches identified as Model 101038-0003, Serial Numbers 1, 2, 3, and 4.
- Monthly Reports M1 through M5
- Nine copies of the final report plus one reproducible copy

APPENDIX A

EFFECTS OF THERMAL ENVIRONMENT CHANGE PLUS OVERLOAD PRESSURE

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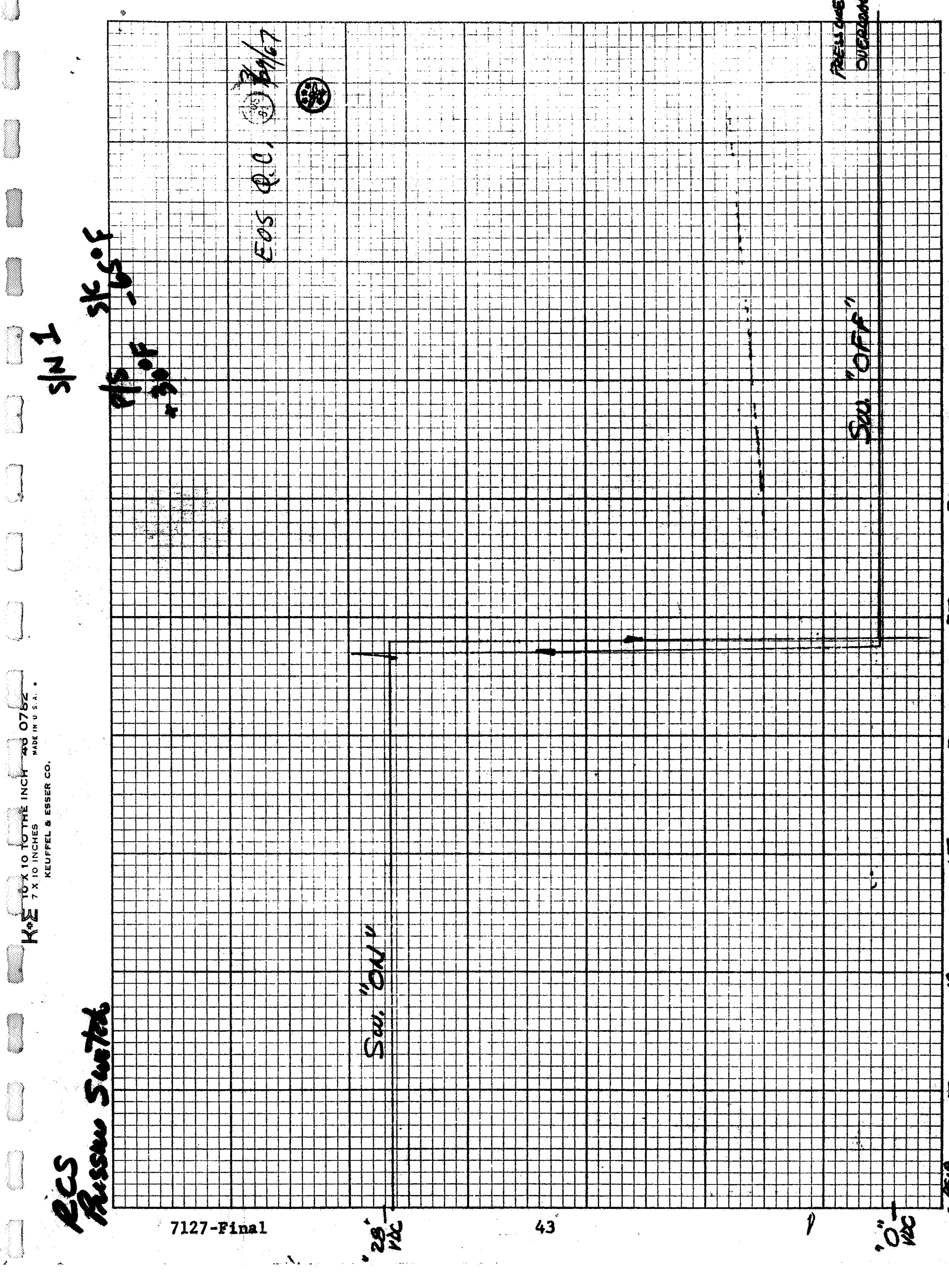


Figure A-1-1. S/N 1

RCS
Pressure Switch

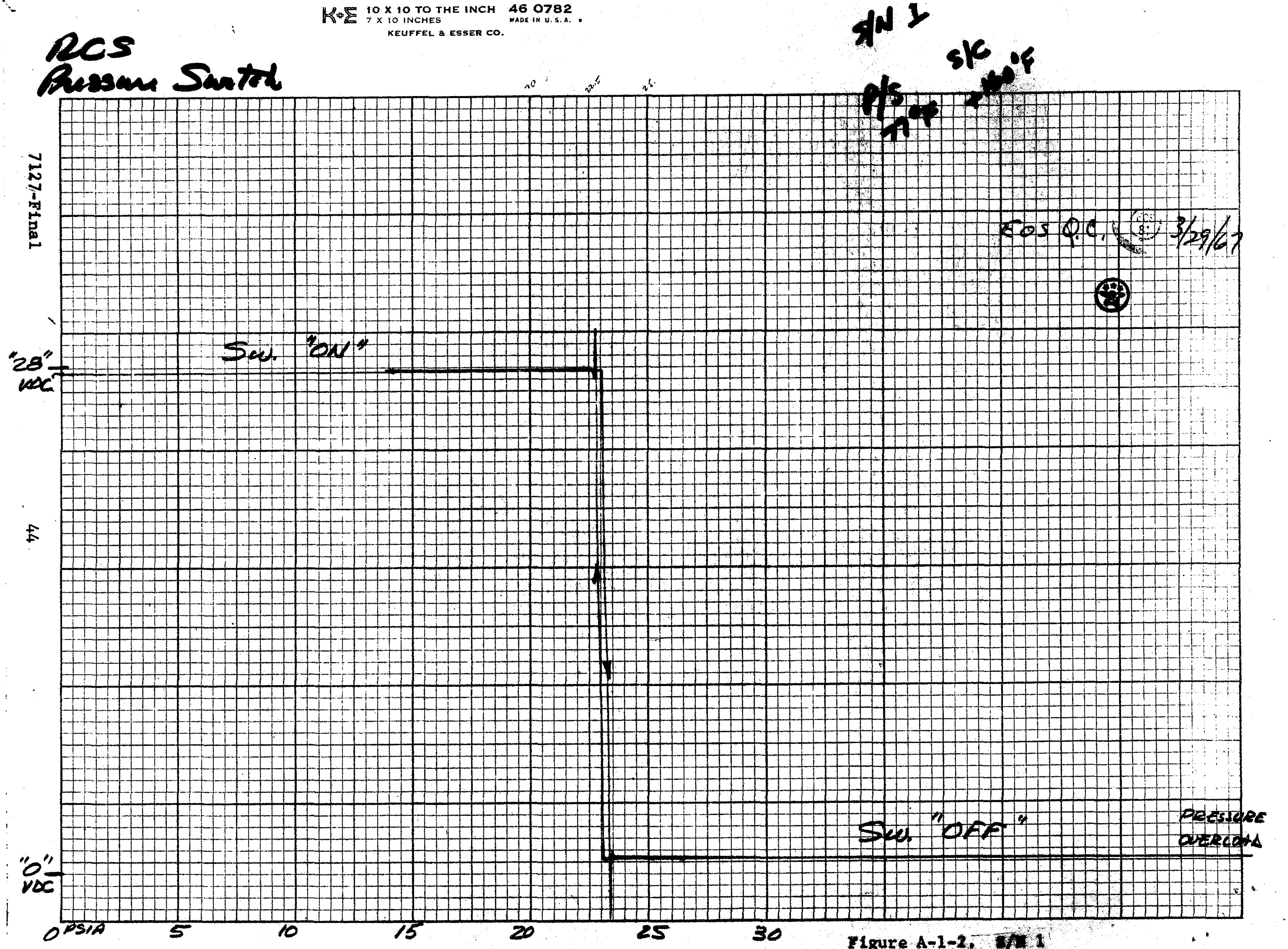


Figure A-1-2, S/N 1

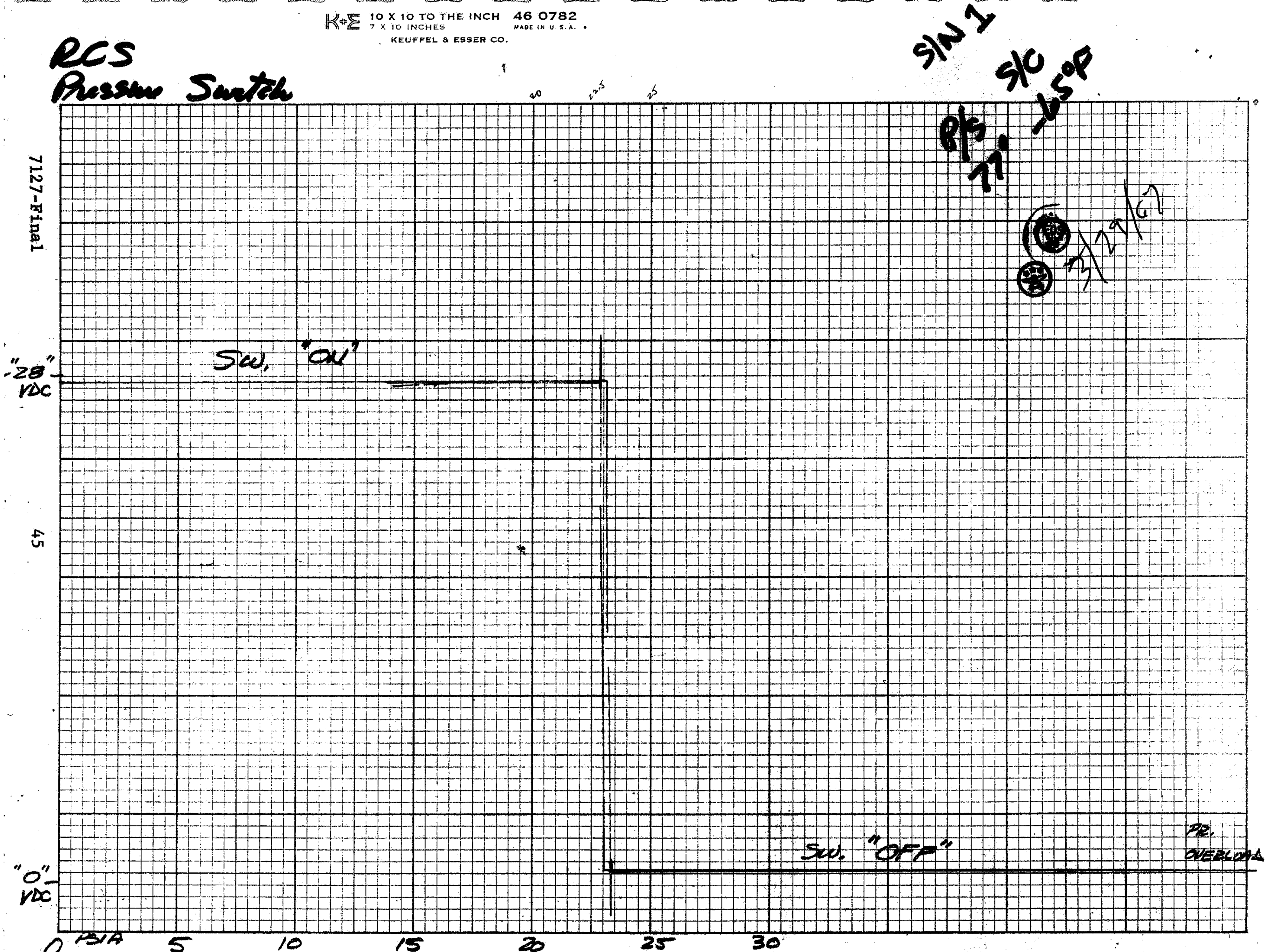


Figure A-1-3. S/N 1

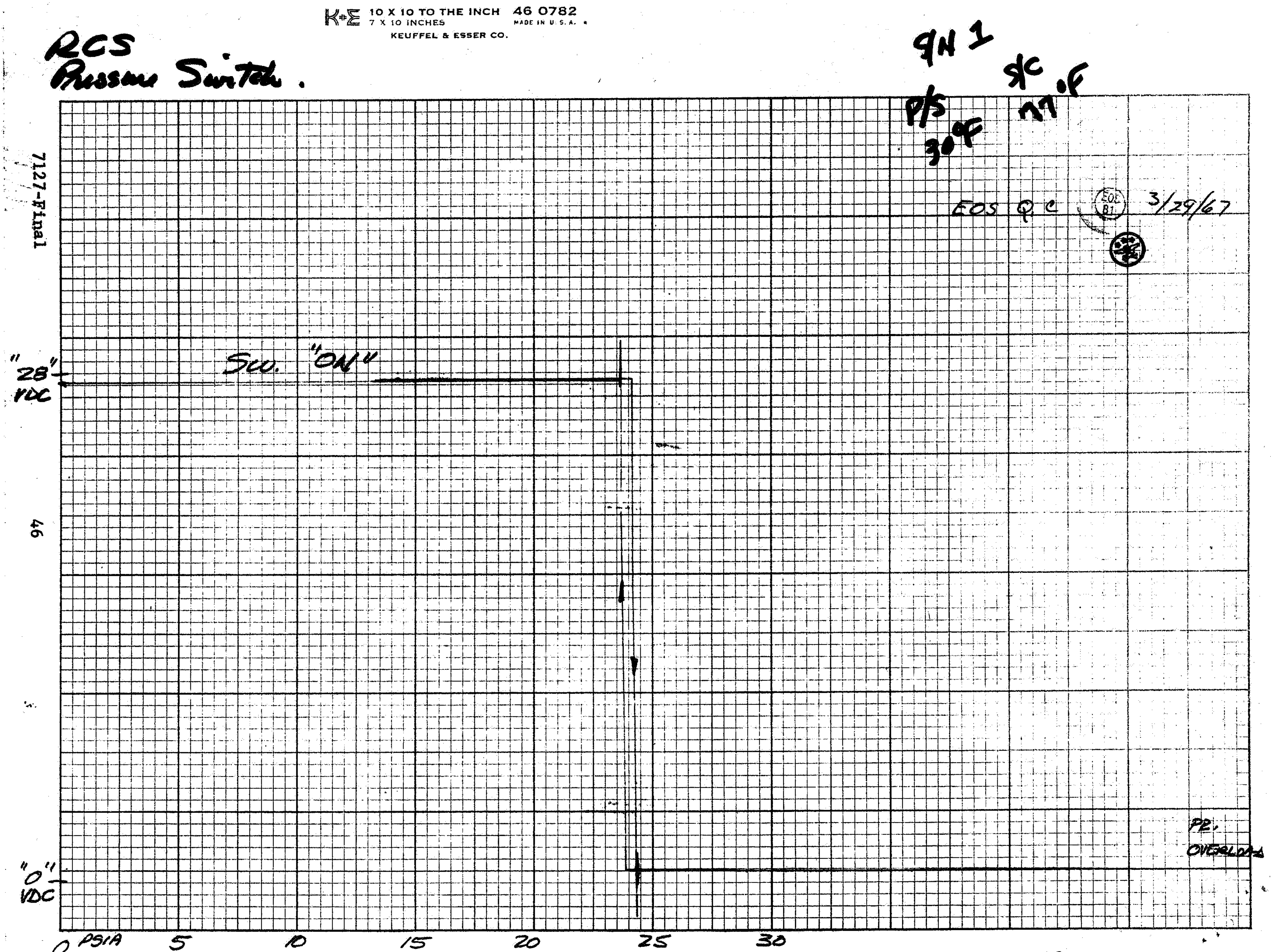


Figure A-1-4. S/N 1

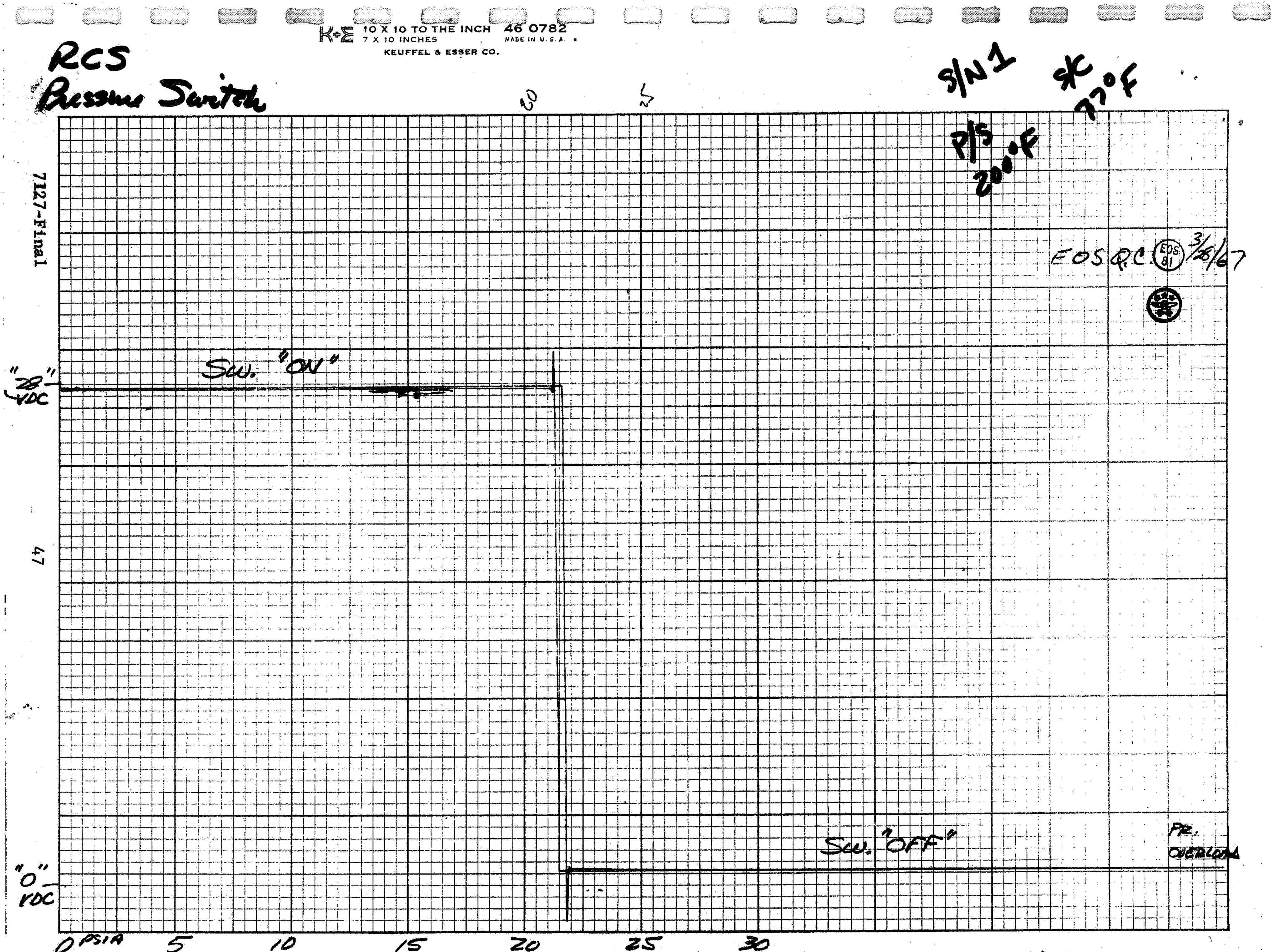


Figure A-1-5. S/N 1

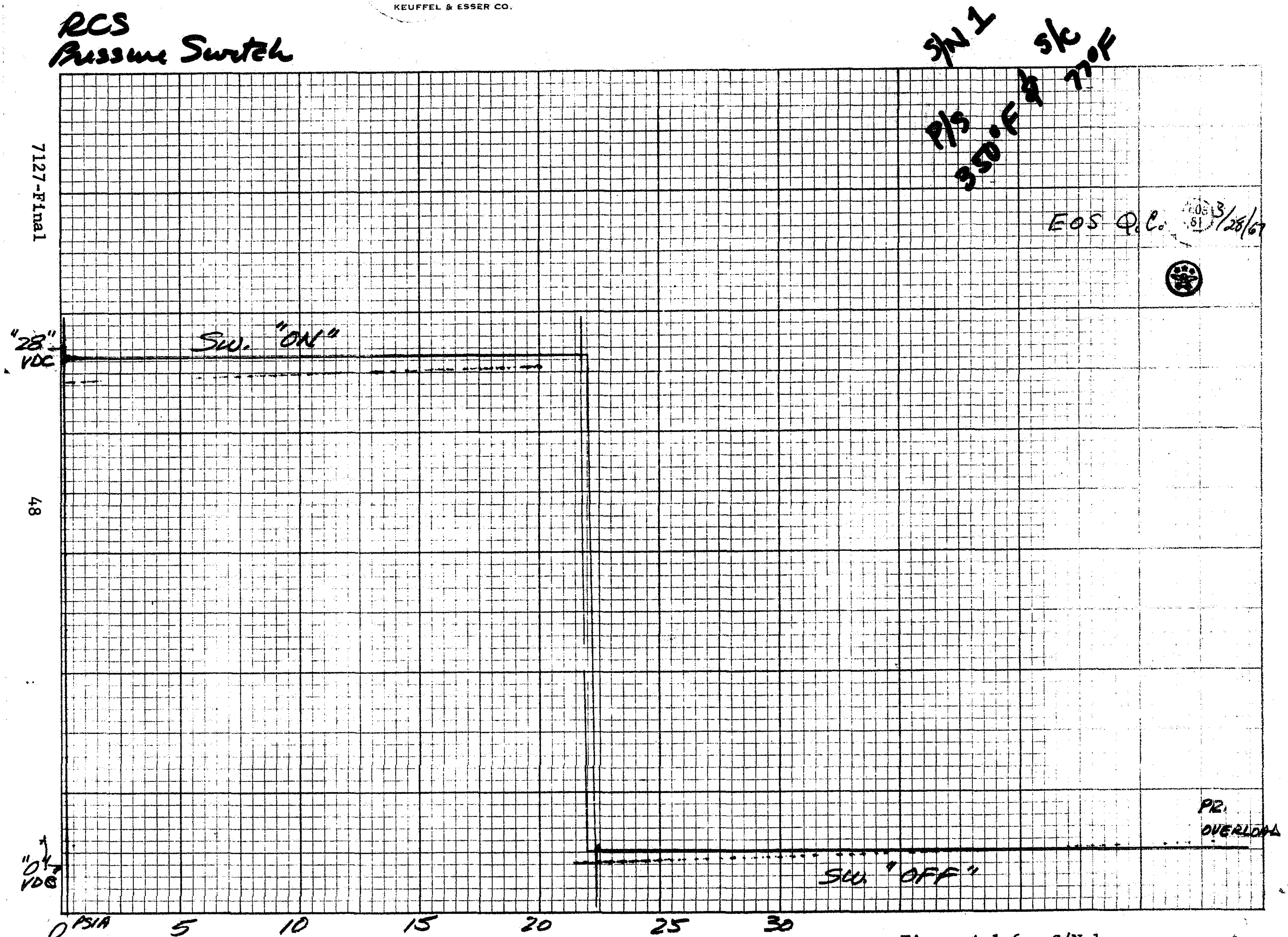


Figure A-1-6. S/N 1

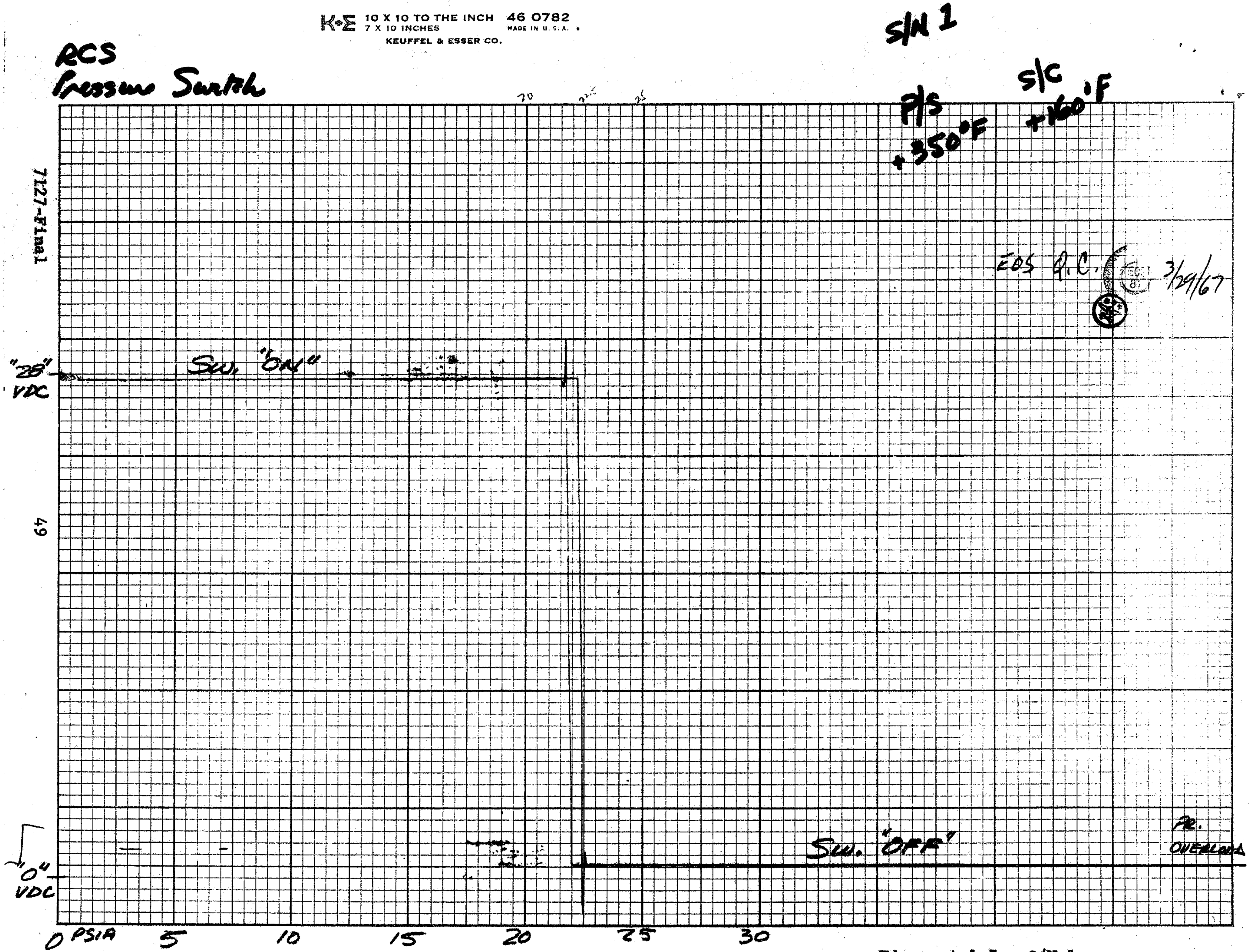


Figure A-1-7. S/N 1

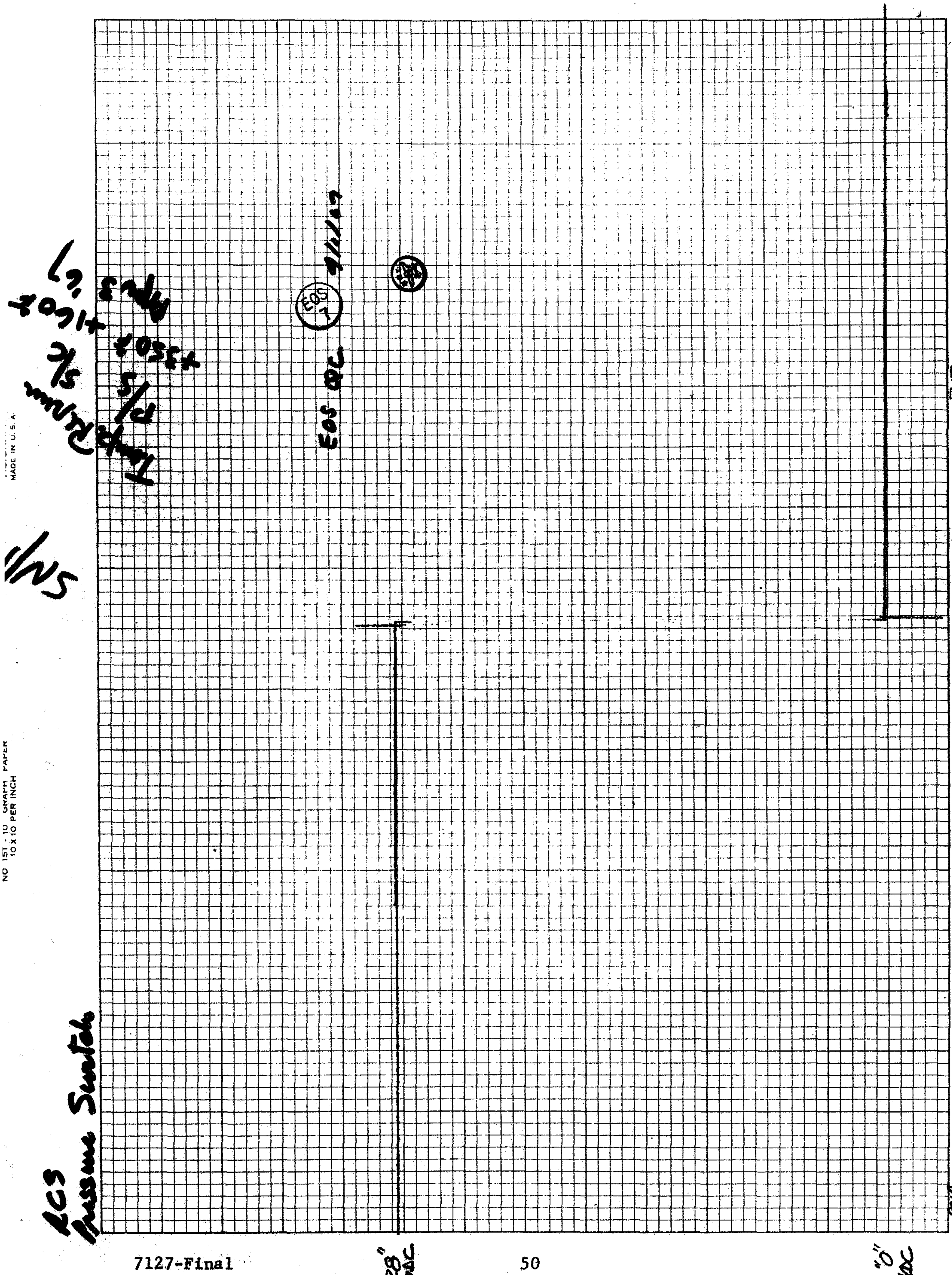


Figure A-1-8. S/N 1

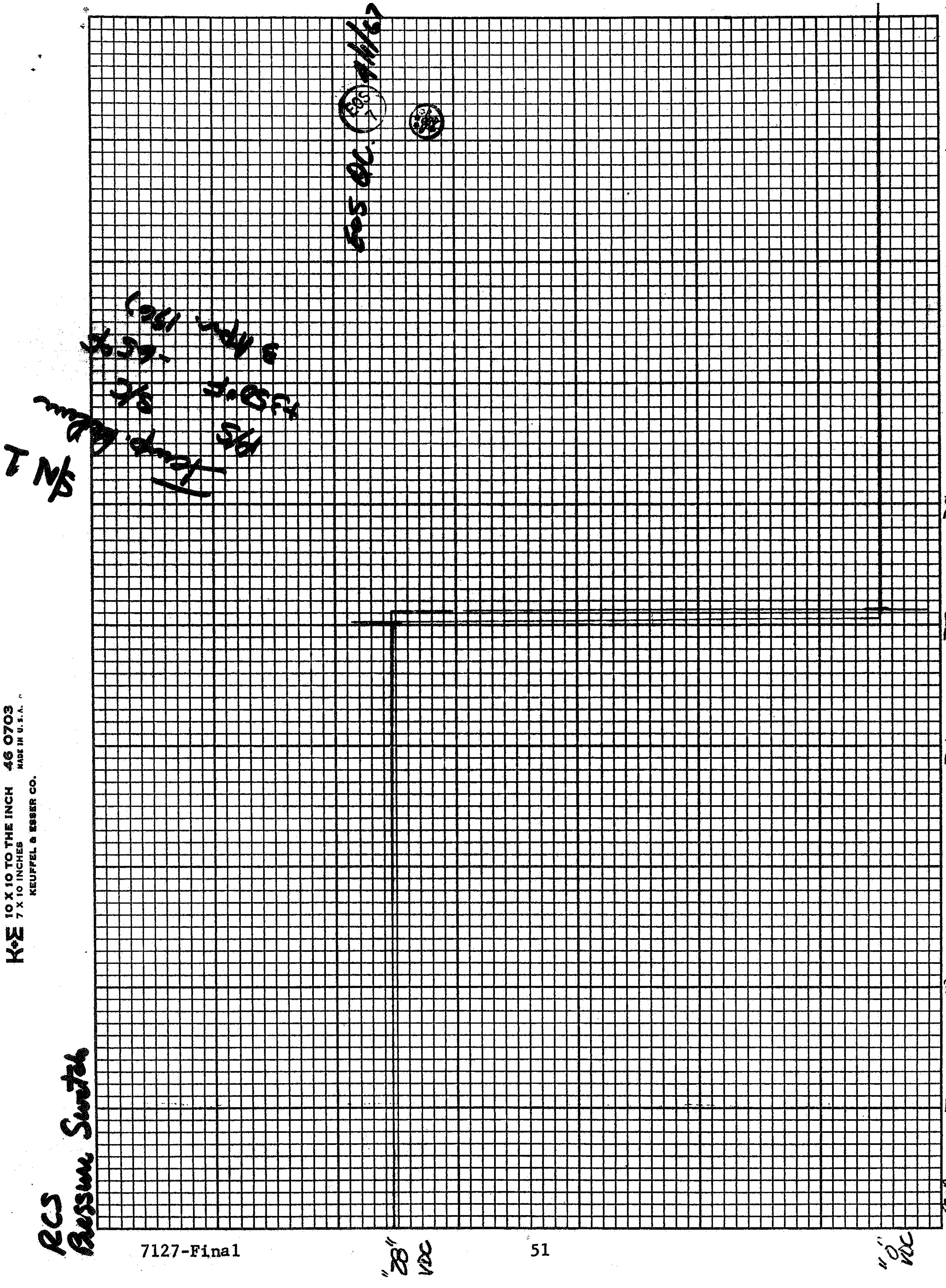


Figure A-1-9. S/N 1

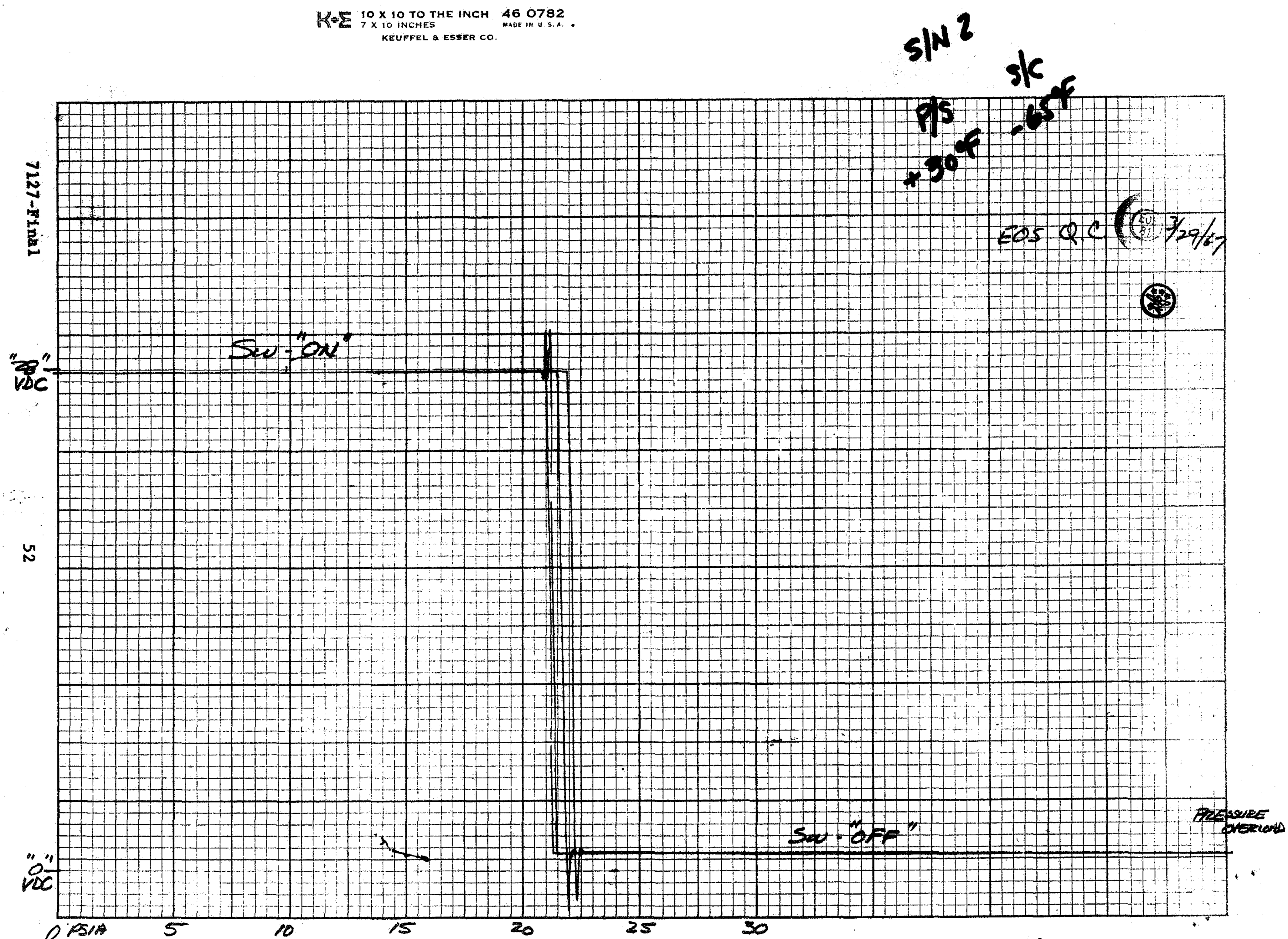


Figure A-2-1. S/N 2

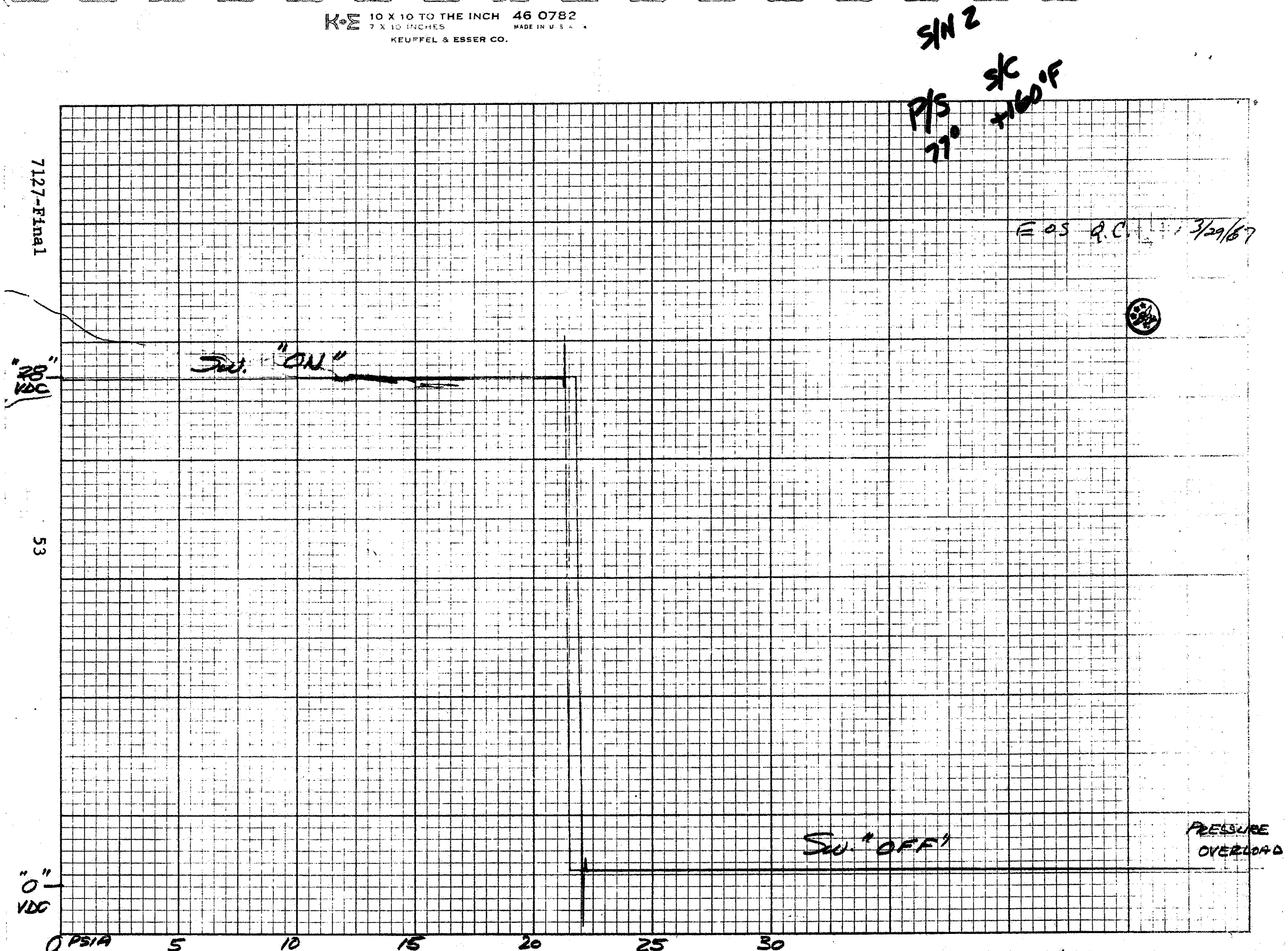


Figure A-2-2. S/N 2

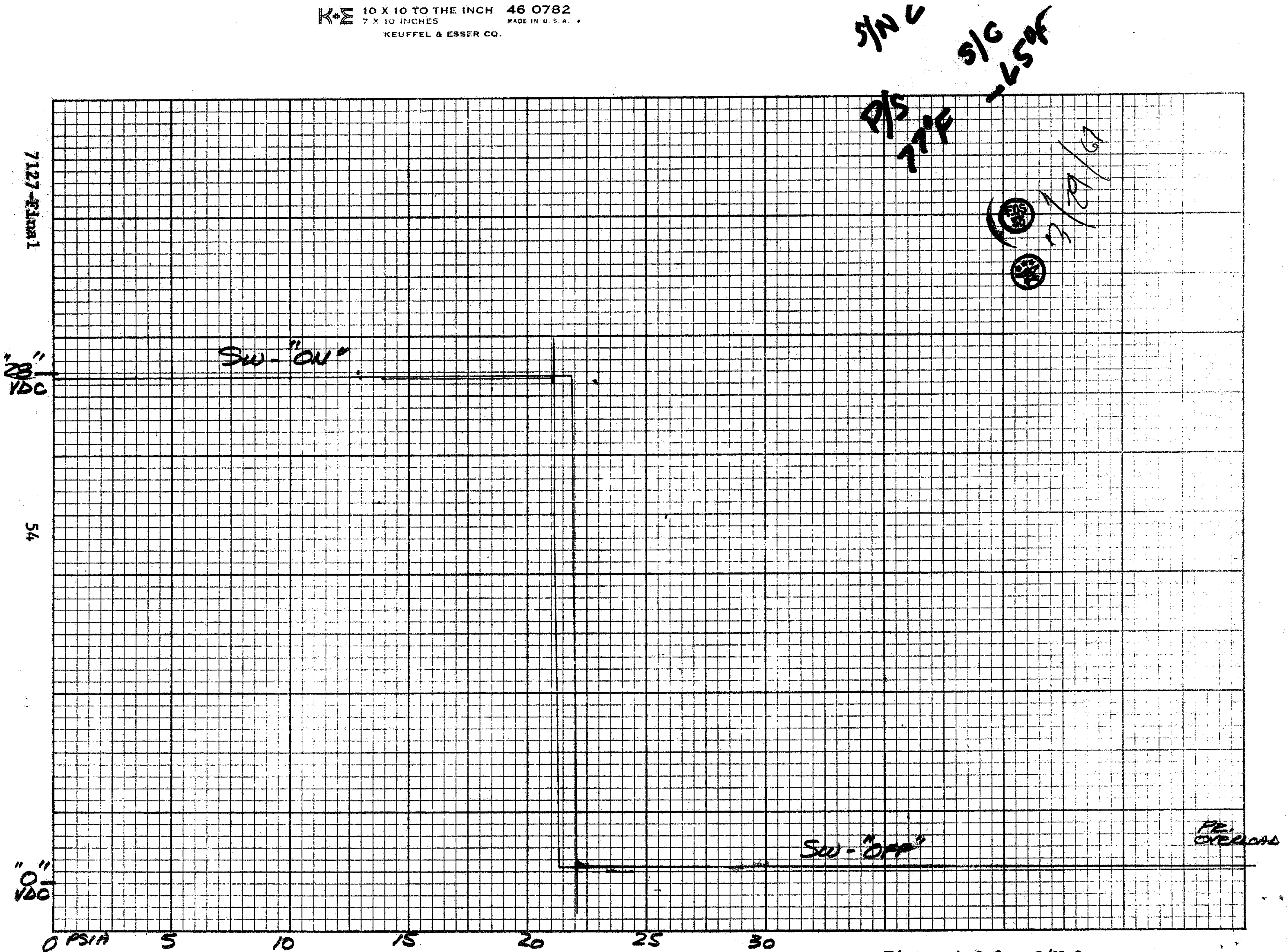


Figure A-2-3. S/N 2

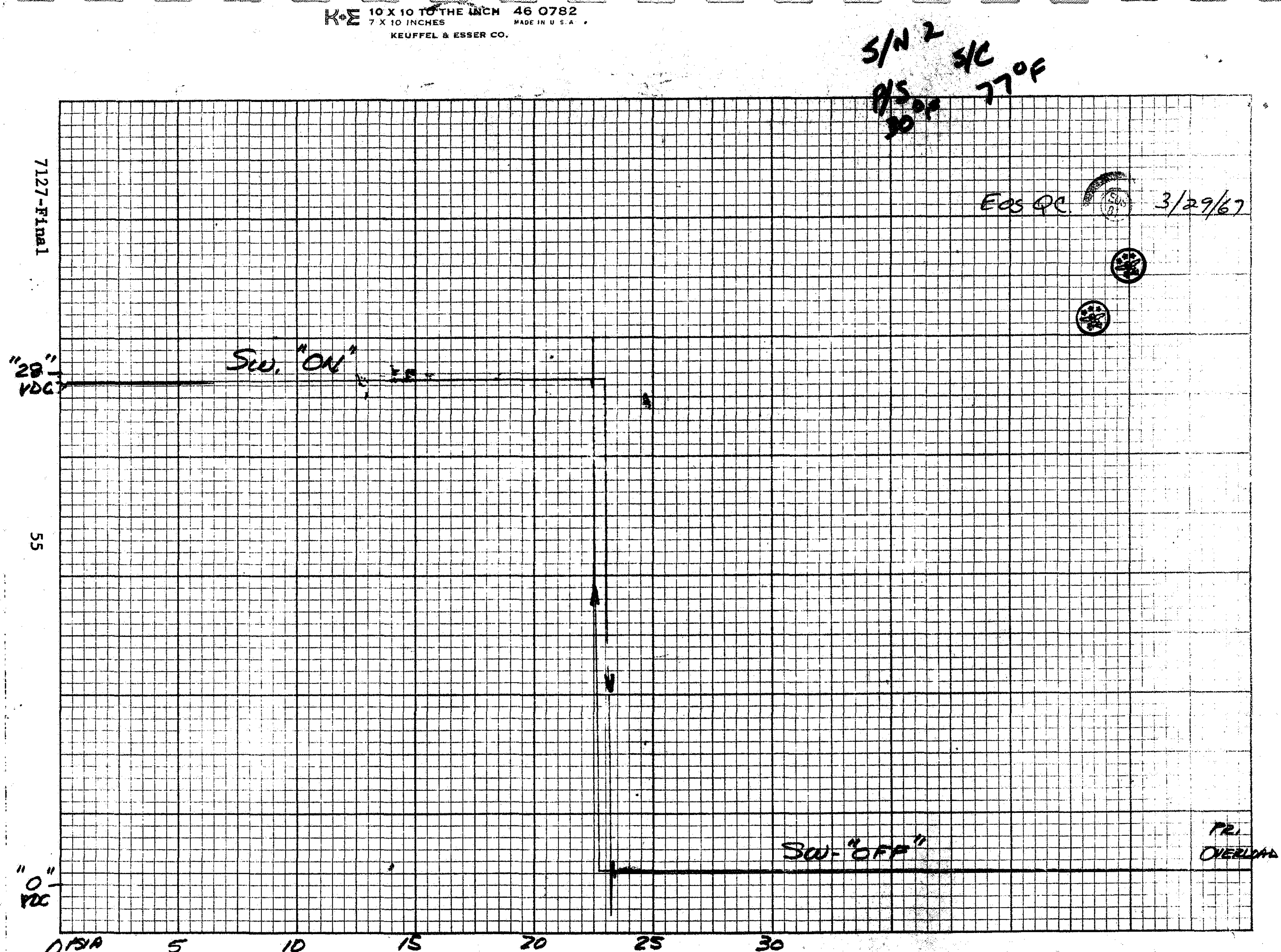


Figure A-2-4. S/N 2

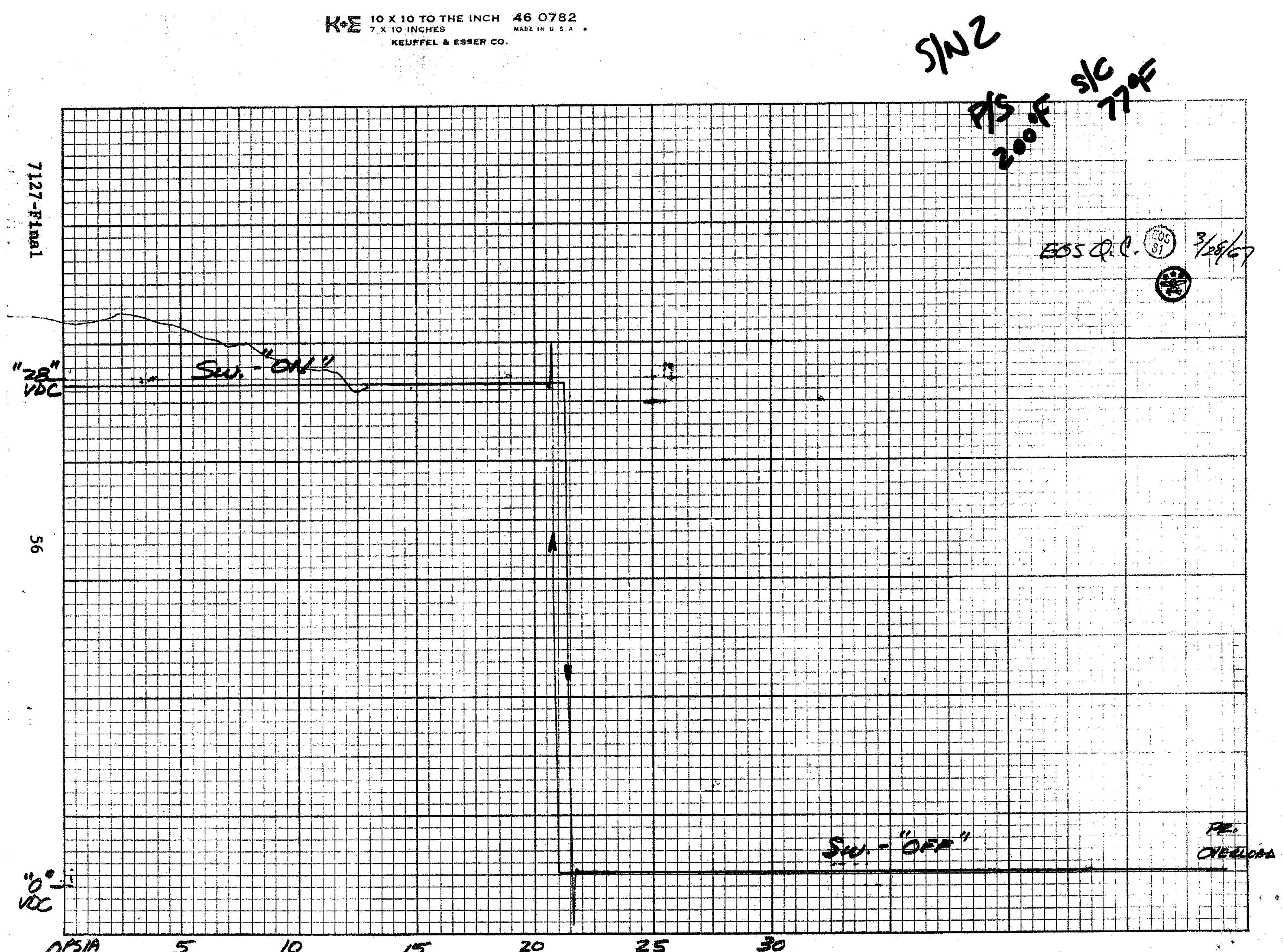
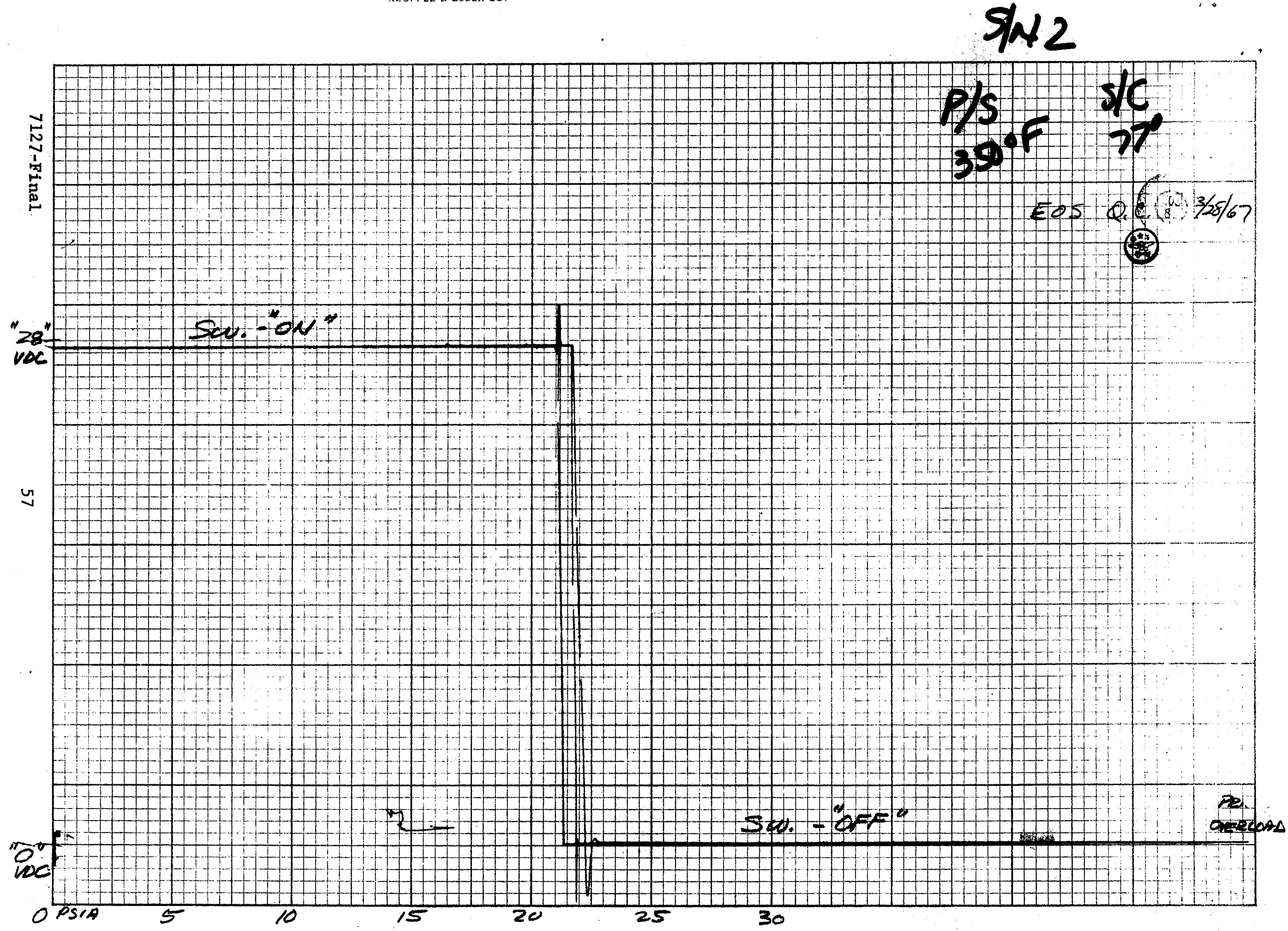


Figure A-2-5. S/N 2



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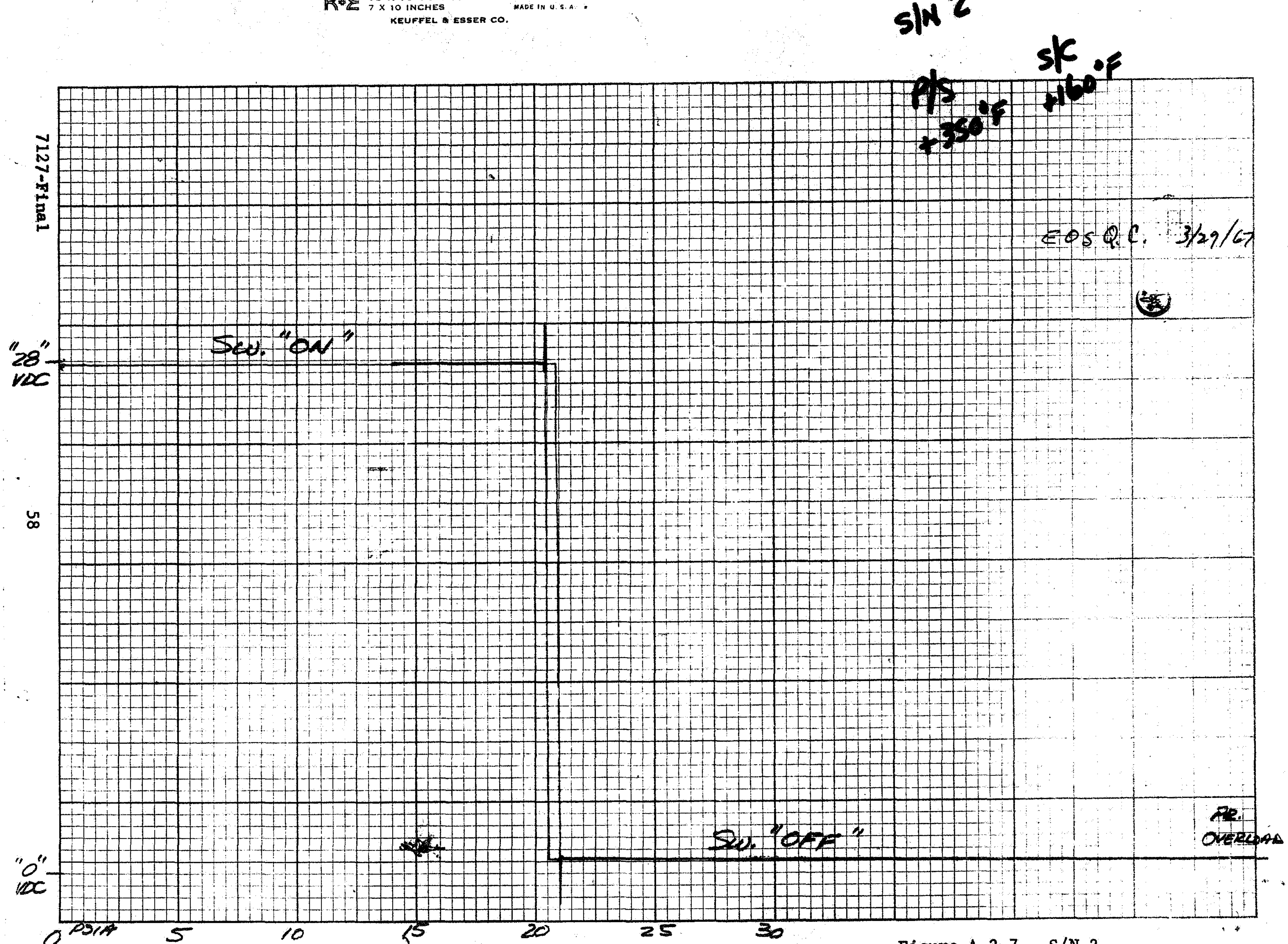


Figure A-2-7. S/N 2

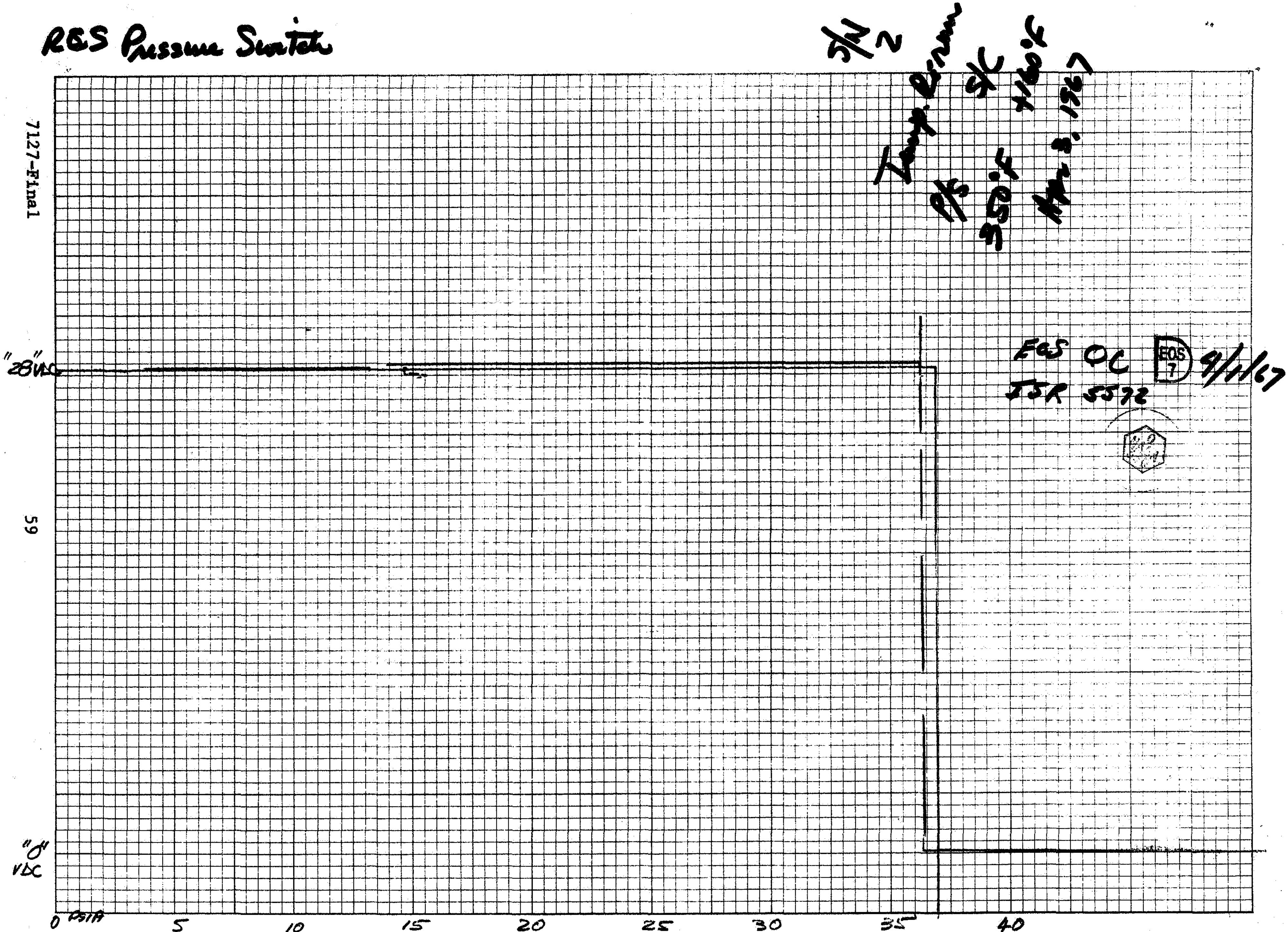
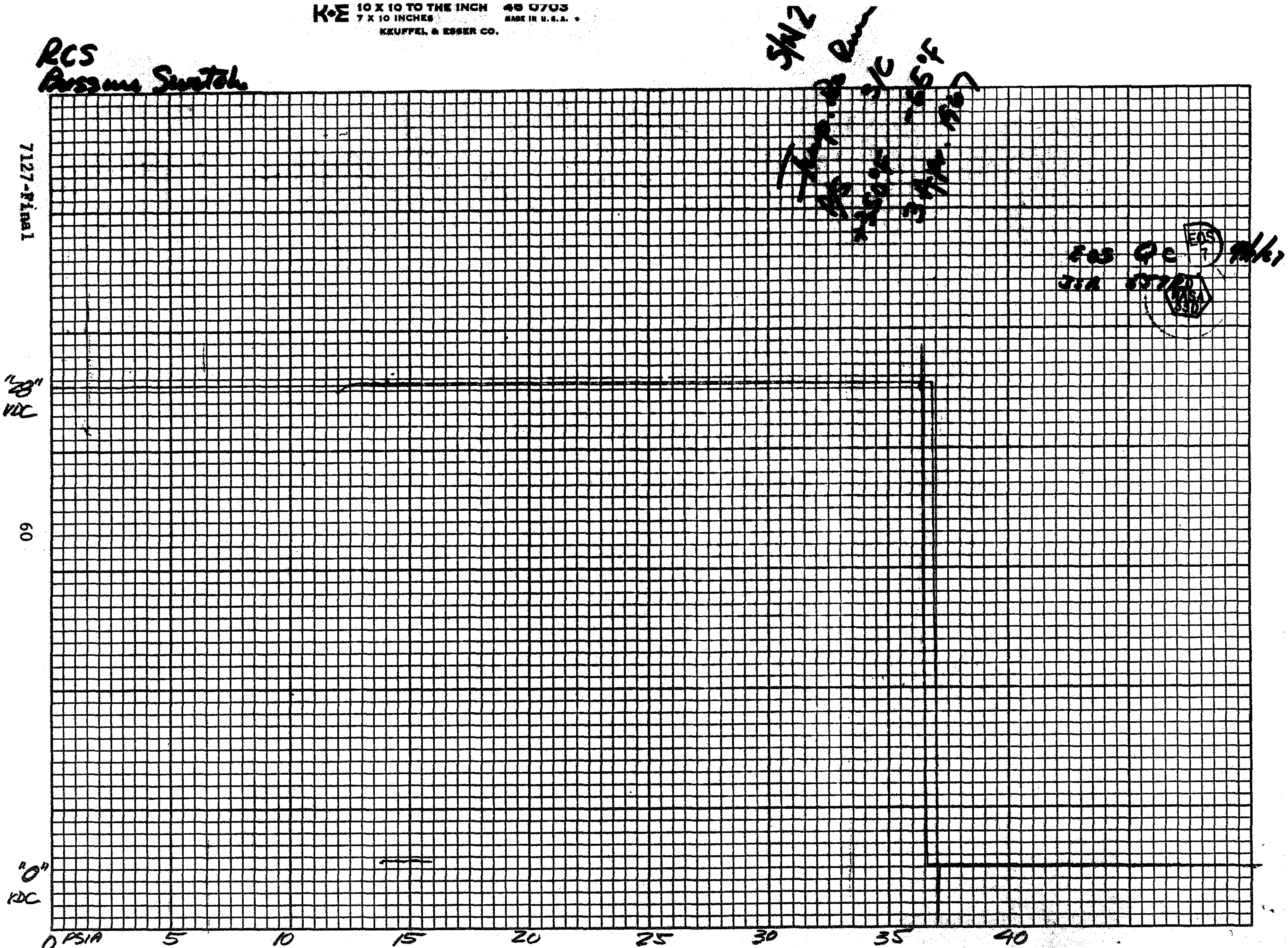


Figure A-2-8. S/N 2



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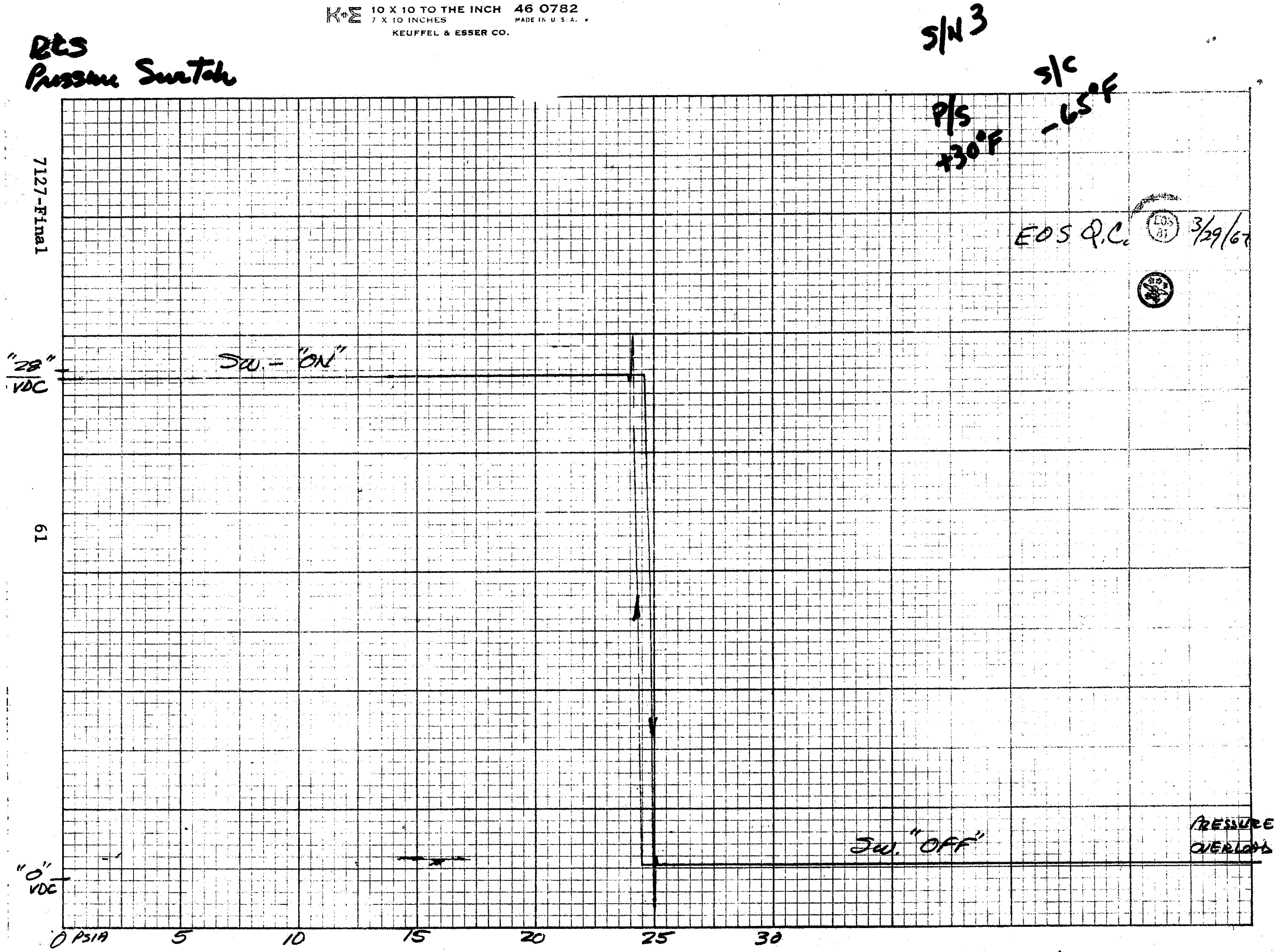


Figure A-3-1. S/N 3

RCS Pressure Switch

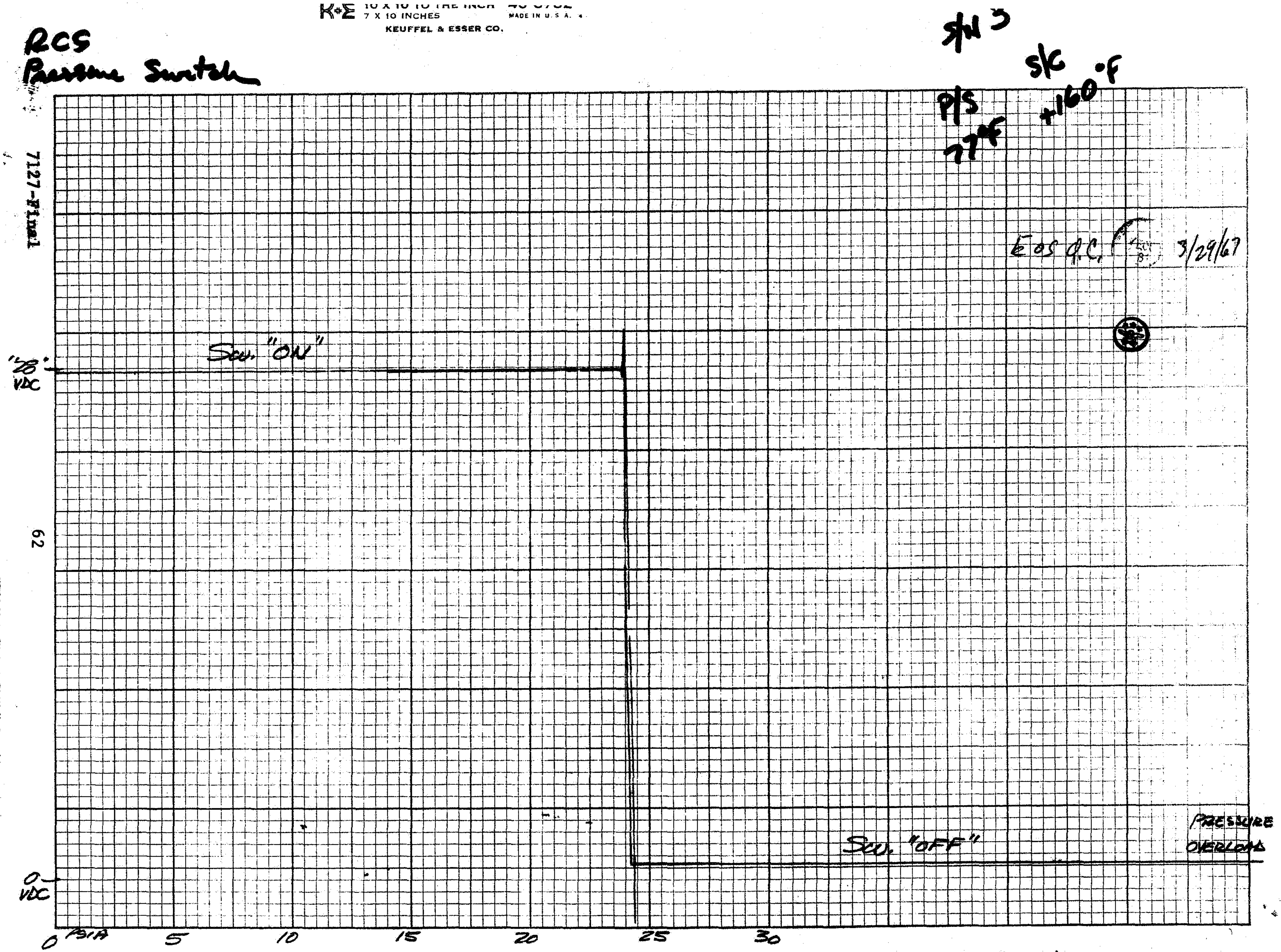


Figure A-3-2. S/N 3

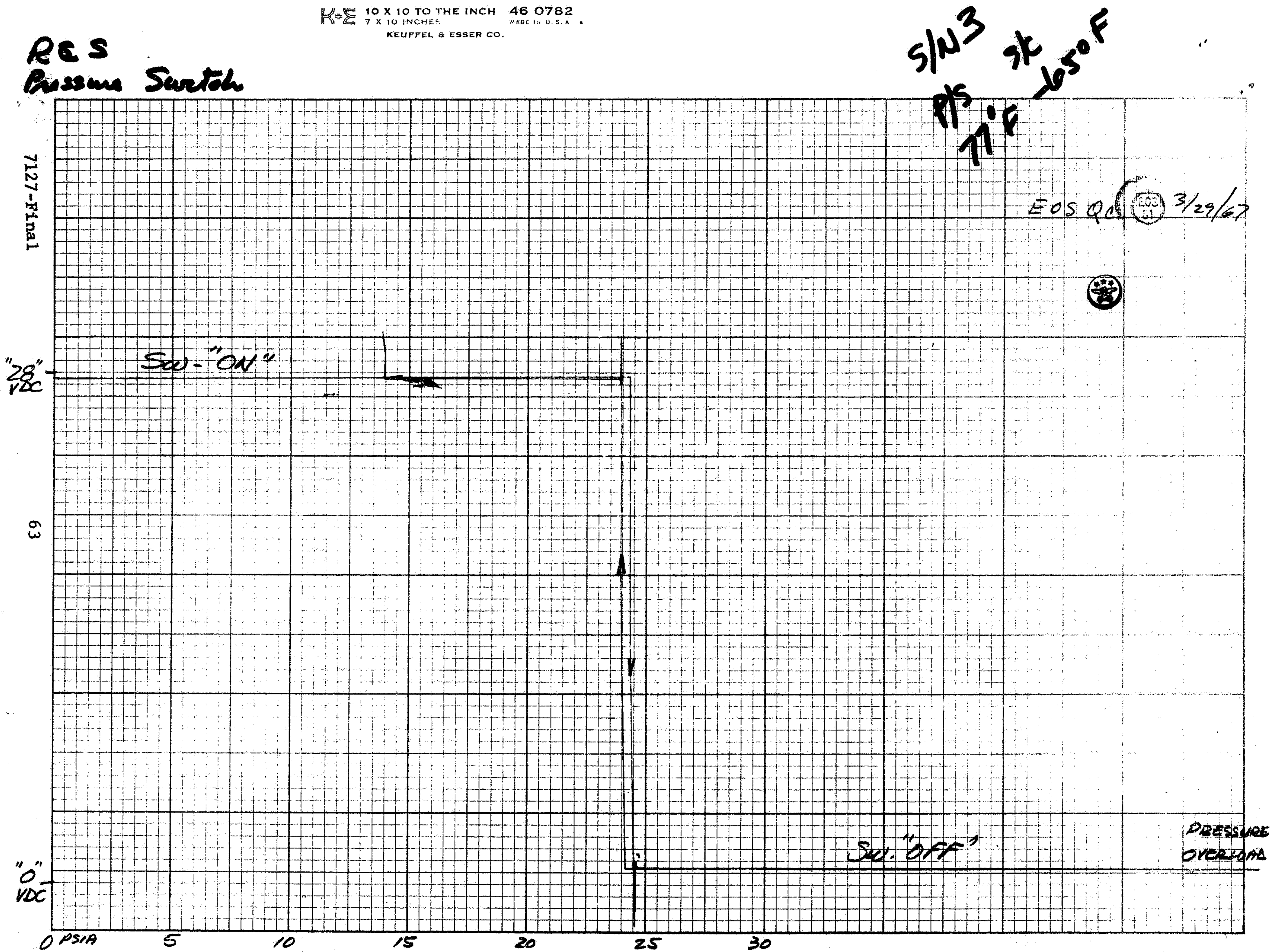


Figure A-3-3. S/N 3

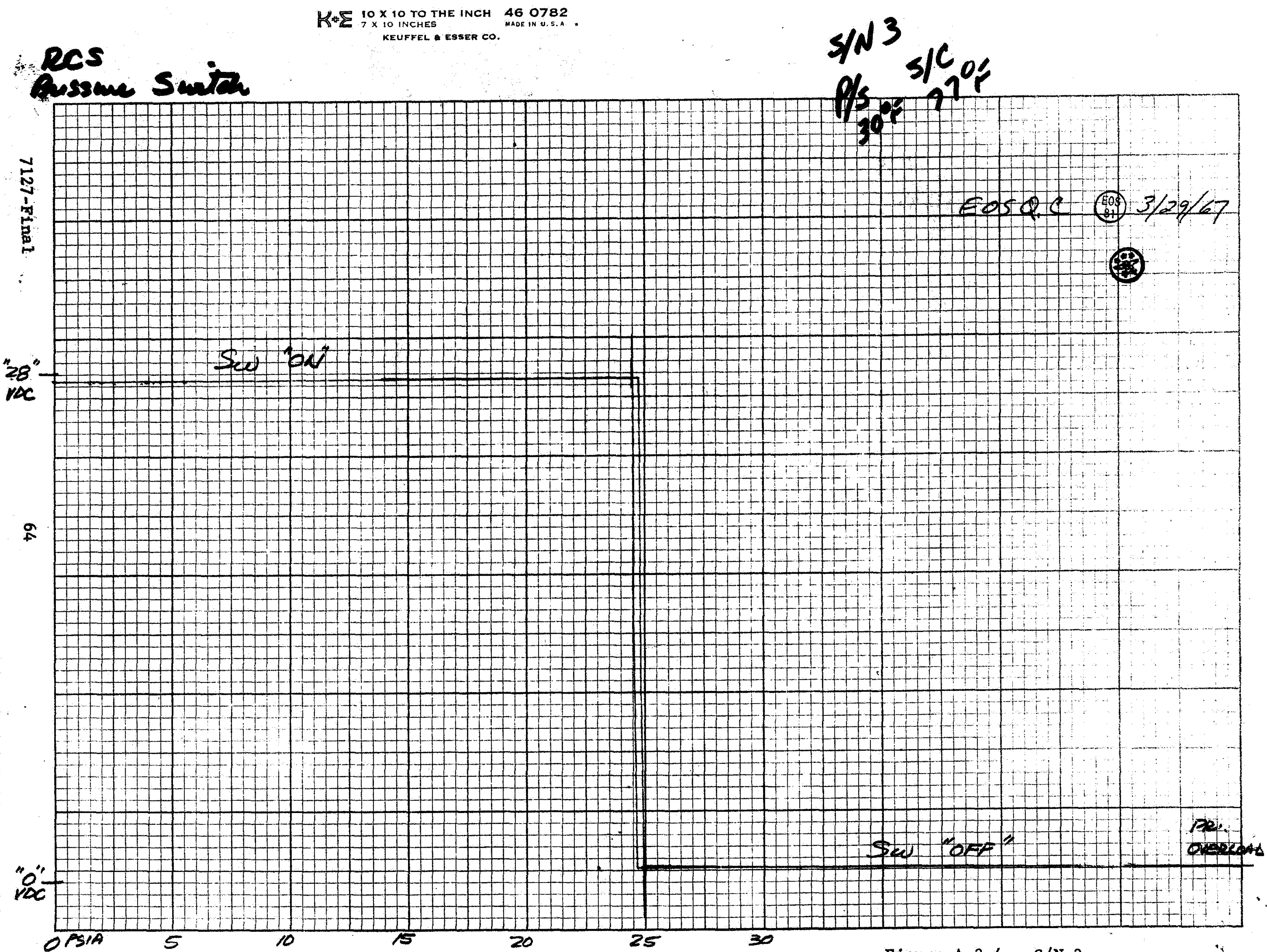


Figure A-3-4. S/N 3

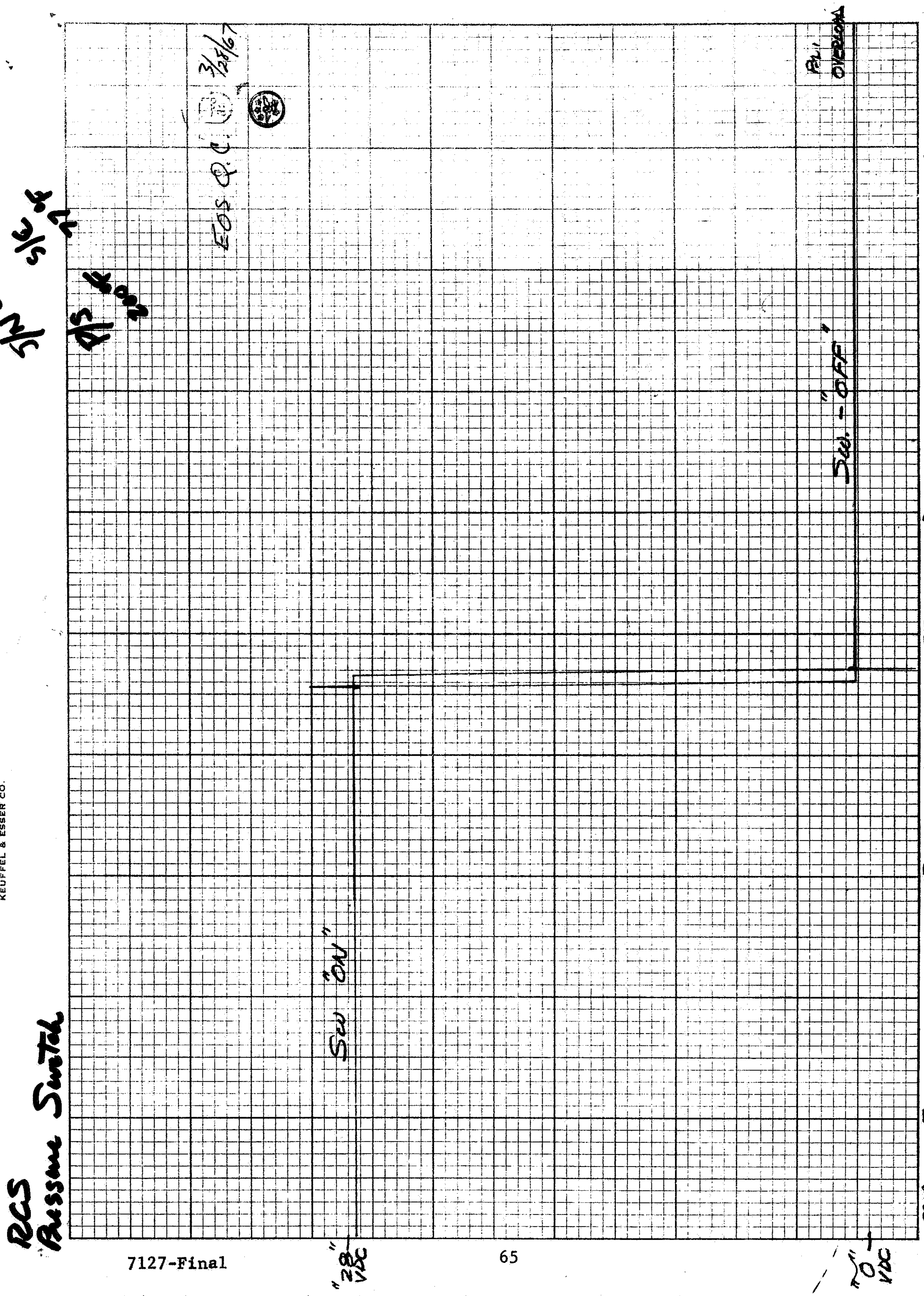


Figure A-3-5. S/N 3

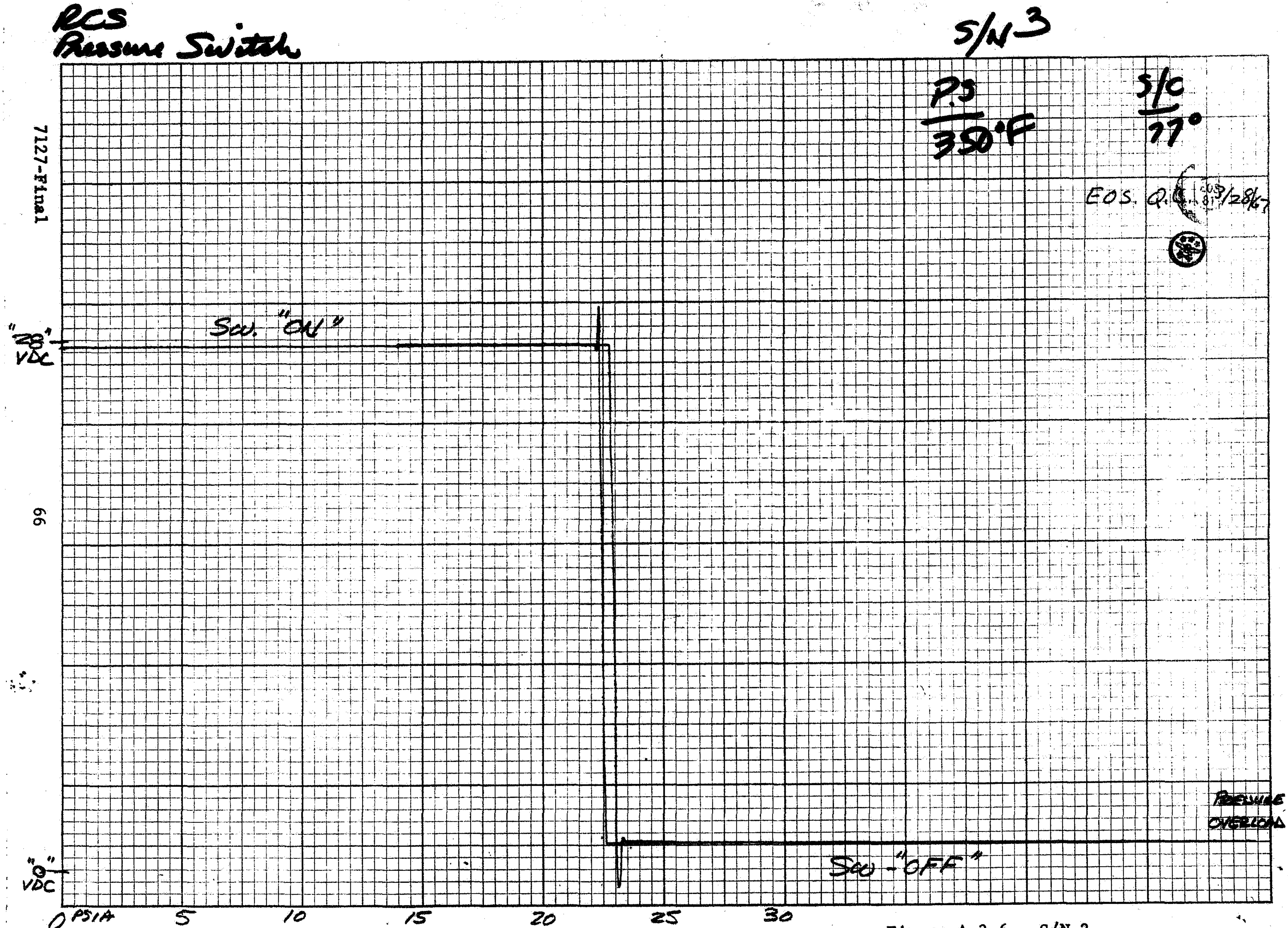


Figure A-3-6. S/N 2

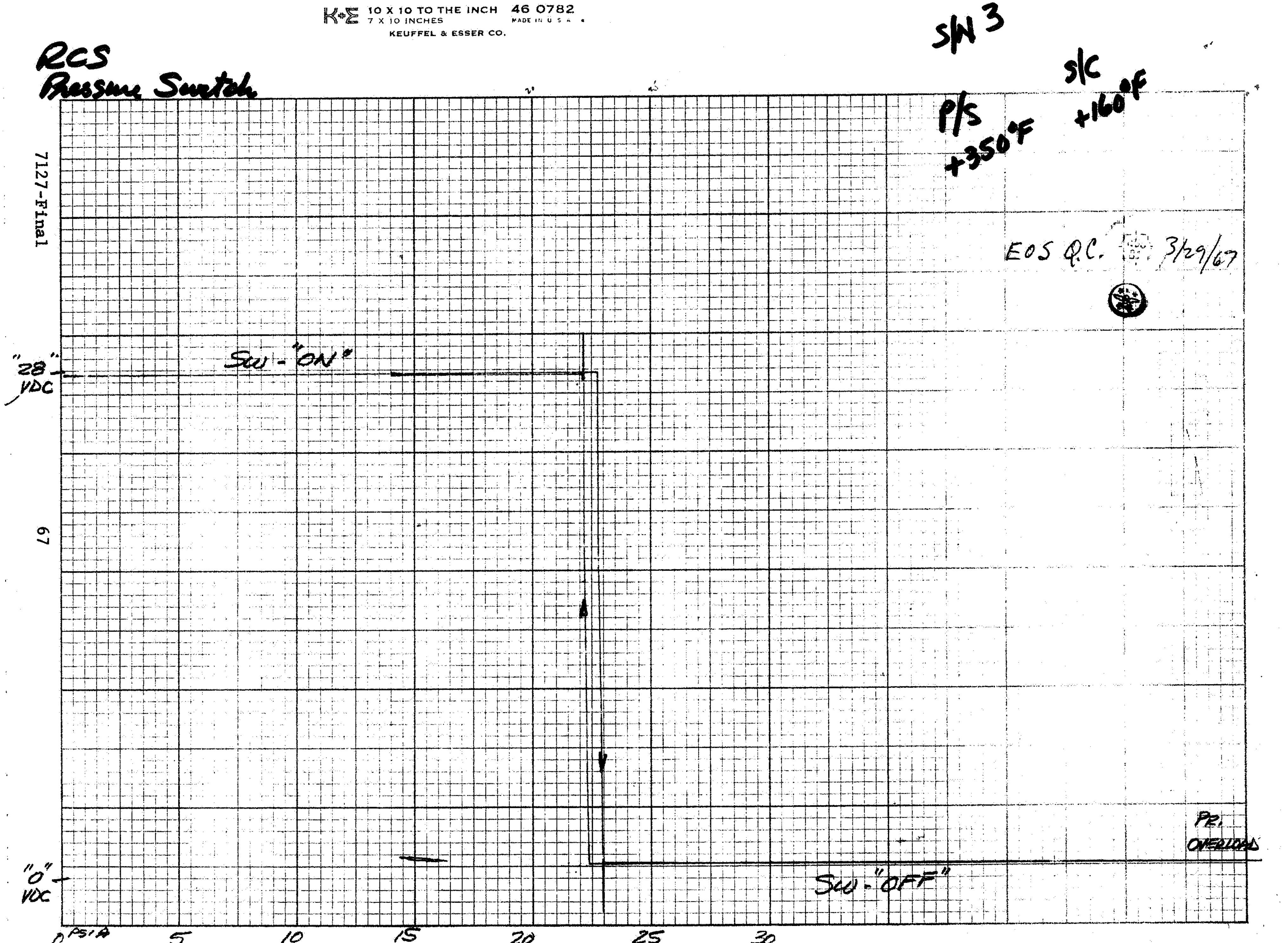


Figure A-3-7. S/N 3

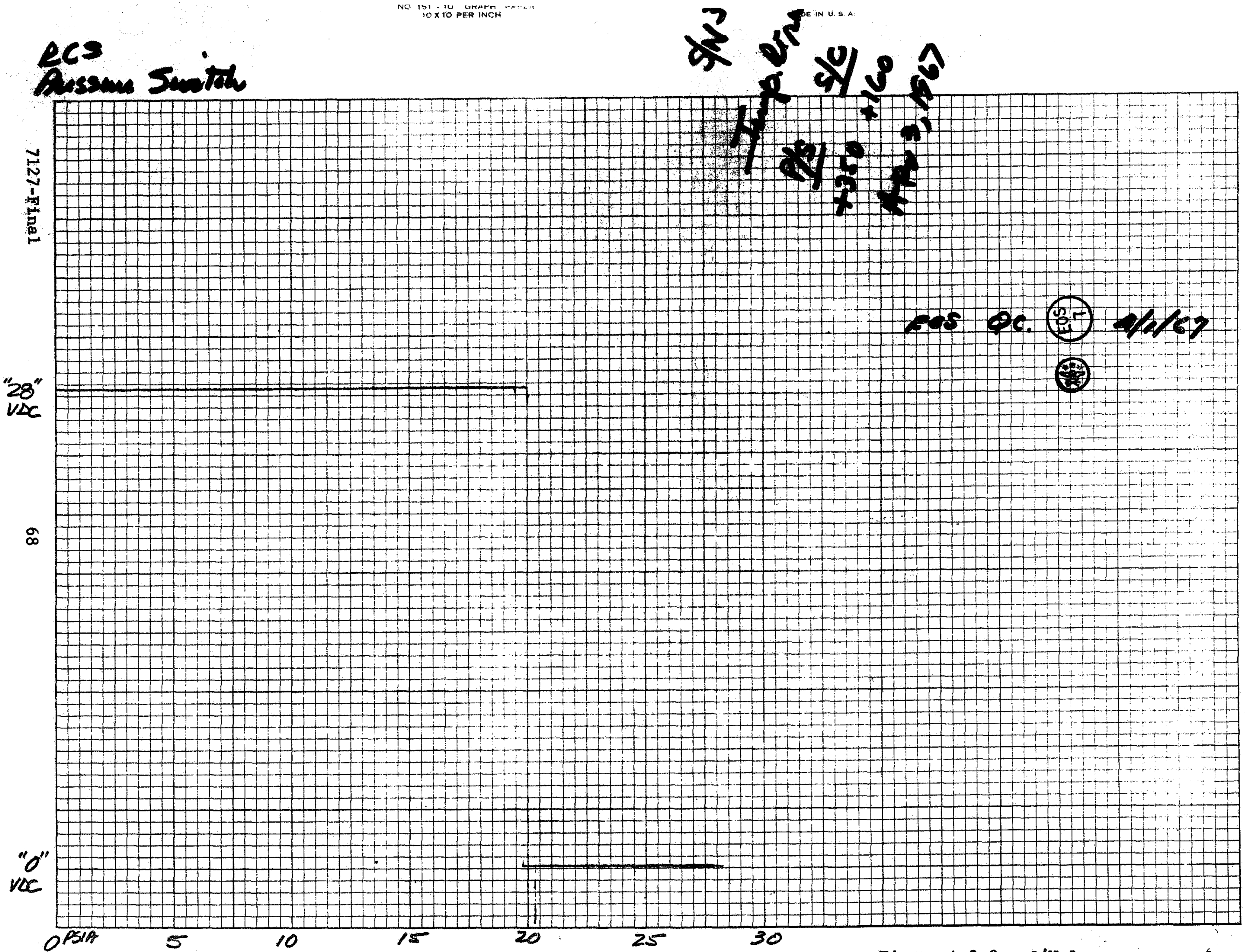


Figure A-3-8. S/N 3

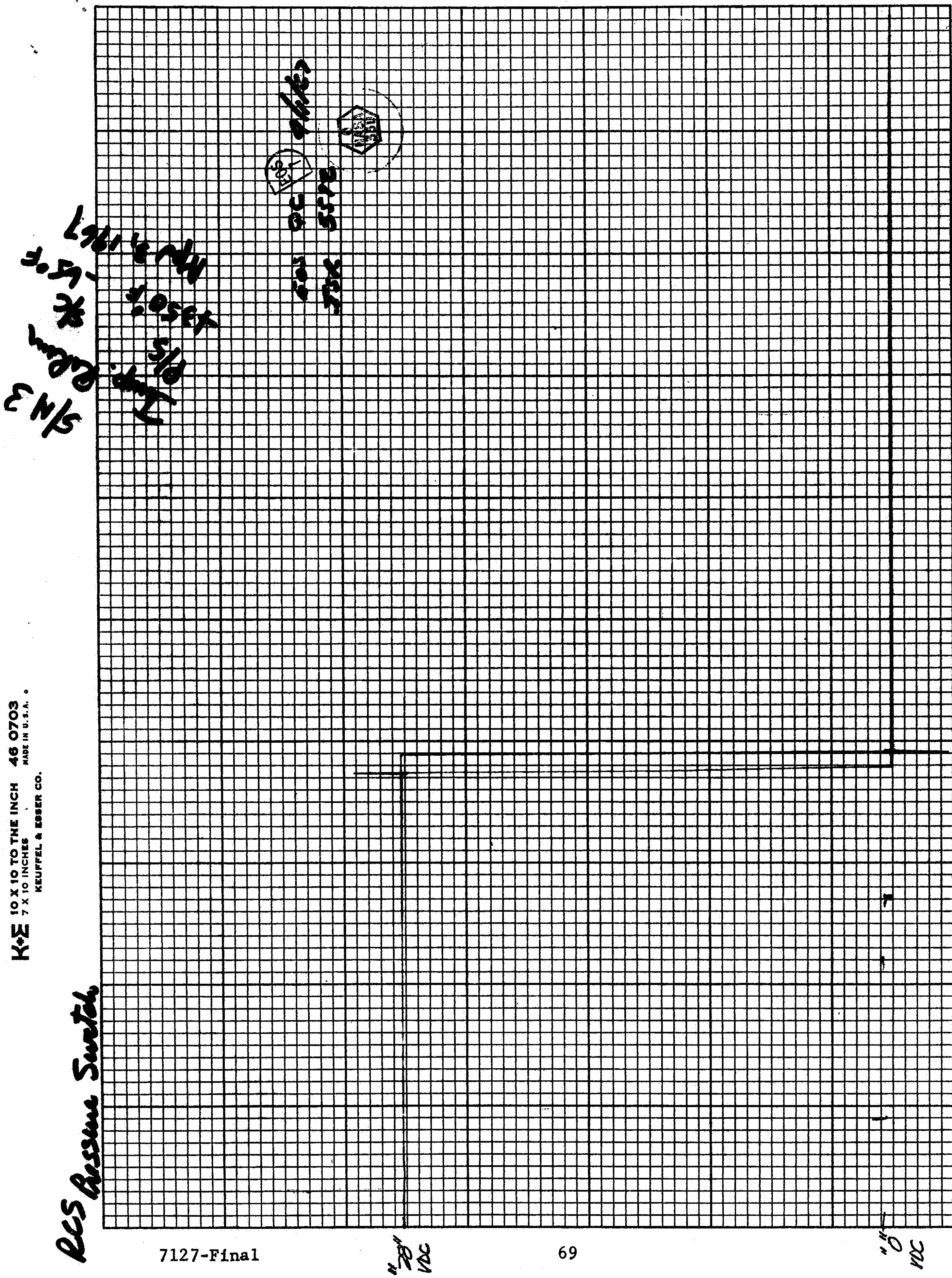


Figure A-3.9. S/N 3

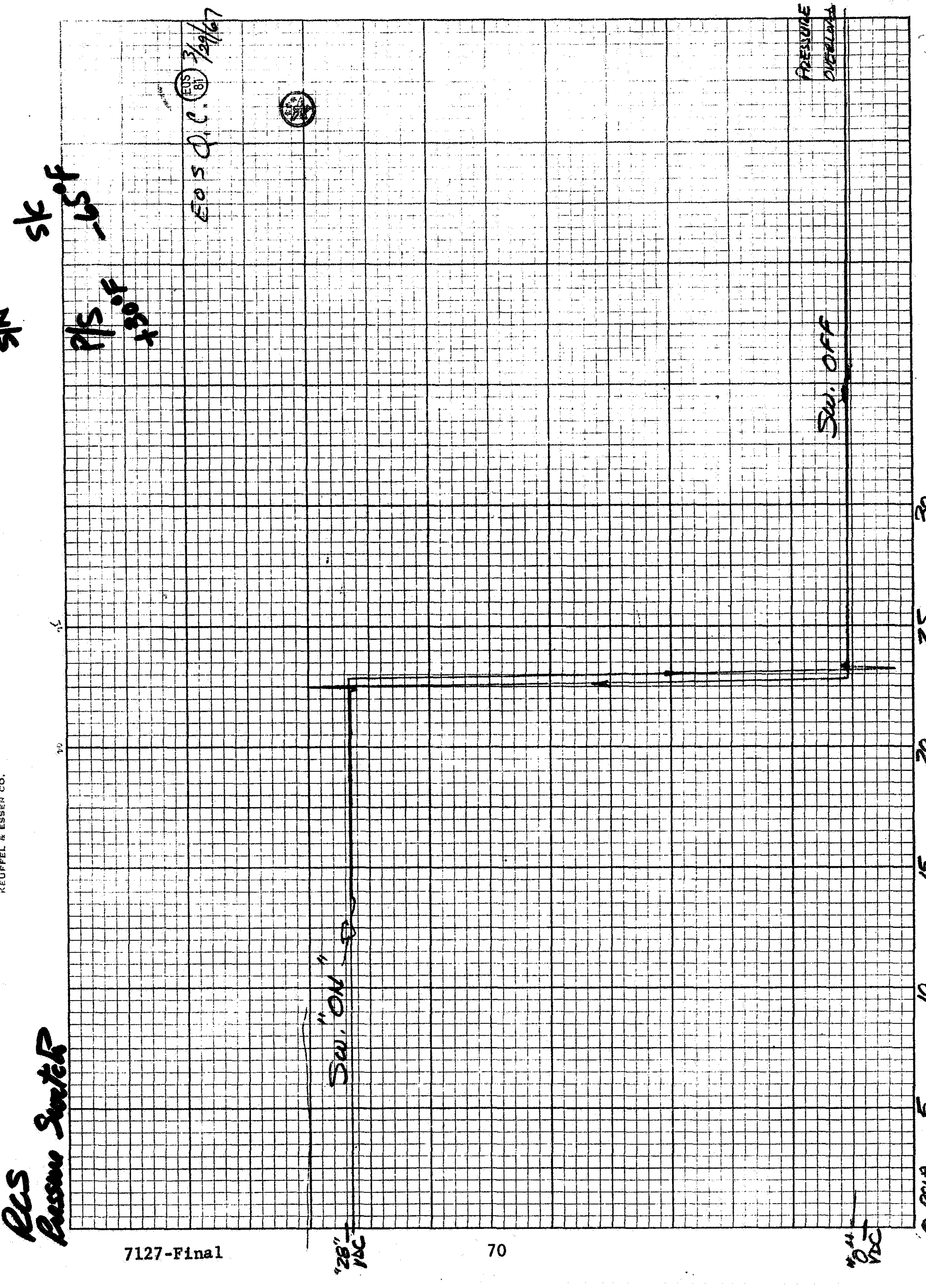

RCS Pressure Switch
Sw. OFF
Sw. "ON"
PRESSURE OVERLOAD
0 PSIA
5
10
15
20
25
30
"28" VDC
"0" VDC
7 X 10 INCHES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

Figure A-4-1.

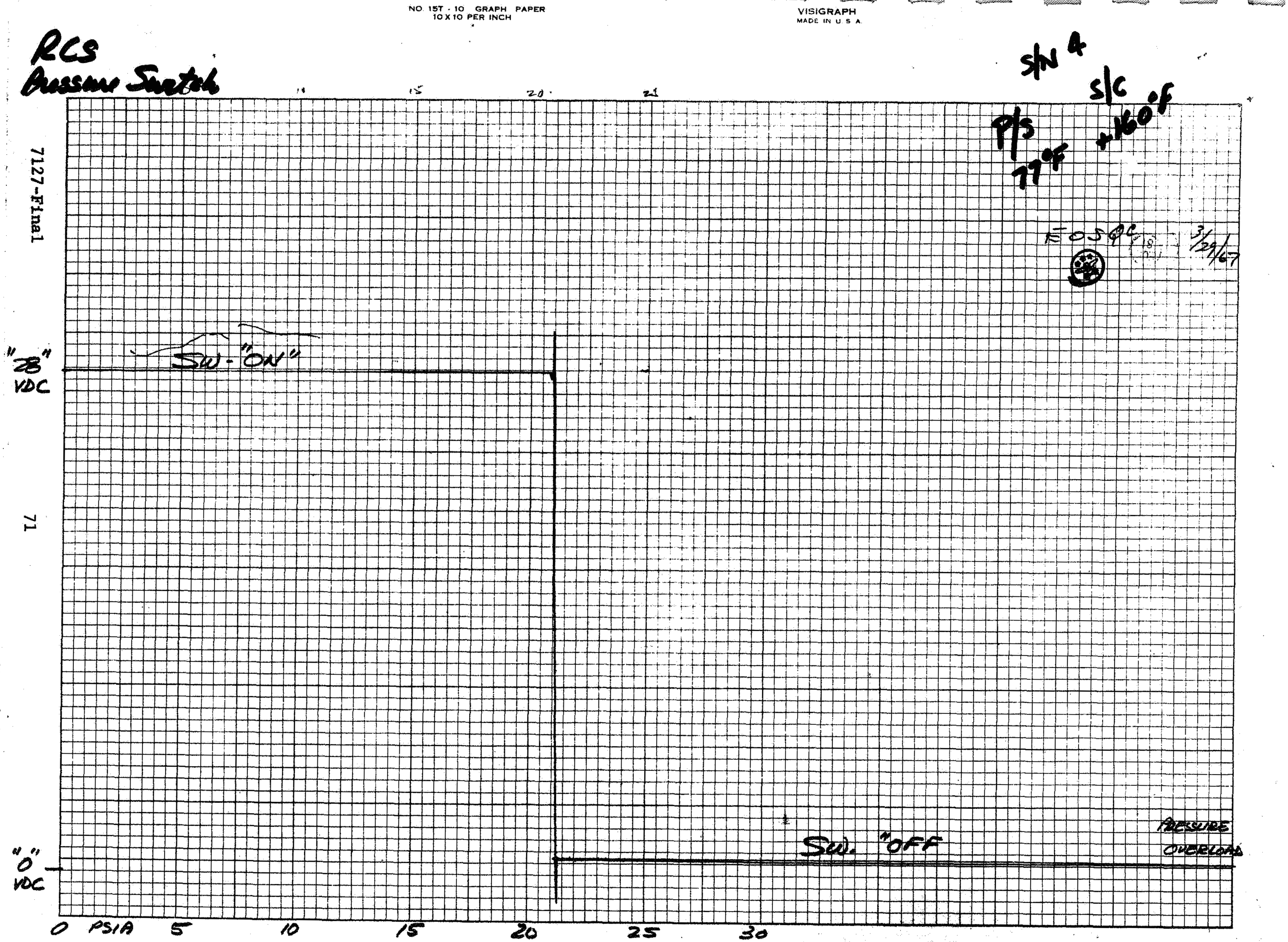


Figure A-4-2. S/N 4

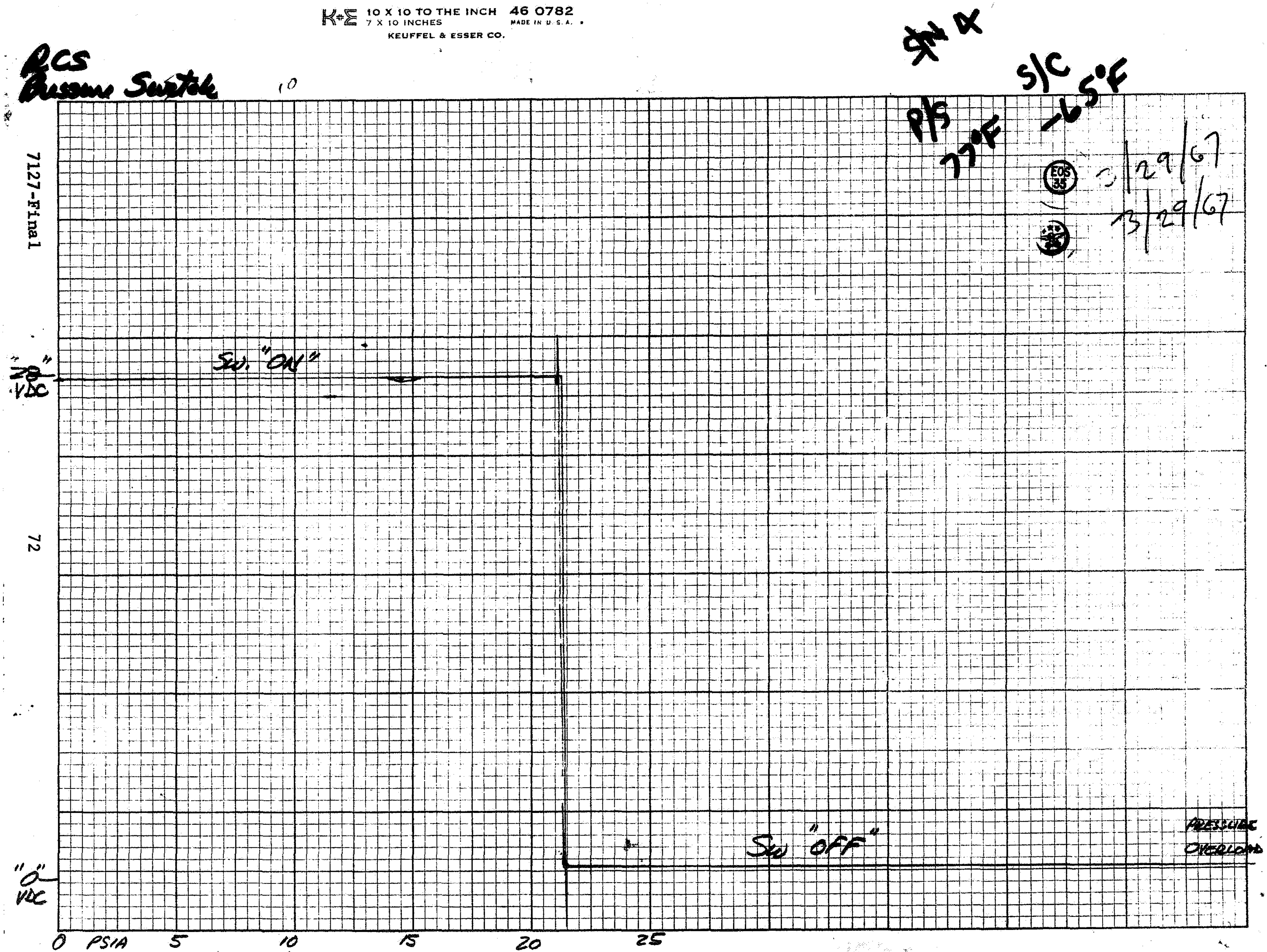


Figure A-4-3. S/N 4

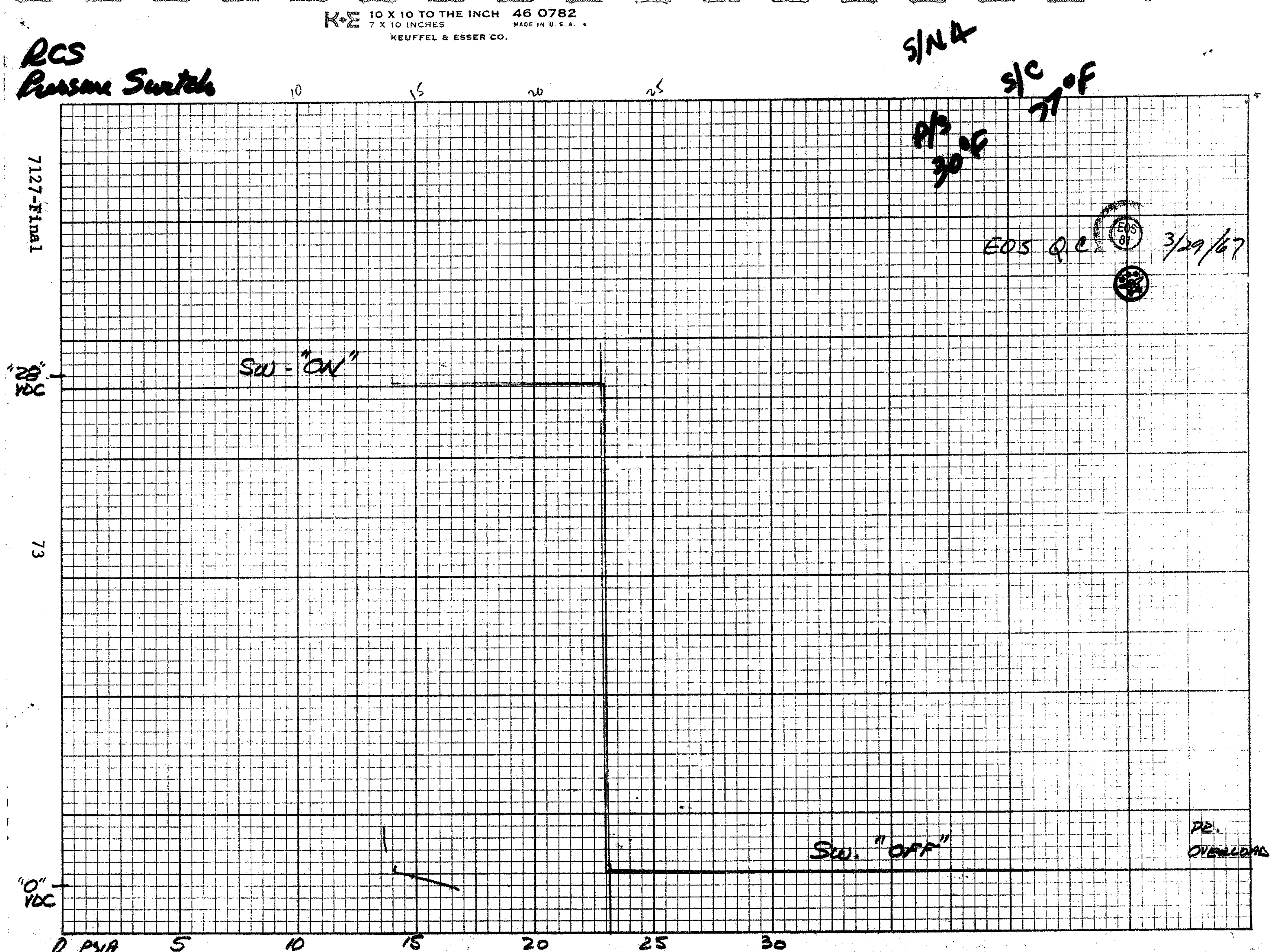


Figure A-4-4. S/N 4

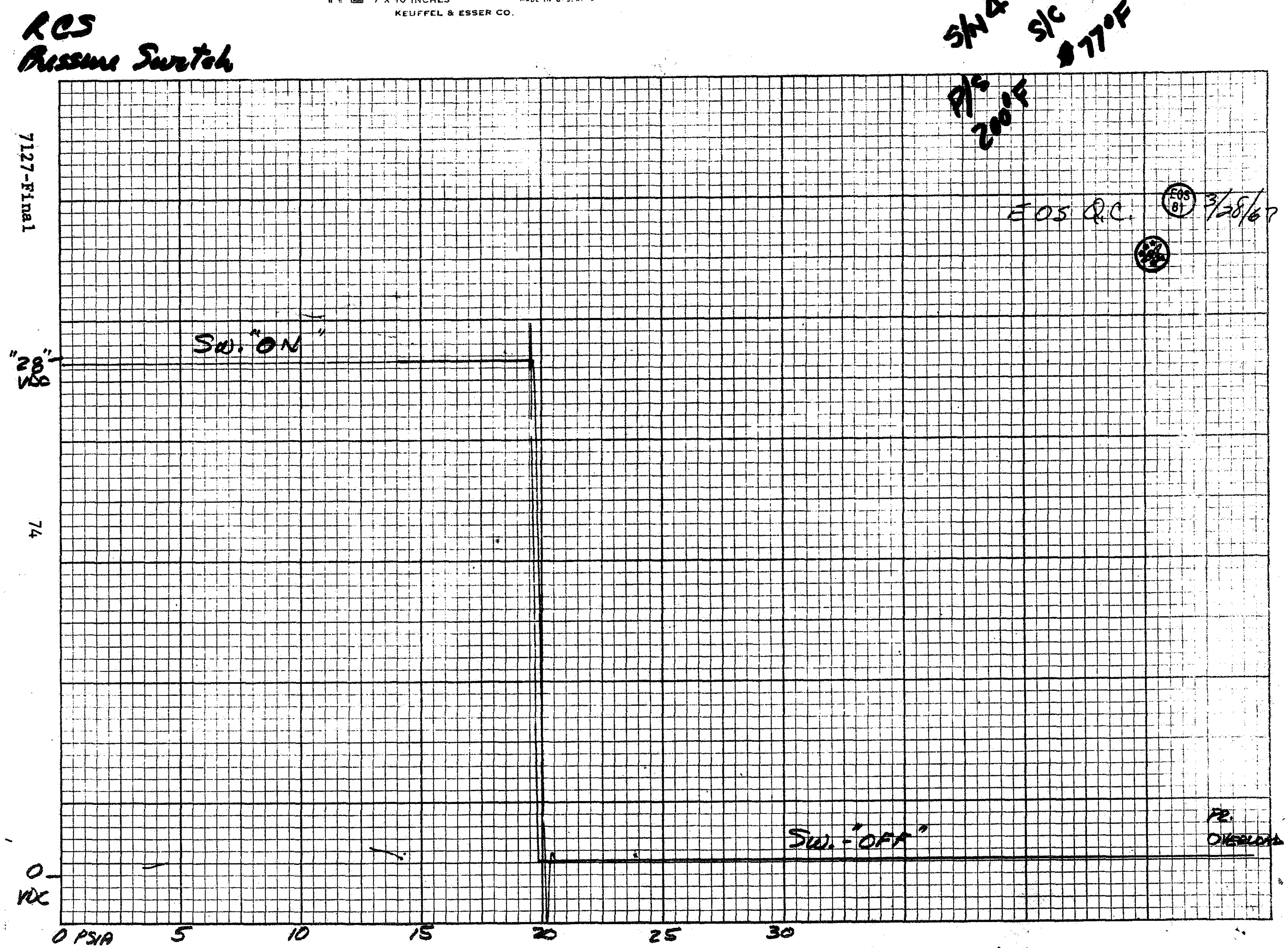


Figure A-4-5. S/N 4

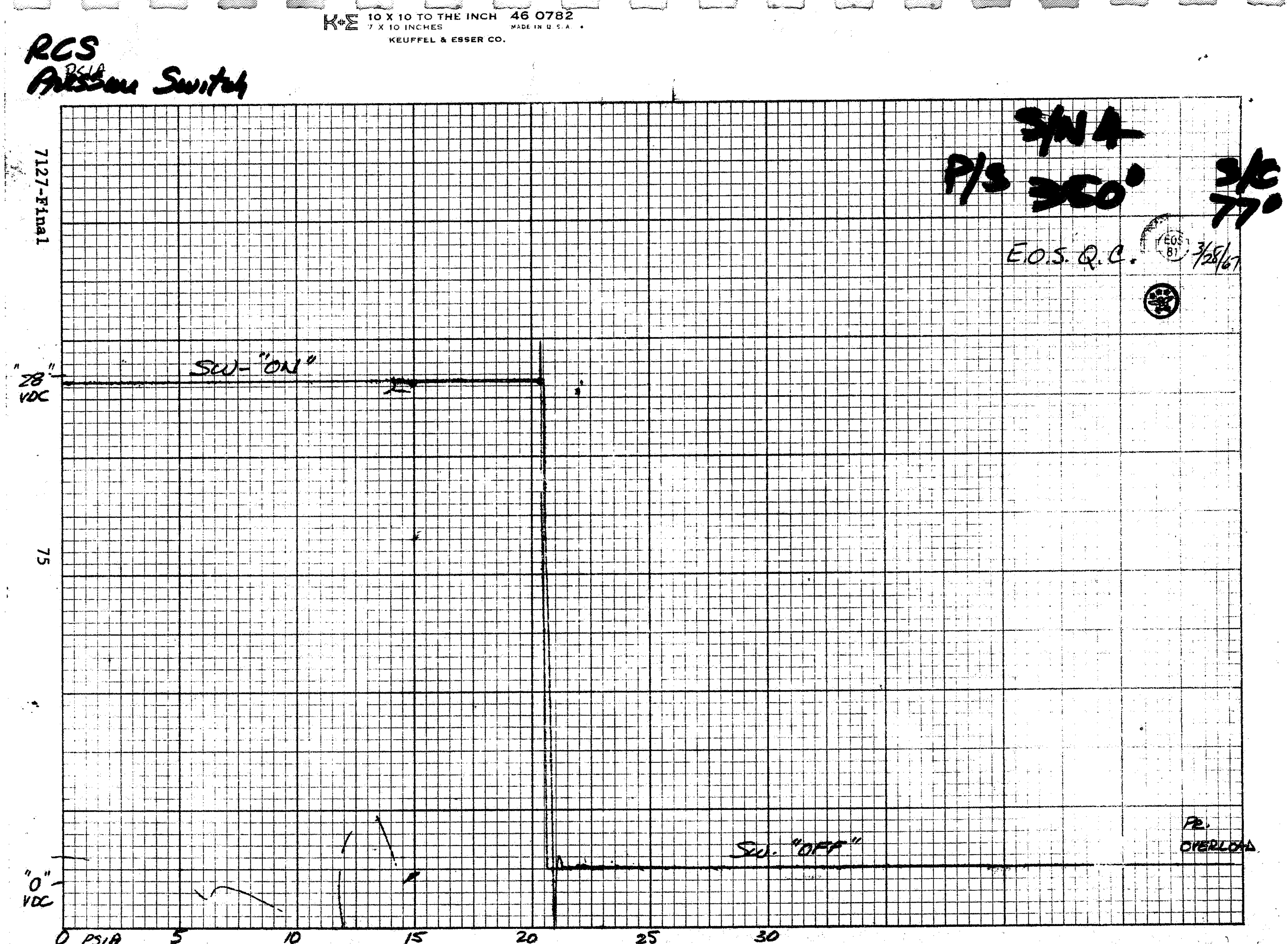
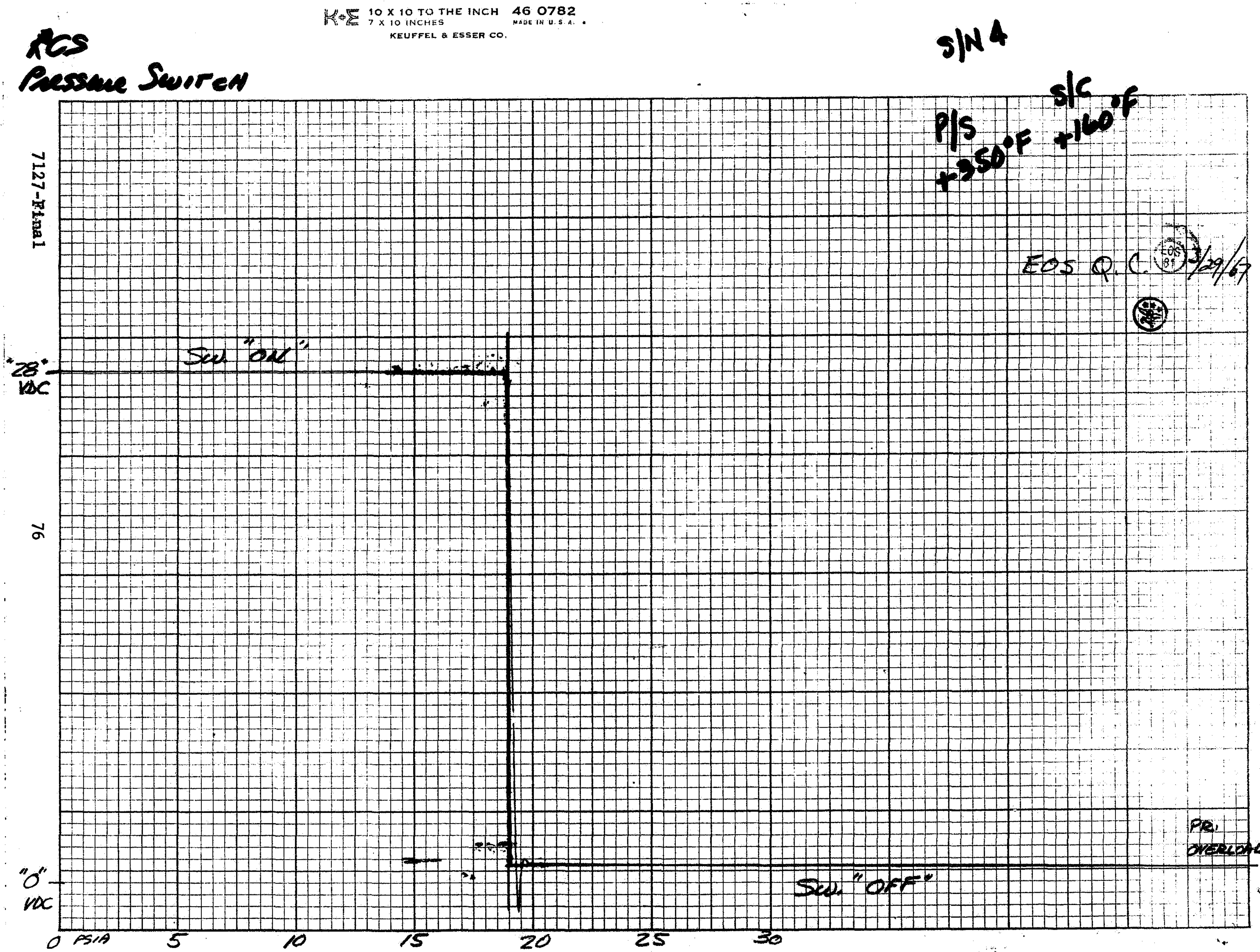


Figure A-4-6. S/N 4



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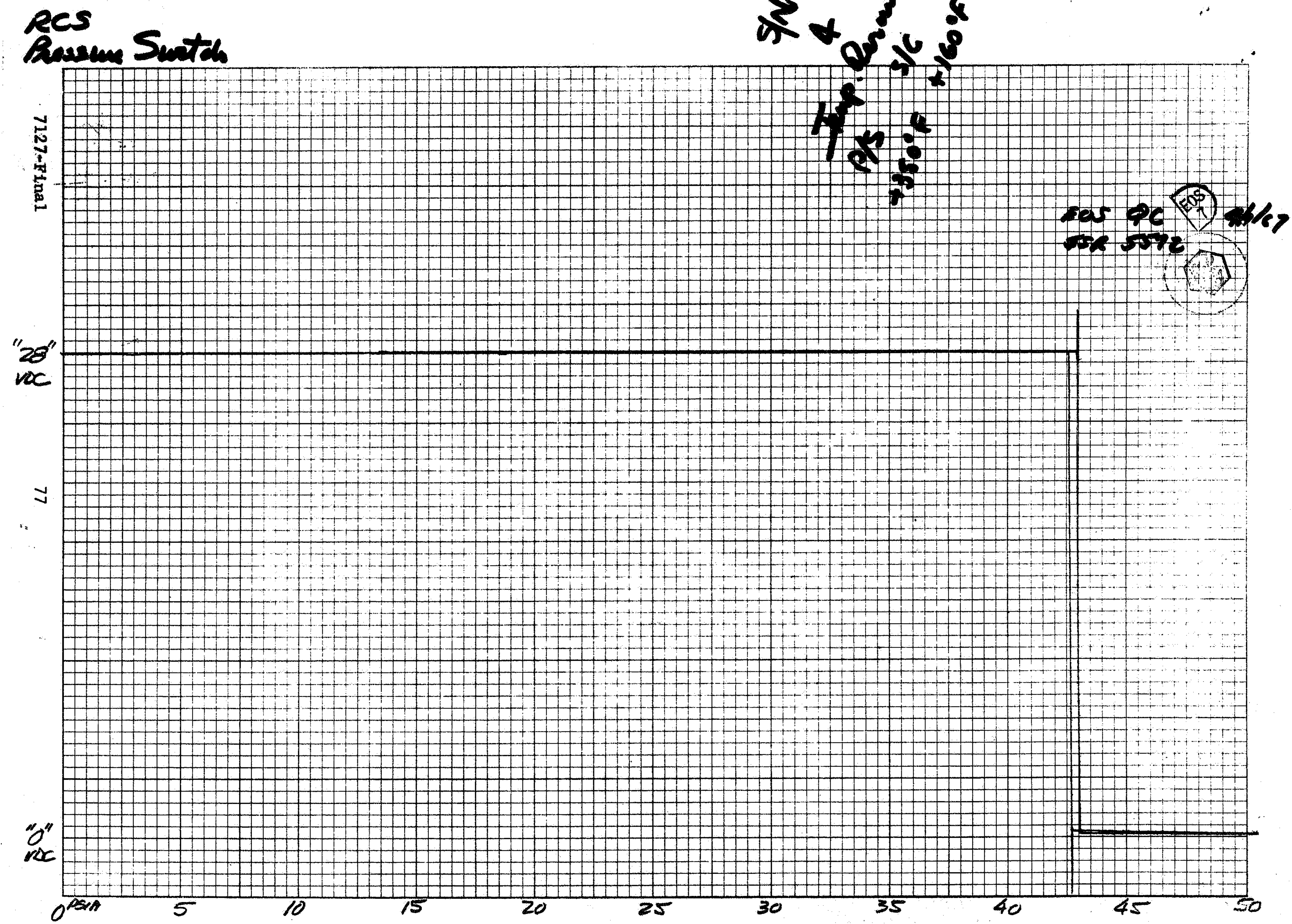

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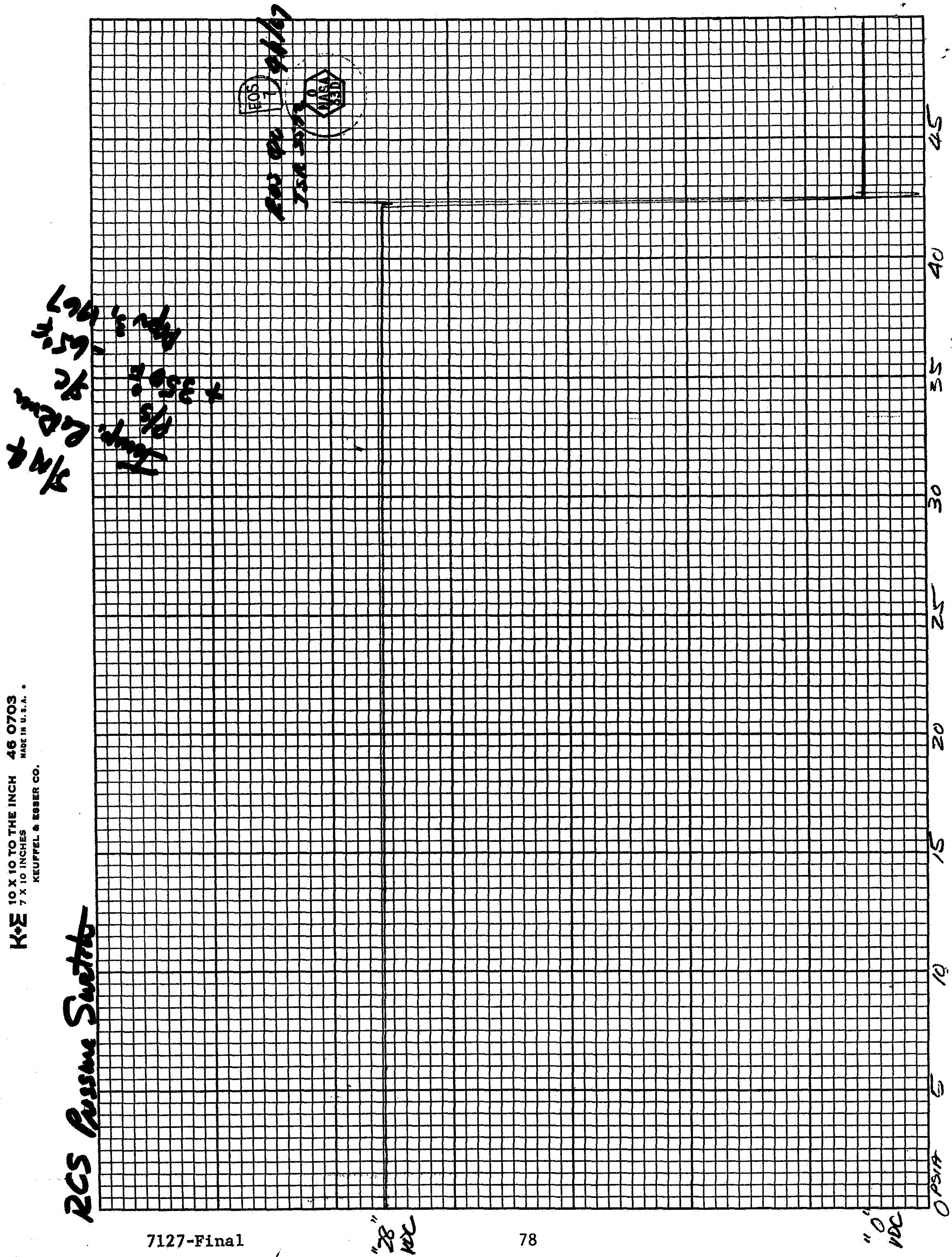

Figure A-4-9. S/N 4

APPENDIX B

EFFECTS OF GROSS OVERPRESSURIZATION ON SWITCH POINT 10 CYCLES OF 5000 PSI

S/N 1 Figs.	S/N 2 Figs.
B-1-1	B-2-1
B-1-2	B-2-2

S/N 3 Figs.	S/N 4 Figs.
B-3-1	B-4-1
B-3-2	B-4-2

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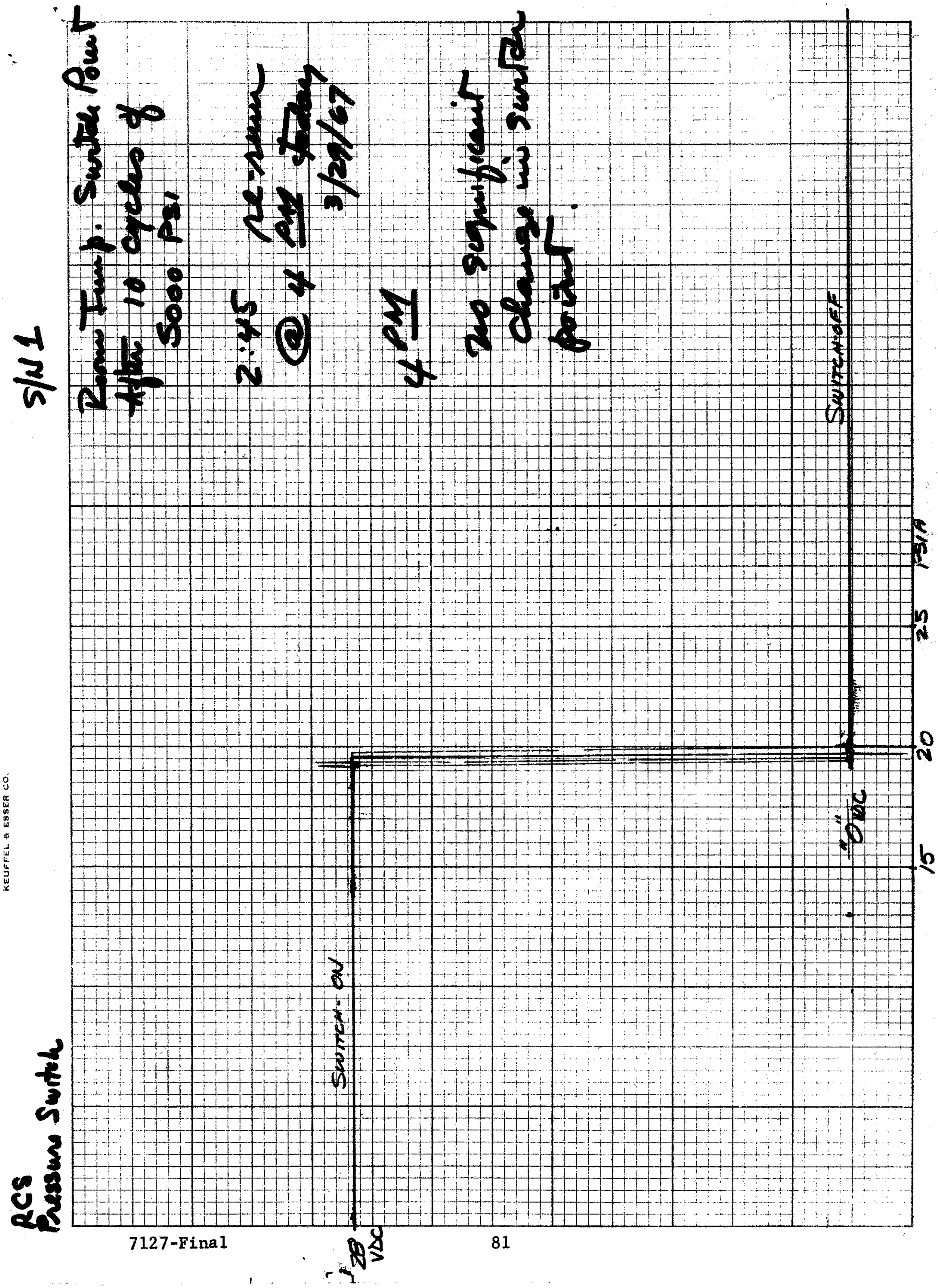


Figure B-1-1. S/N 1

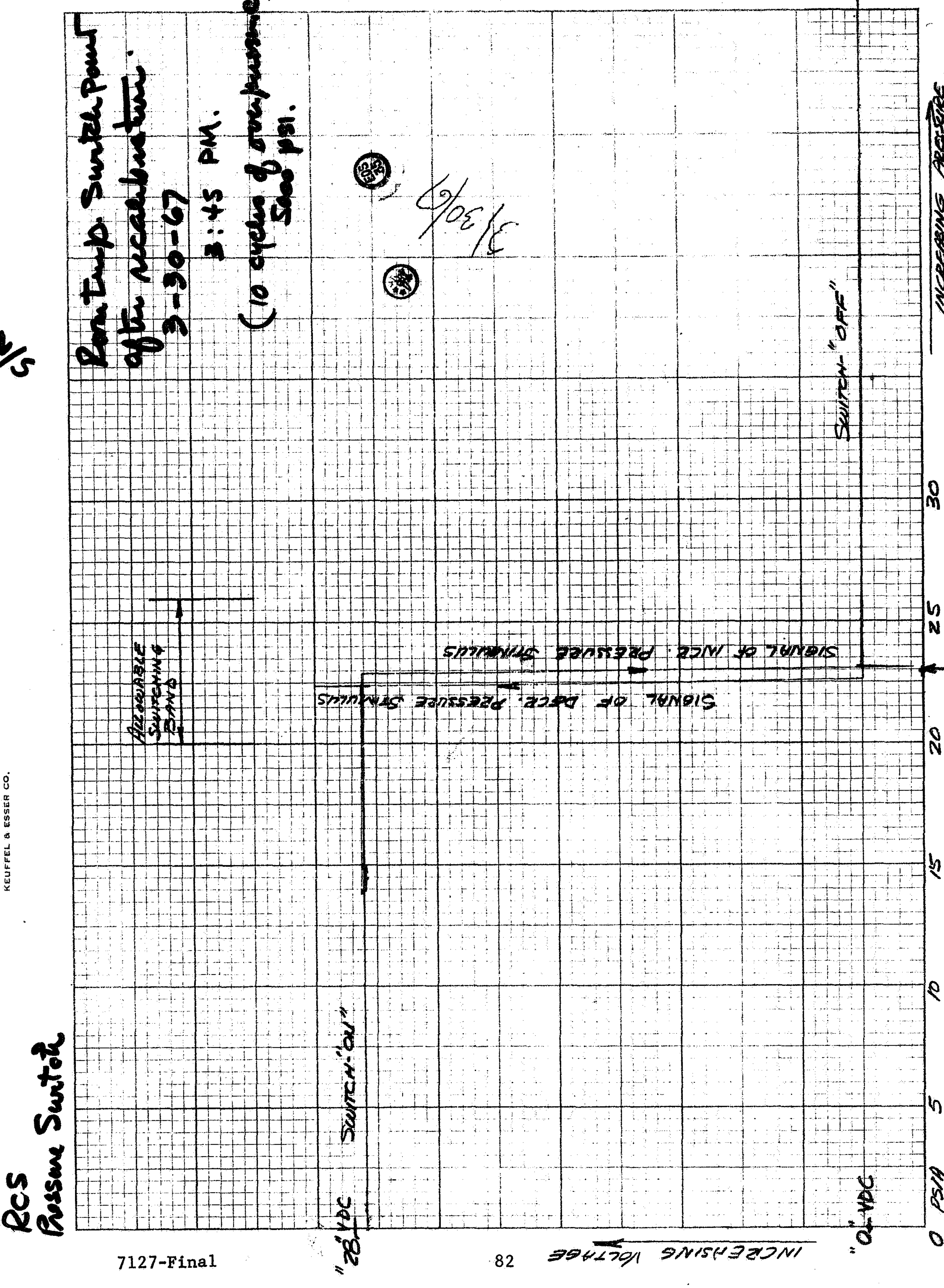


Figure B-1-2. S/N 1

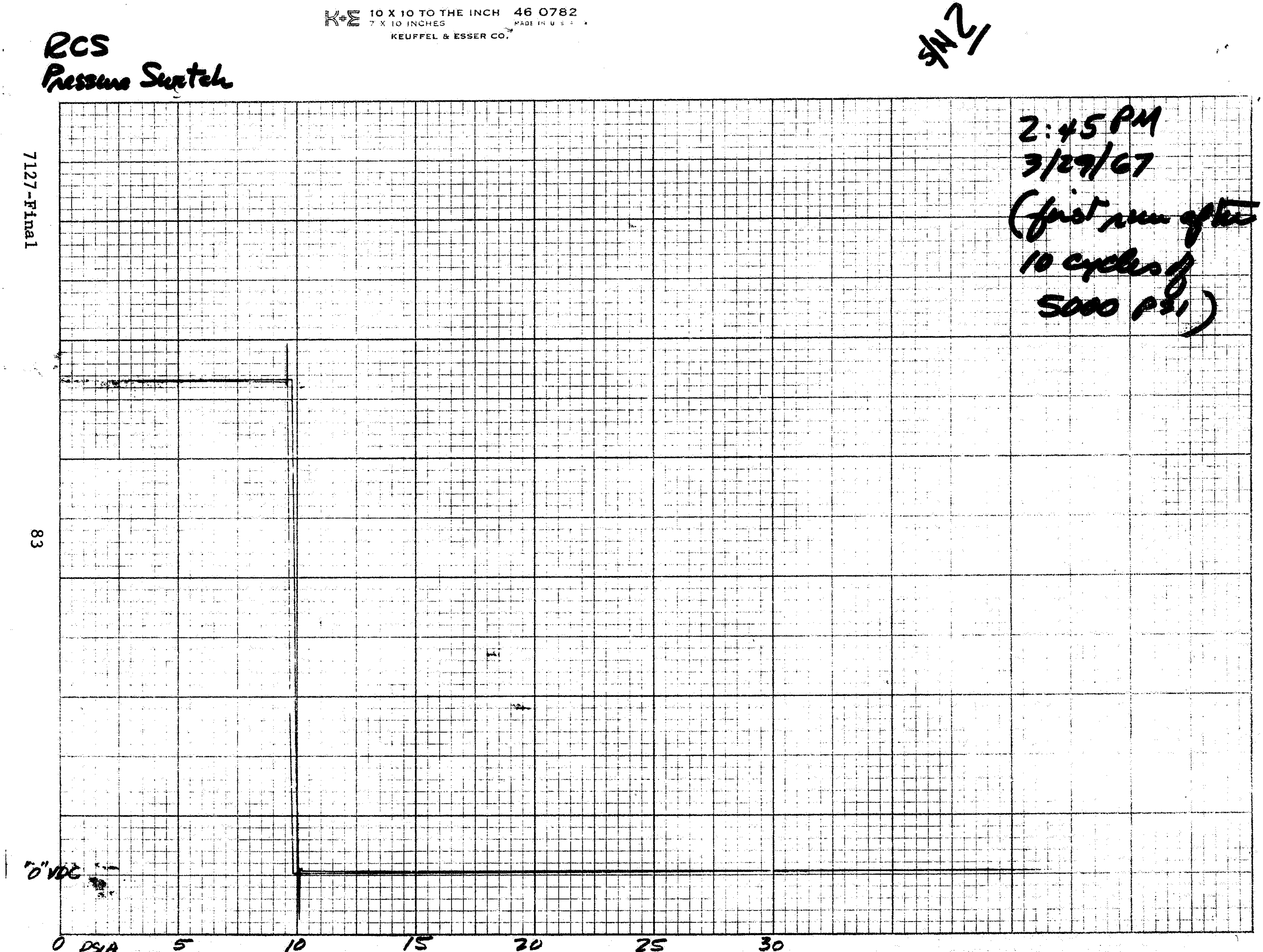


Figure B-2-1. S/N 2

RCS
Pressure Switch

10 X 10 TO THE INCH 46 0782
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

S/N 2

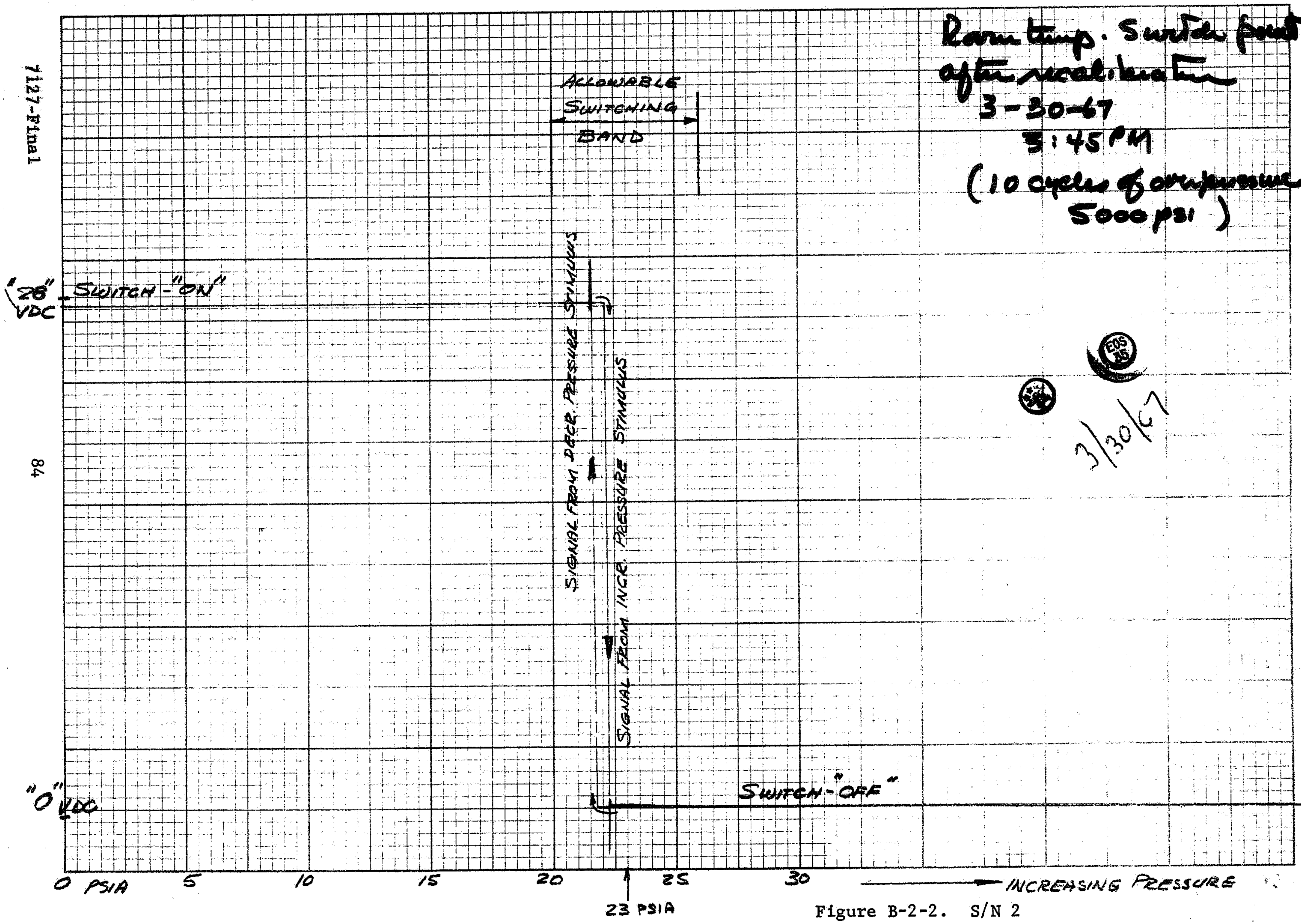


Figure B-2-2. S/N 2

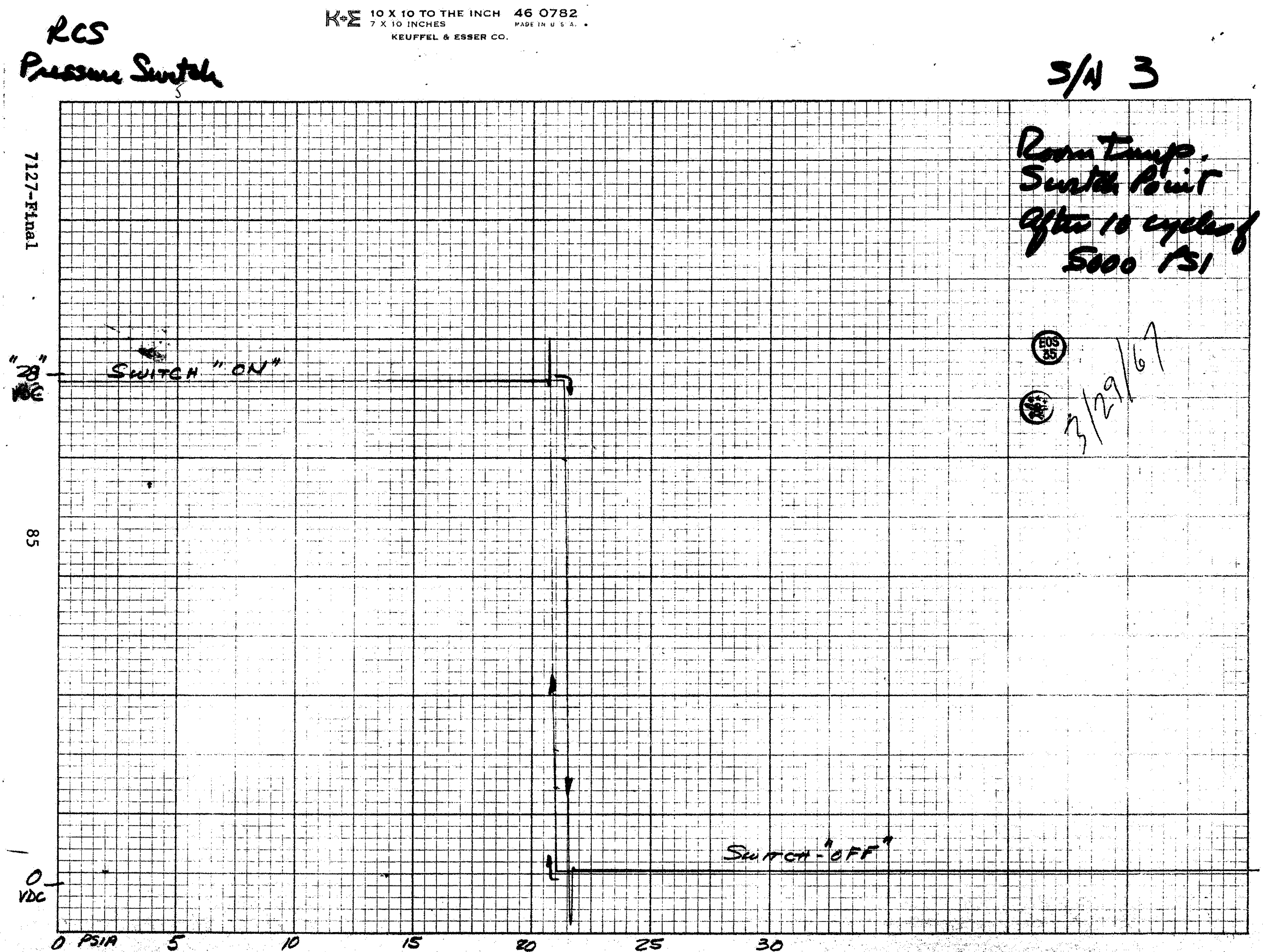


Figure B-3-1. S/N 3

RCS
Pressure Switch

S/N 3

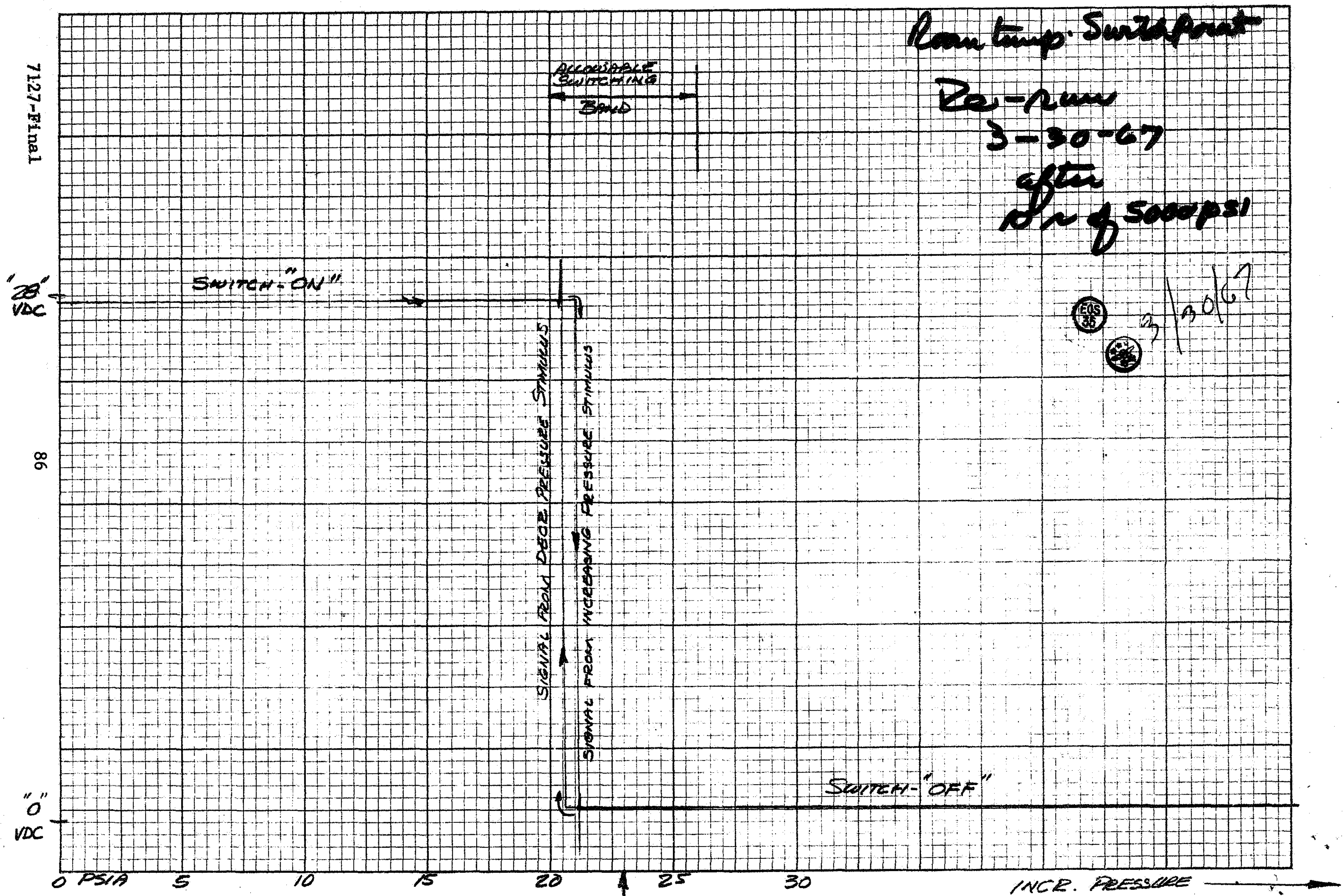


Figure B-3-2. S/N 3

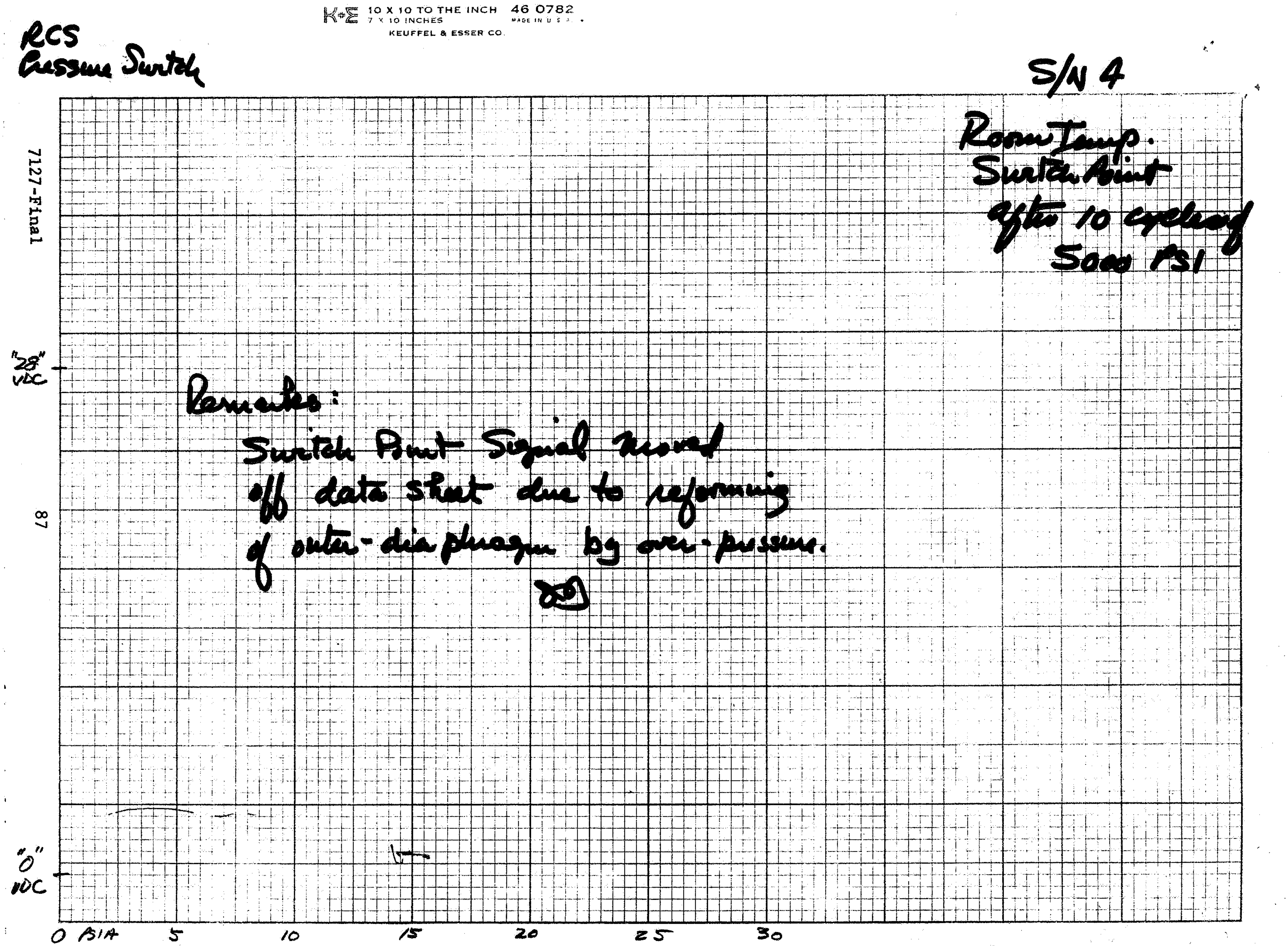


Figure B-4-1. S/N 4

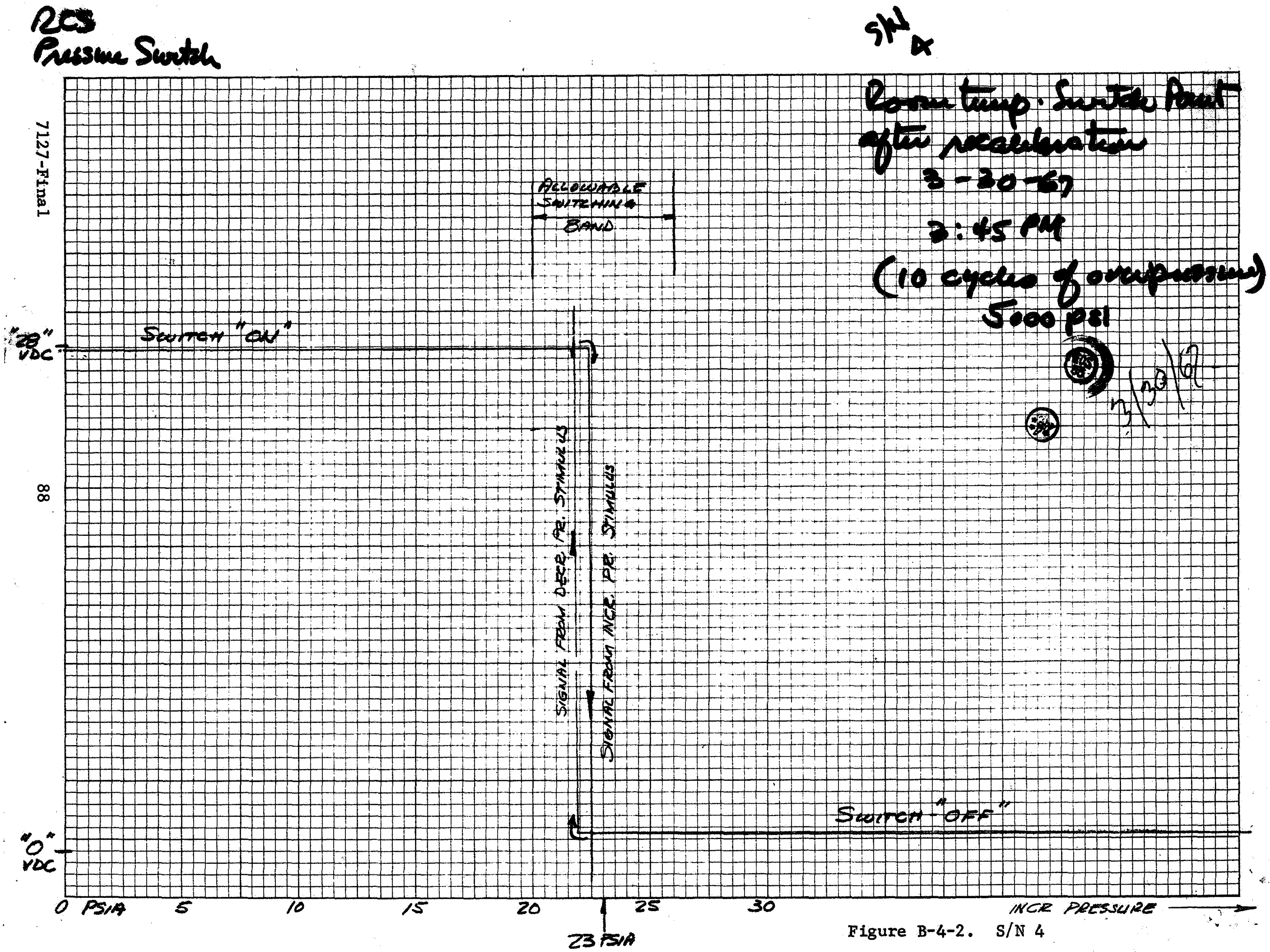


Figure B-4-2. S/N 4

APPENDIX C

EFFECTS OF SUPPLY VOLTAGE VARIATION UPON SWITCH POINT

S/N 1 — Fig. C-1-1

S/N 2 — Fig. C-2-1

S/N 3 — Fig. C-3-1

S/N 4 — Fig. C-4-1

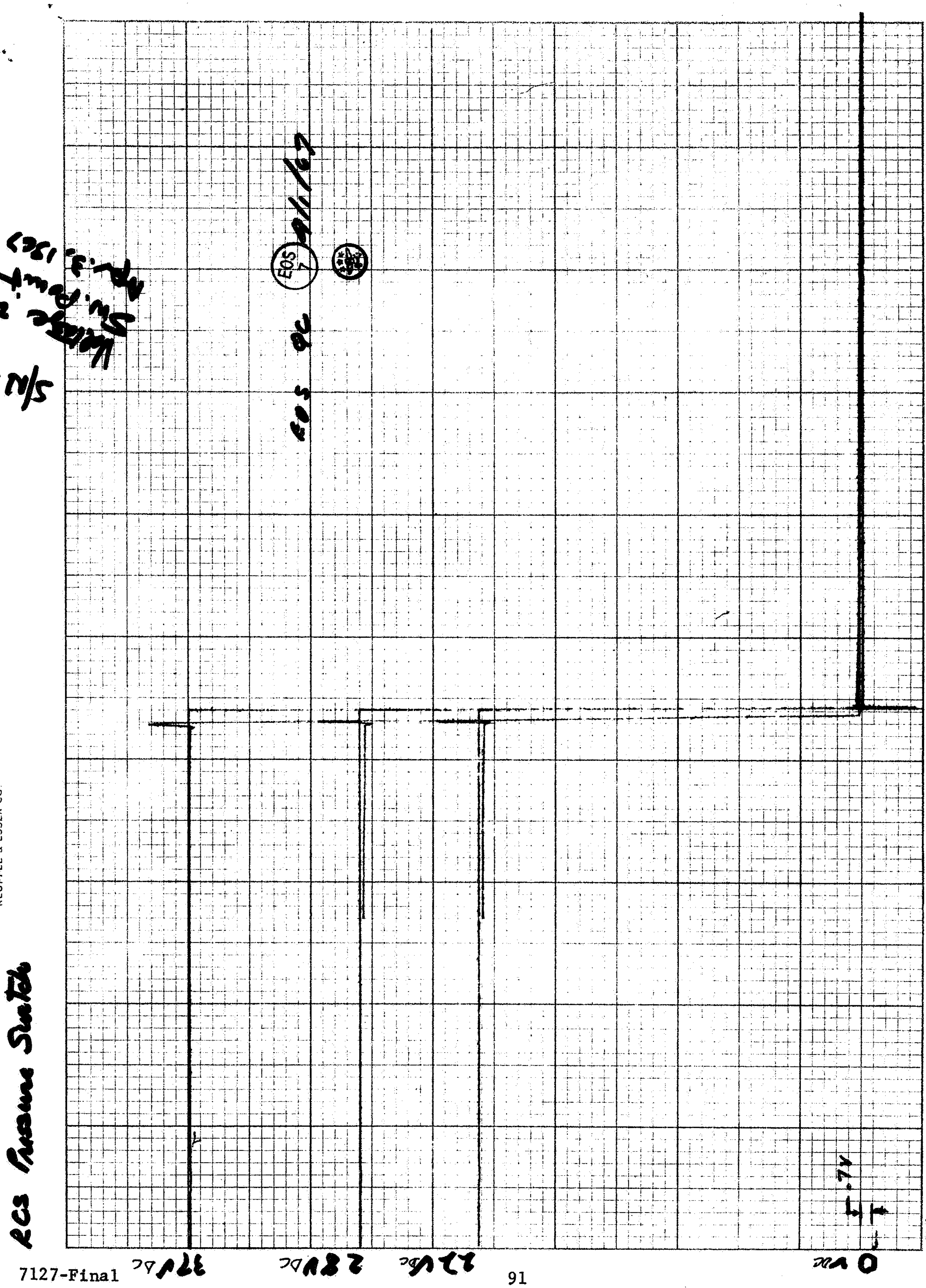


Figure C-1-1. S/N 1

Figure C-2-1. S/N 2

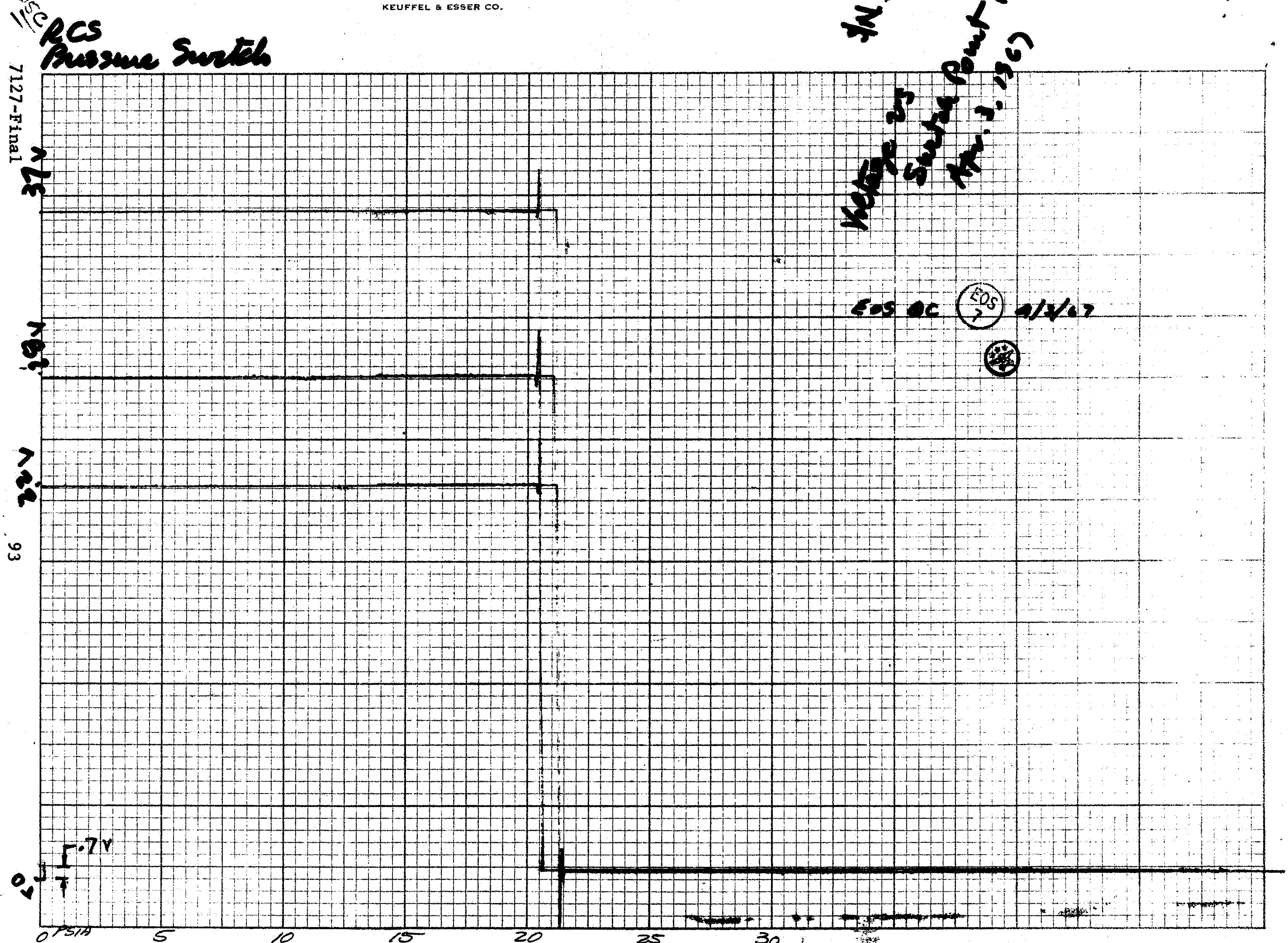


Figure C-3-1. S/N 3

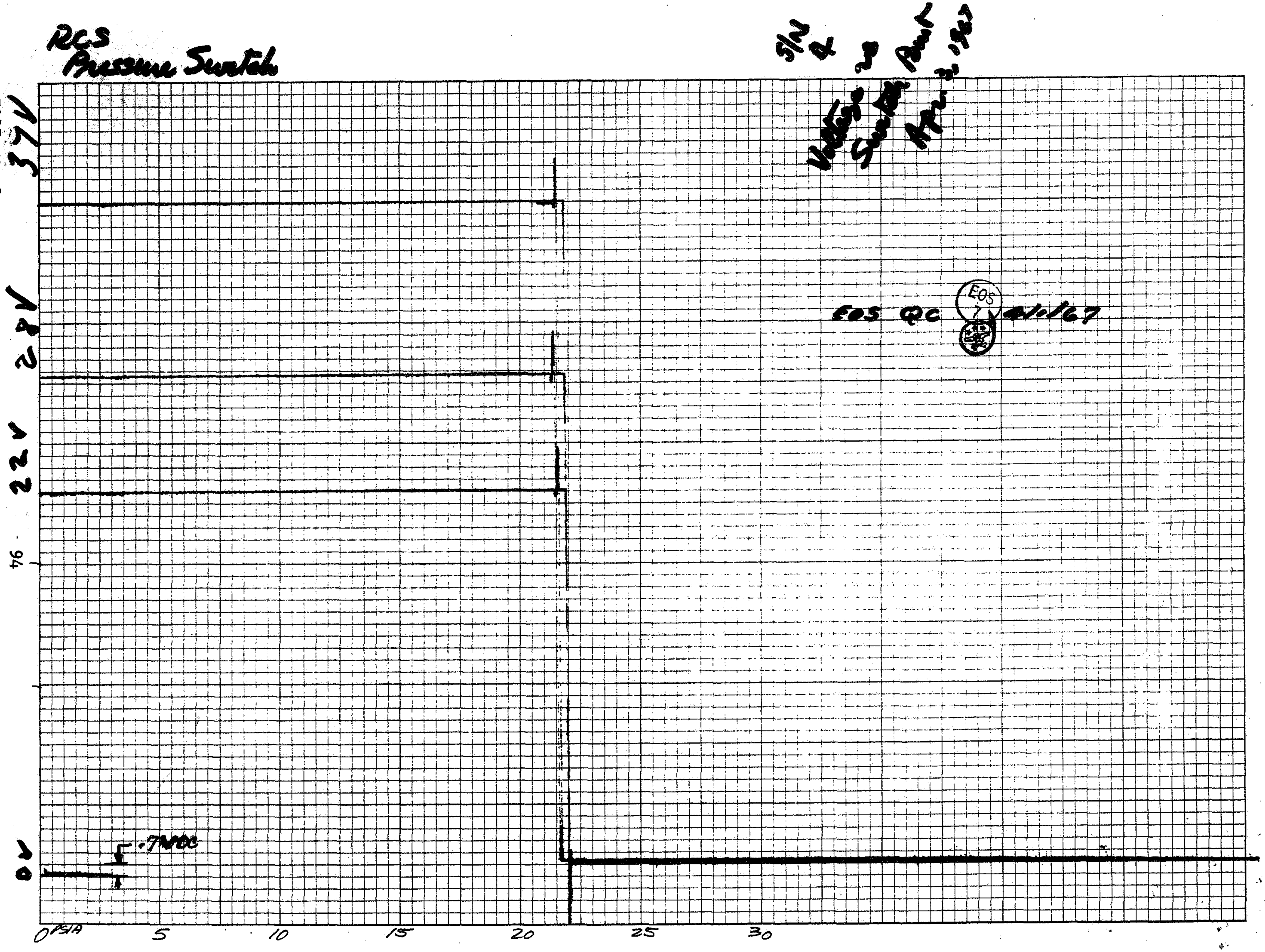


Figure C-4-1. S/N 4

APPENDIX D

RCS PRESSURE SWITCH S/N 4

D-1. VIBRATORY ACCELERATION LOADING REQUIREMENTS

1. Vibration (random and sinusoidal to be used sequentially) random and sinusoidal motion will be applied sequentially along each of three mutually perpendicular axes.

   1.1 Random spectra are referenced to a log-log plot and held to a ±30 percent power spectral density.

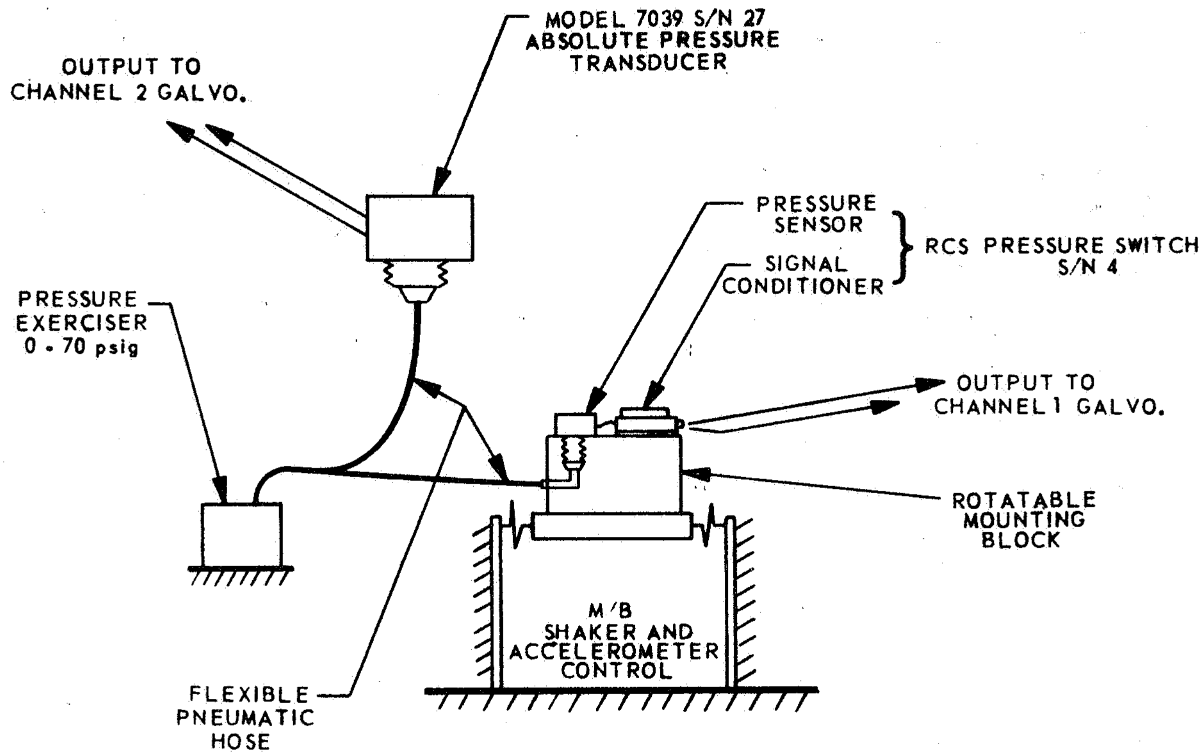
   12.3g rms for five minutes

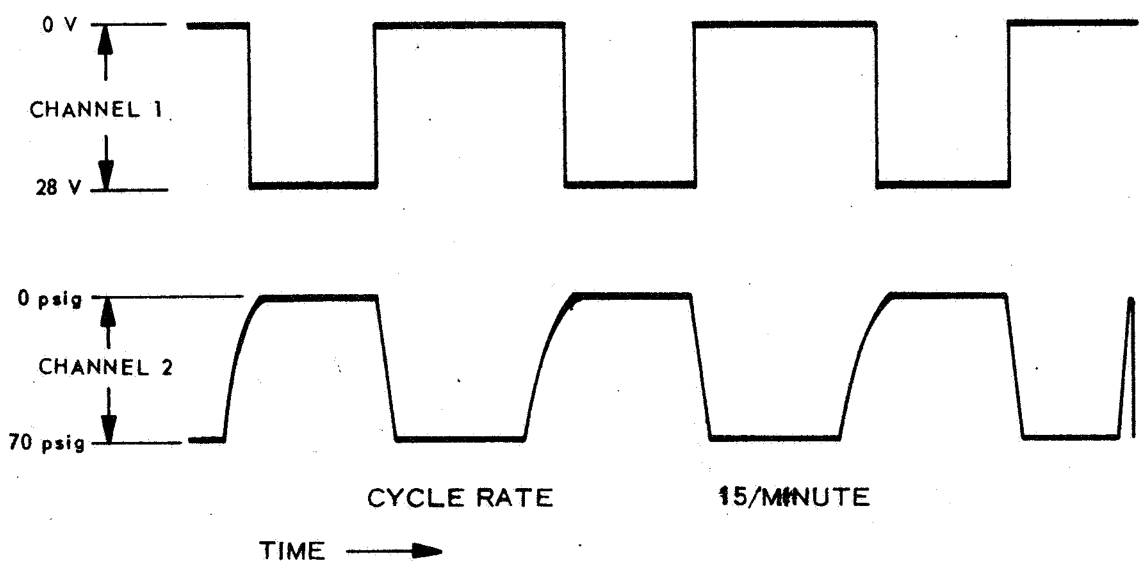
10 Hz		0.01 g^2/Hz
10- 75 Hz	linear increase to	0.14 g^2/Hz
75- 200 Hz	constant	0.14 g^2/Hz
200-2000 Hz	linear decrease to	0.05 g^2/Hz

   1.2 Sinusoidal vibration frequency shall be swept logarithmically from 5 Hz to 2000 Hz to 5 Hz at one-half octave per minute for 2 sweep cycles.

0.20 inch DA	5-16 Hz
2.5g	16-90 Hz
0.006 inch DA	90-140 Hz
6.0g	140-350 Hz
0.001 inch DA	350-500 Hz
11g	500-2000 Hz

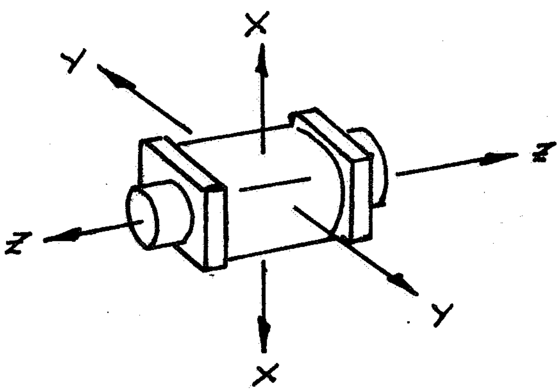
D-2. TEST SETUP

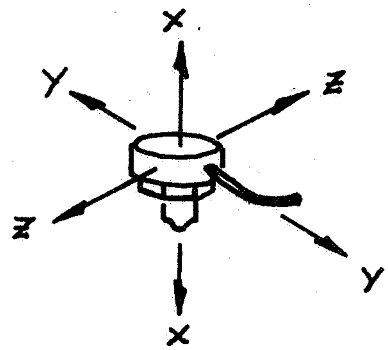




ENVIRONMENTAL TEST PROCEDURE

DATE 4-3-67 W.A. NO. 7127-02-00 PAGE 1 OF 16





TYPE OF TEST VIBRATION

CONTROLLING DOCUMENTS AND PARAGRAPHS PER EOS TEST PROCEDURE WORK AUTHORIZATION NO. 7127-00-00 DATED 9 AUG. 1966 PARA 3.7.1 & PER VERBAL INSTRUCTIONS BY J. DEL MONTE

DESCRIPTION OF TEST SPECIMEN (P/N & S/N) RCS PRESSURE SWITCH MODEL #101038-0003
S/N 4

TEST PROCEDURE TEST STARTED 3-31-67, COMPL. 3-31-67
THE TEST FIXTURE WAS MOUNTED TO THE VIBRATION EXCITER & THE VIBRATION SYSTEM EQUALIZED TO THE FOLLOWING RANDOM SPECTRUM:

20 - 75 cps - LINEAR INCREASE TO 0.14 g^2/cps.
75 - 200 cps - CONSTANT AT 0.14 g^2/cps.
200 - 2000 cps - LINEAR DECREASE TO 0.05 g^2/cps.
RANDOM SPECTRUM RMS WEK = 12.3 g's

A PLOT WAS MADE TO VERIFY EQUALIZATION TO WITHIN ±30 PERCENT P.S.D CONT—.

OPERATOR [signature]

ELECTRO-OPTICAL SYSTEMS, INC.
A Subsidiary of Xerox Corporation

ENVIRONMENTAL TEST REMARKS

DATE 4-3-67 W.A. NO. 7127-02-00

RCS PRESSURE SWITCH MOD. #101238-0003 S/N 4

VIBRATION TEST PROCEDURE CONTINUED —

FOLLOWING FIXTURE EQUALIZATION, THE SPECIMEN WAS MOUNTED TO THE TEST FIXTURE & SUBJECTED TO THE ABOVE RANDOM LEVEL FOR 5 MINUTES. A PLOT WAS AGAIN MADE DURING THE TEST PERIOD TO ASSURE WITHIN TEST CONDITIONS.

AT THE CONCLUSION OF THE RANDOM VIBRATION, THE SPECIMEN WAS SUBJECTED TO THE FOLLOWING SINE VIBRATION LEVELS:

5-16 cps @ 0.20 INCH D.A.
16-90 cps @ 2.5 g's Pk.
90-140 cps @ 0.006 INCH D.A.
140-350 cps @ 6.0 g's Pk.
350-500 cps @ 0.001 INCH D.A.
500-2000 cps @ 11.0 g's Pk.

SWEEP TIME PER J. DELMONTE FROM 5 TO 2000 TO 5 cps IN 18 MINUTES.

RANDOM & SINE VIBRATION WAS PERFORMED IN EACH OF 3 MUTUALLY PERPENDICULAR AXES.

SPECIMEN OUTPUT WAS RECORDED & MONITORED DURING THE ENTIRE TEST PERIOD.

OPERATOR [signature]

7127-Final

EOS FORM NO.4625 REPLACES FORM 306

ENVIRONMENTAL TEST INSTRUMENTATION AND DRAWINGS

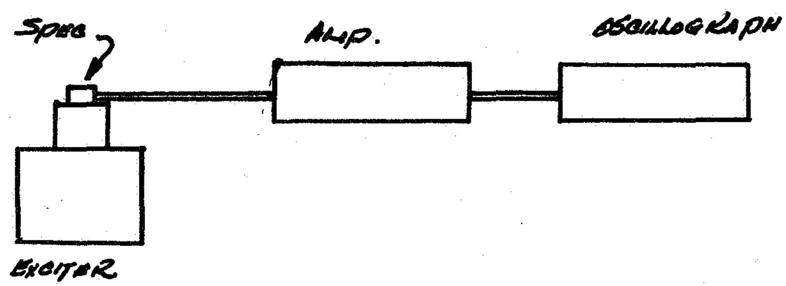
DATE 4-3-67 W.A. NO. 7127-02-00 PAGE 3 OF 16

DESCRIPTION OF TEST SPECIMEN (P/N & S/N)
RCS PRESSURE SWITCH MODEL 101038-0003 S/N 4

INSTRUMENTATION & EQUIPMENT

MB VIBRATION EXCITER	MOD. C-50
MB. VIBRATION AMPLIFIER	MOD. T-451
MB VIBRATION RANDOM CONSOLE	MOD. T-288
ENDEVCO ACCELEROMETER S/N ND49	MOD. 2213E
DANA AMPLIFIER	MOD. 3420
MIDWESTERN OSCILLOGRAPH	MOD. 621
FLUKE DIFF. VOLTMETER	MOD. 825AR

DIAGRAMS OR DRAWINGS



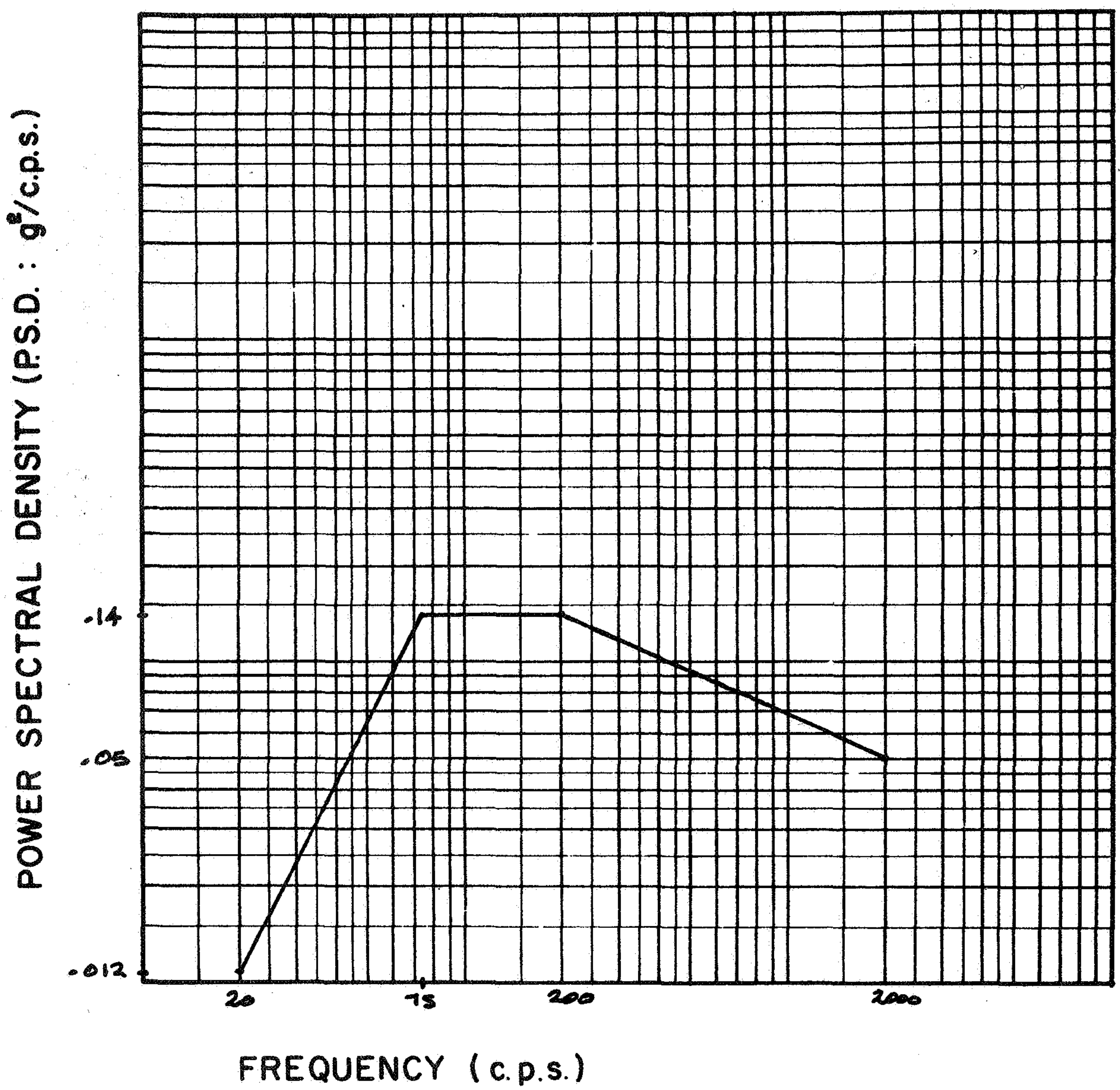
RANDOM VIBRATION

DATE 4-3-67

DESCRIPTION OF TEST SPECIMEN (P/N & S/N)

RCS PRESSURE SWITCH MOD 101038-0003 S/N 4

RANDOM SPECTRUM X-AXIS



R.M.S. G's OF RANDOM SPECTRUM 12.3

EQUALIZATION TOLERANCE + 1.5 DB; - 1.5 DB

RUNNING TIME

REMARKS FIXTURE EQUALIZATION

OPERATOR Brito

EOS FORM No 304 7127-Final

RANDOM VIBRATION

DATE 3-31-67 TIME 0955 W.A. 7127-02-00

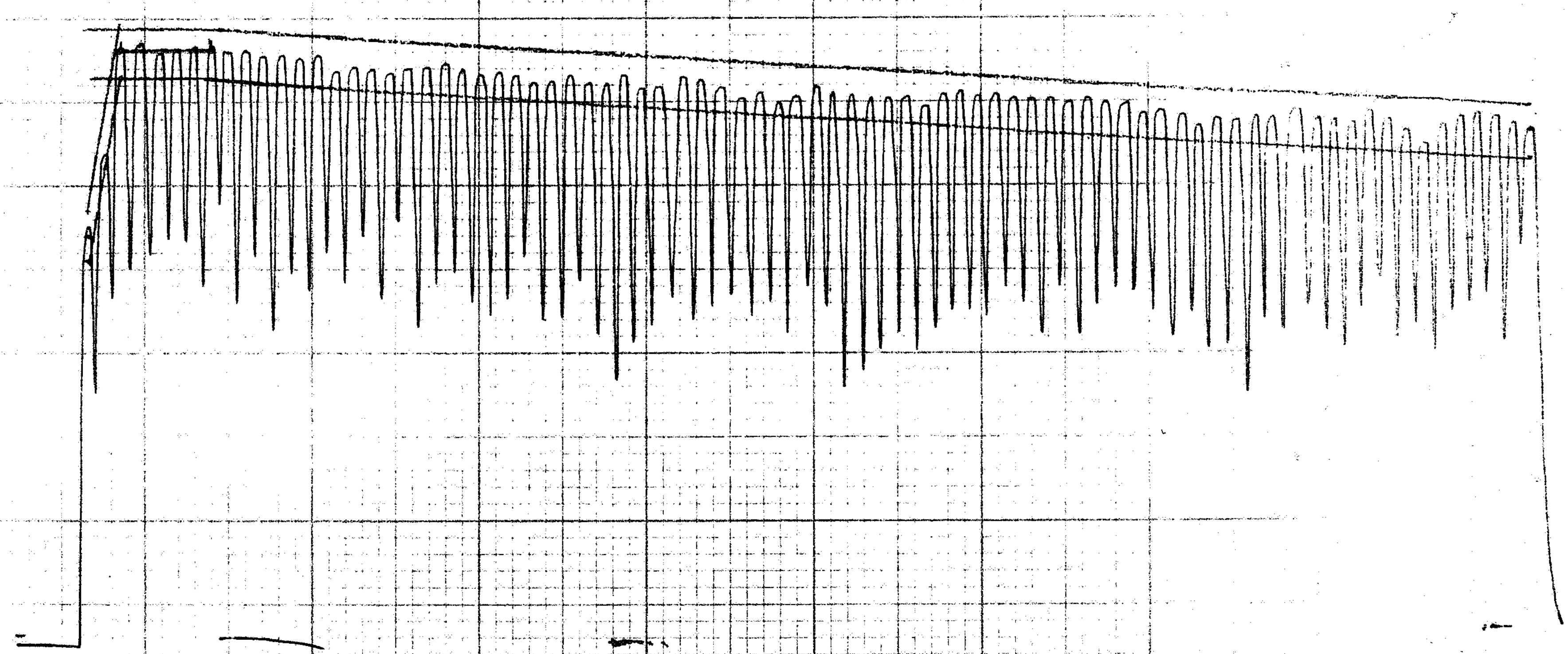
AXIS — RUN TIME — G-RMS 12.3

TEST SPECIFICATION EDS T.P. WA. #7127-00-00 Dated 9 Aug. 1966 Para. 3.7.1.

RCS Pressure Switch Mod. 101036-0003 S/N 4 Fixture Equalization for X-Axis.

TEMPERATURE Rm REMARKS X-Y Plotter Calib. by 1db/minor div., Plot at < ± 1.5db.

TECHNICIAN [illegible]



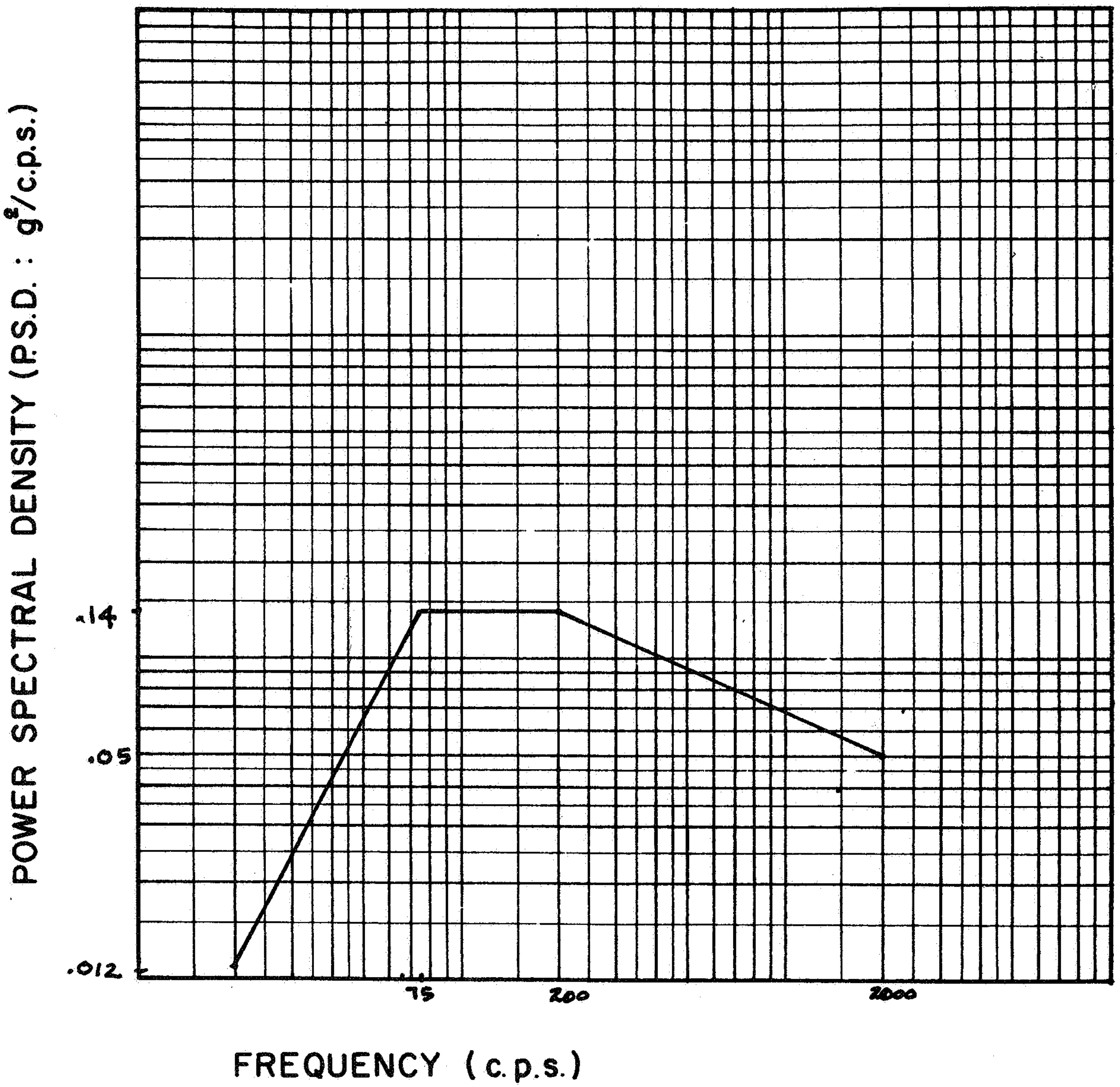
RANDOM VIBRATION

DATE 4-367 PAGE 6 OF 16

DESCRIPTION OF TEST SPECIMEN (P/N & S/N)

RCS PRESSURE SWITCH MOD. 101038-0003 S/N 4

RANDOM SPECTRUM X-AXIS



R.M.S. G's OF RANDOM SPECTRUM 12.3

EQUALIZATION TOLERANCE + 1.5 DB; - 1.5 DB

RUNNING TIME 5 MIN.

REMARKS TEST PLOT

OPERATOR [signature]

EOS FORM No 304 7127-Final

RANDOM VIBRATION

DATE 3-31-67 TIME 1100 W.A. 7127-02-00

AXIS Y RUN TIME 5 min. G-RMS 12.3

TEST SPECIFICATION EOS TP no #7127-00-00
Dated 9 Aug. 1966 Para 3.7.1
RCS Switch-Press Mod. #101038-0003
S/N 4 Test Plot

TEMPERATURE Amb REMARKS X-Y Plotter Calib.
@ 1 db/Major Div., Test Req to within
±1.5 db. TECHNICIAN [signature]

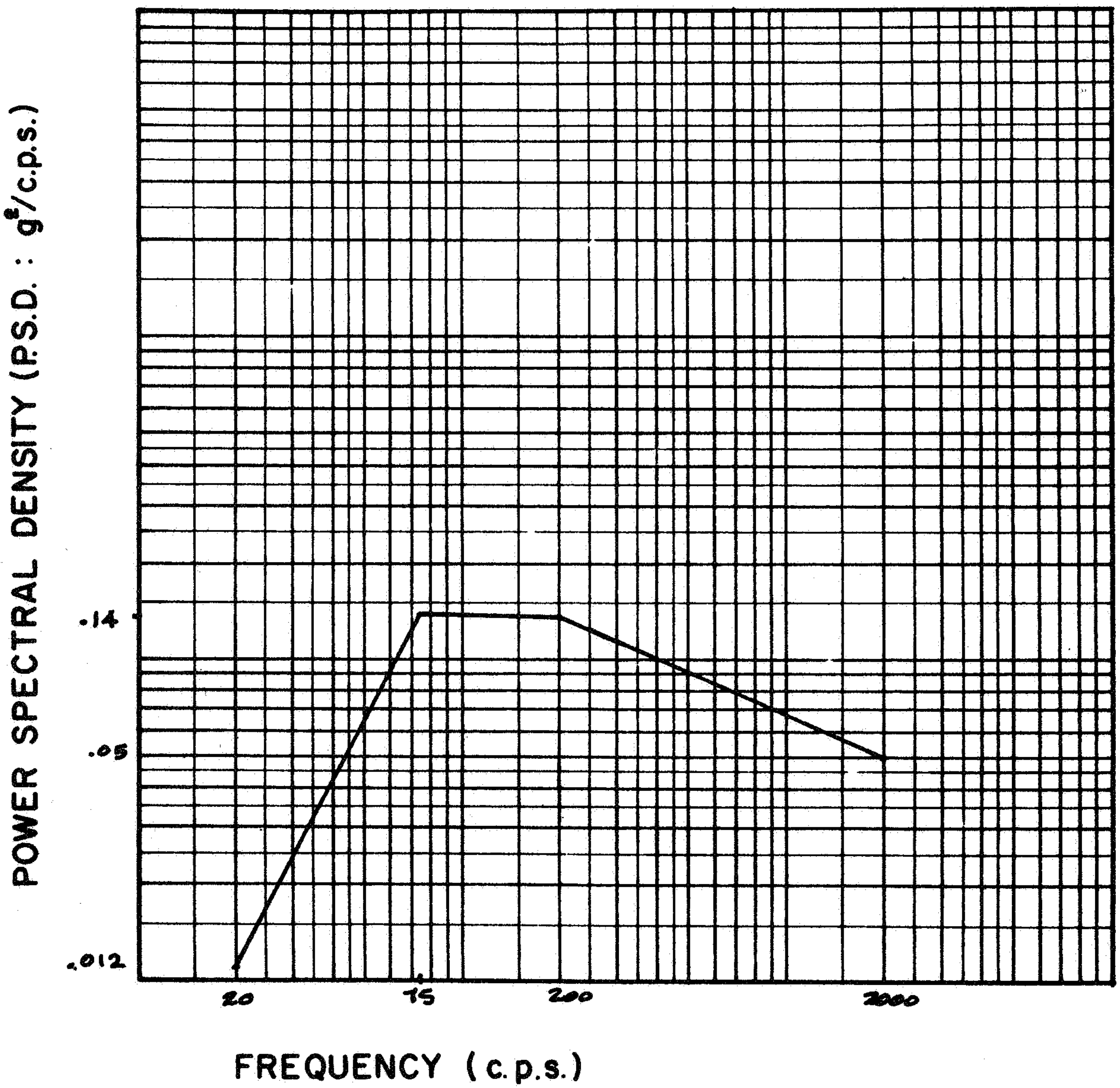
RANDOM VIBRATION

DATE 4-3-67 PAGE 8 OF 16

DESCRIPTION OF TEST SPECIMEN (P/N & S/N)

ECS PRESSURE SWITCH MOD. 101038-0003 S/N 4

RANDOM SPECTRUM Y-AXIS



R.M.S. G's OF RANDOM SPECTRUM 12.3

EQUALIZATION TOLERANCE + 1.5 DB; - 1.5 DB

RUNNING TIME

REMARKS FIXTURE EQUALIZATION

OPERATOR [illegible]

9.

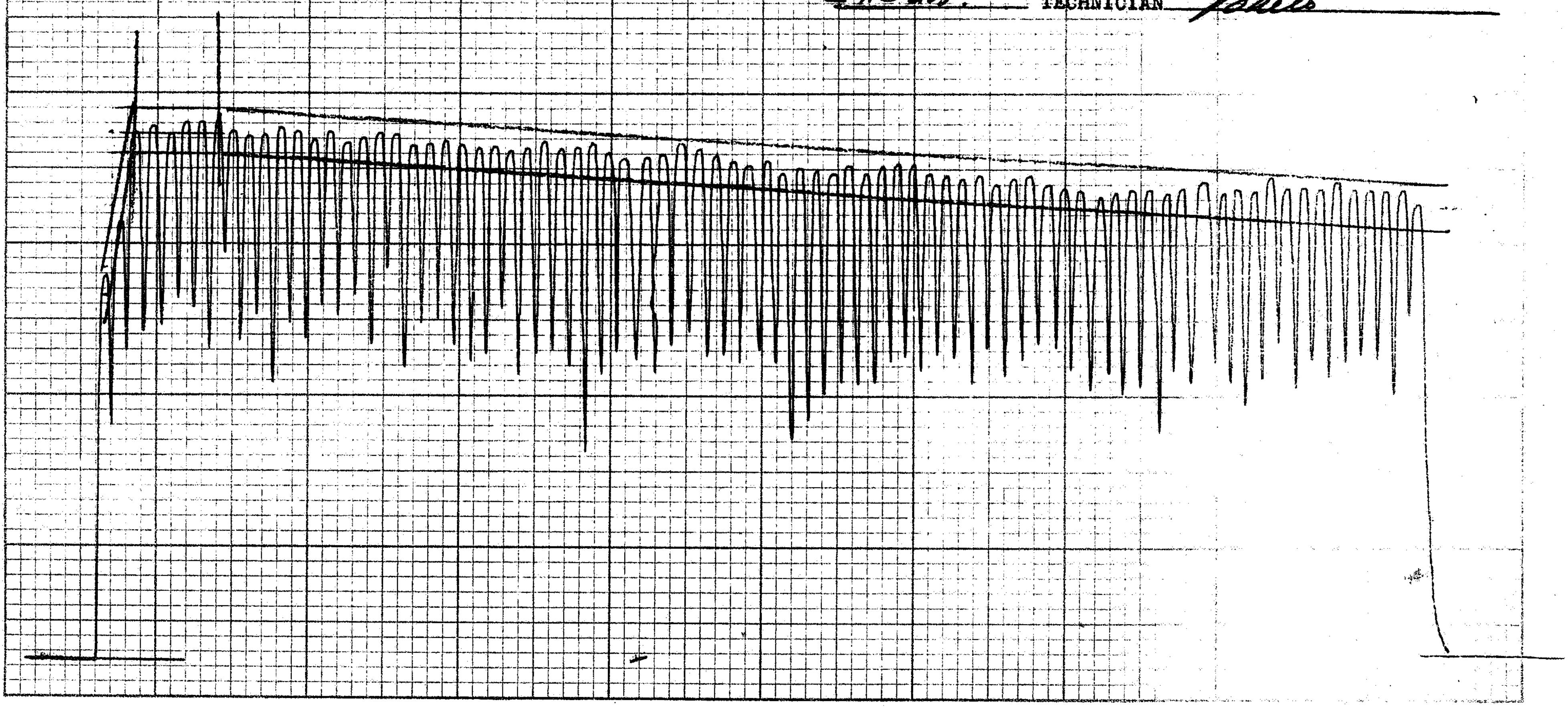
RANDOM VIBRATION

DATE 3-31-67 TIME 1141 W.A. 7127-02-00

AXIS — RUN TIME — G-RMS 12.3

TEST SPECIFICATION EOS TP WA # 7127-00-00
Dated 9 Aug. 1966 Para. 3.7.1
RCS Press. Switch Mod 101038-0003
S/N 4 Y-Axis Ent. Equalization

TEMPERATURE Amb REMARKS X-Y Plotter Calib.
@ ±1db/minor Div., Equal to within
±1.5db. TECHNICIAN [illegible]



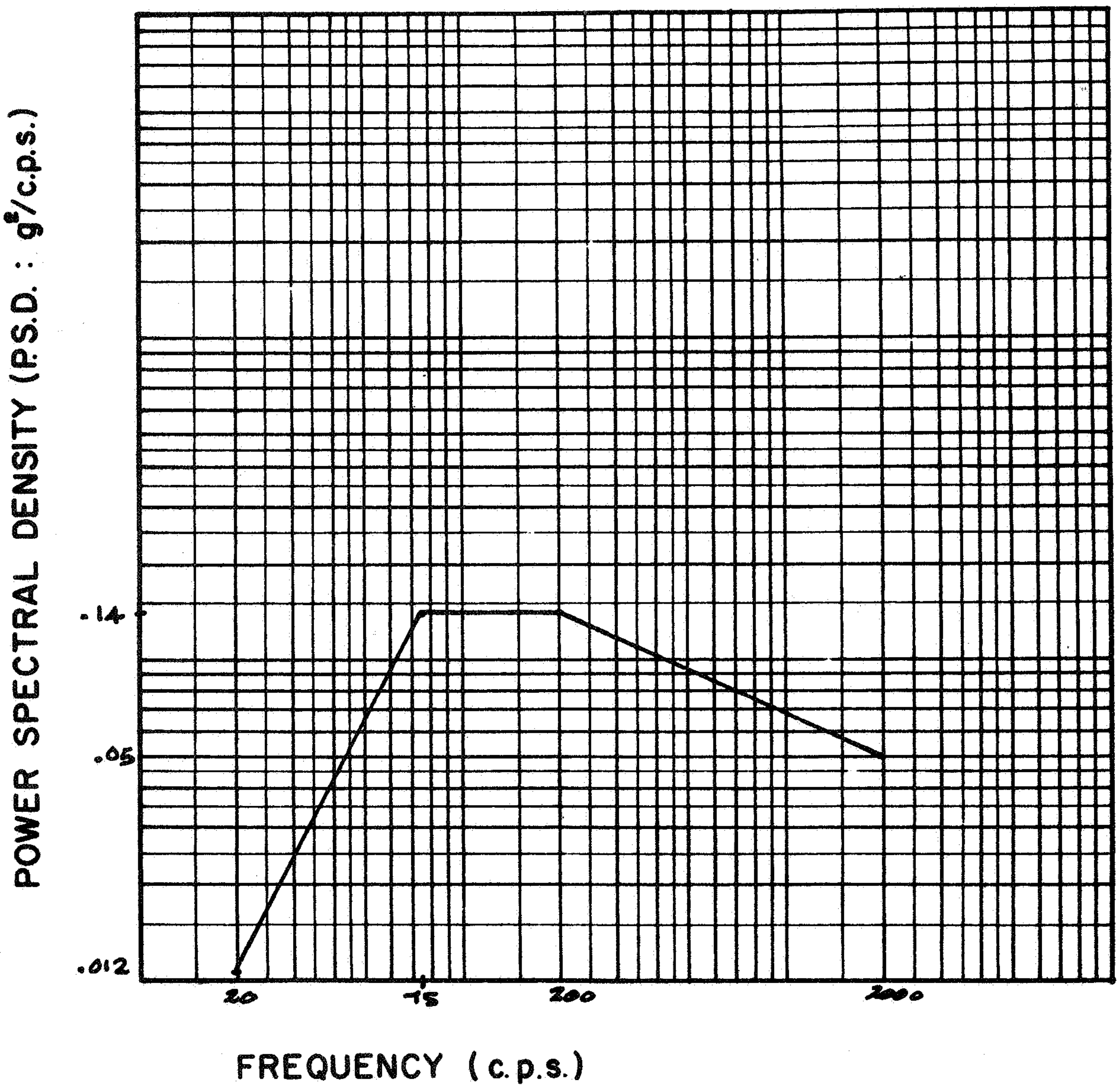
RANDOM VIBRATION

DATE 4-3-67 PAGE 10 OF 16

DESCRIPTION OF TEST SPECIMEN (P/N & S/N)

RCS PRESSURE SWITCH MOD. 101038-0003 S/N 4

RANDOM SPECTRUM Y-AXIS



R.M.S. G's OF RANDOM SPECTRUM 12.3

EQUALIZATION TOLERANCE + 1.5 DB; - 1.5 DB

RUNNING TIME 5 MIN

REMARKS TEST PLOT.

OPERATOR [signature]

10 X 10 TO THE INCH 46 0782
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

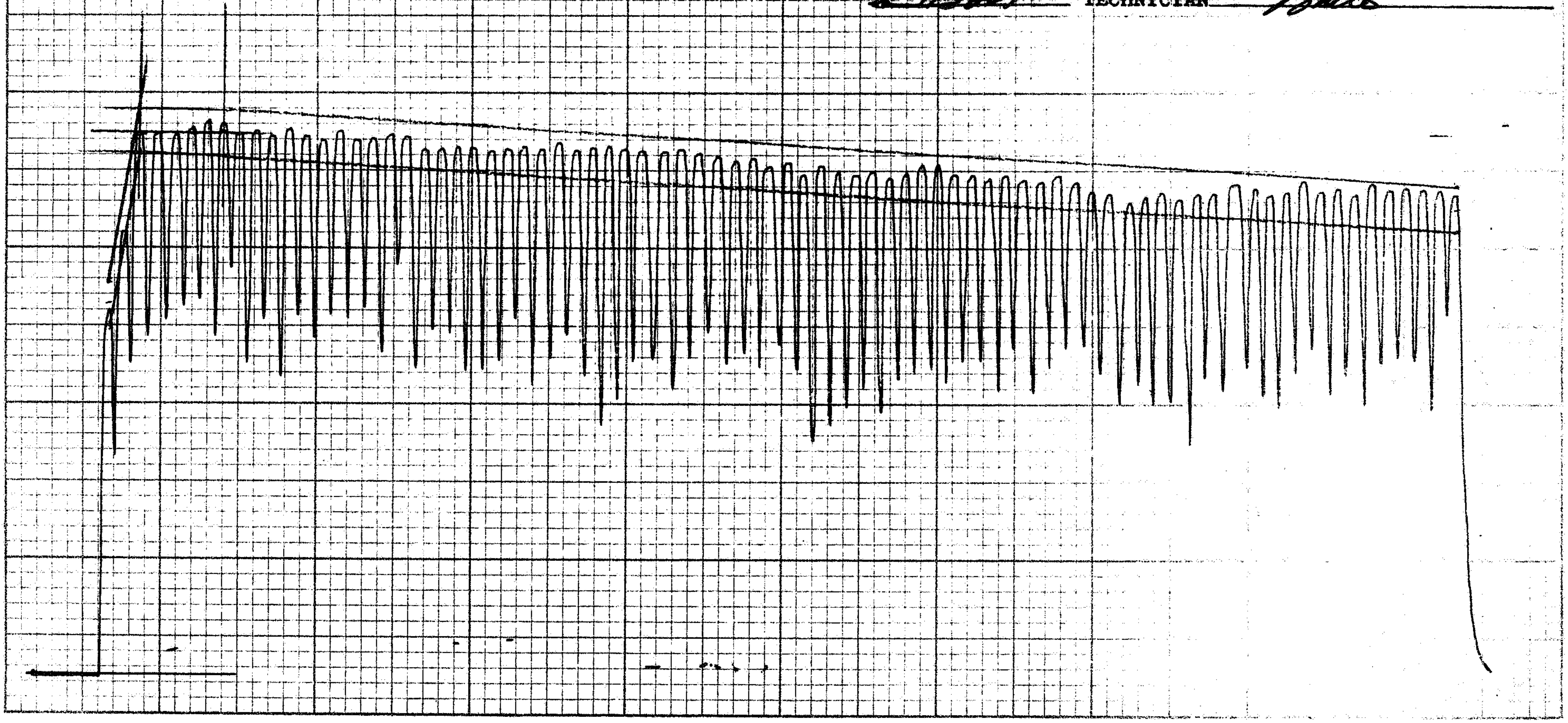
RANDOM VIBRATION

DATE 3-31-67 TIME 1155 W.A. 7127-02-00

AXIS Y RUN TIME 5 min. G-RMS 12.3

TEST SPECIFICATION EOS TP WA# 7127-60-00
Dated 9 Aug 1966 Para. 3.7.1
RCS Press. Switch Mod. 101038-0003
S/N 4

TEMPERATURE Rm REMARKS K-4 Plotter Calib.
@ ±1db Minor Div. Test Plot to within
±1.5db TECHNICIAN [signature]



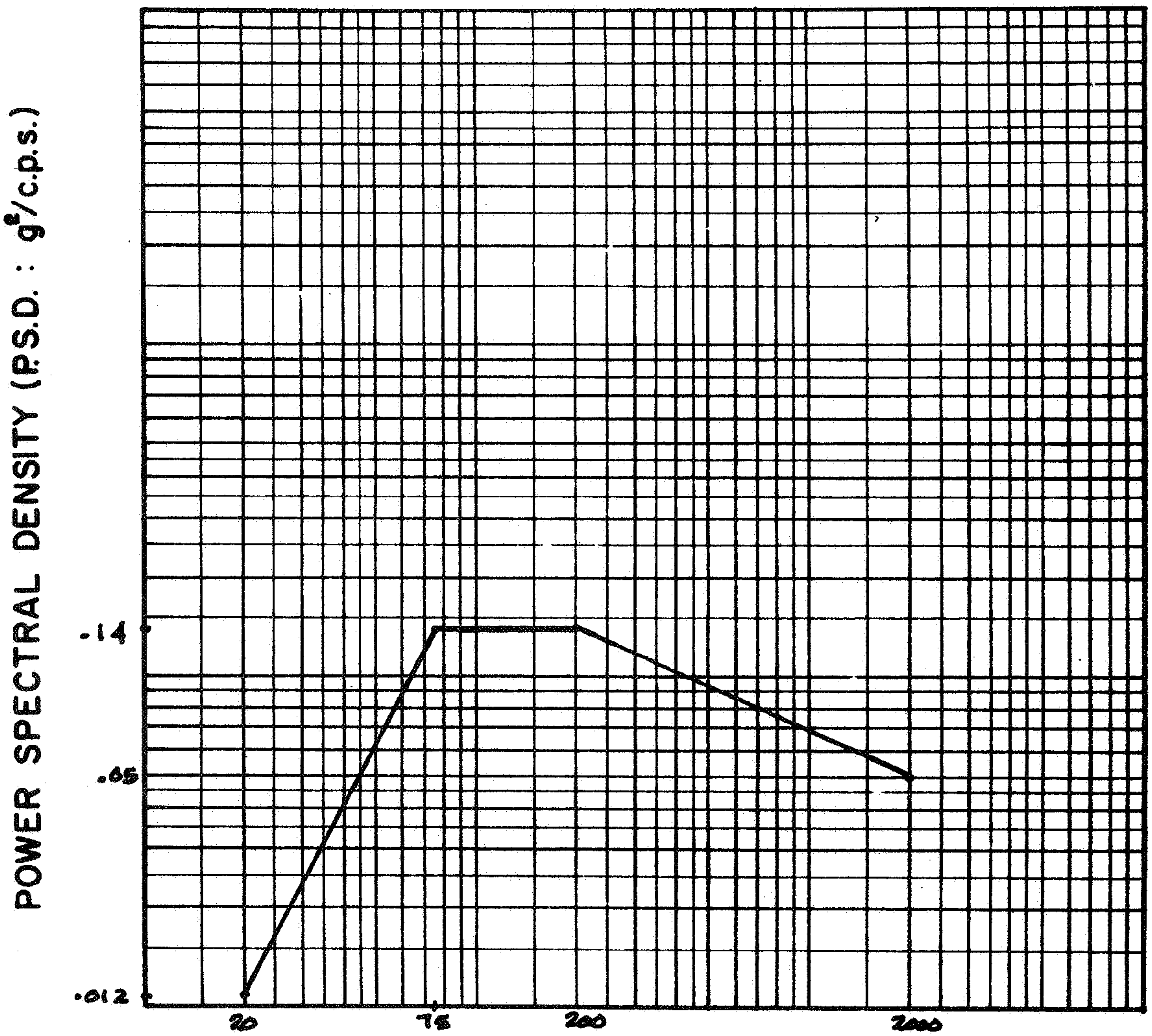
RANDOM VIBRATION

DATE 4-3-67 PAGE 12 OF 16

DESCRIPTION OF TEST SPECIMEN (P/N & S/N)

RCS PRESSURE SWITCH MOD. 101038-0003 S/N 4

RANDOM SPECTRUM Z-AXIS



FREQUENCY (c.p.s.)

R.M.S. G's OF RANDOM SPECTRUM 12.3

EQUALIZATION TOLERANCE + 1.5 DB; - 1.5 DB

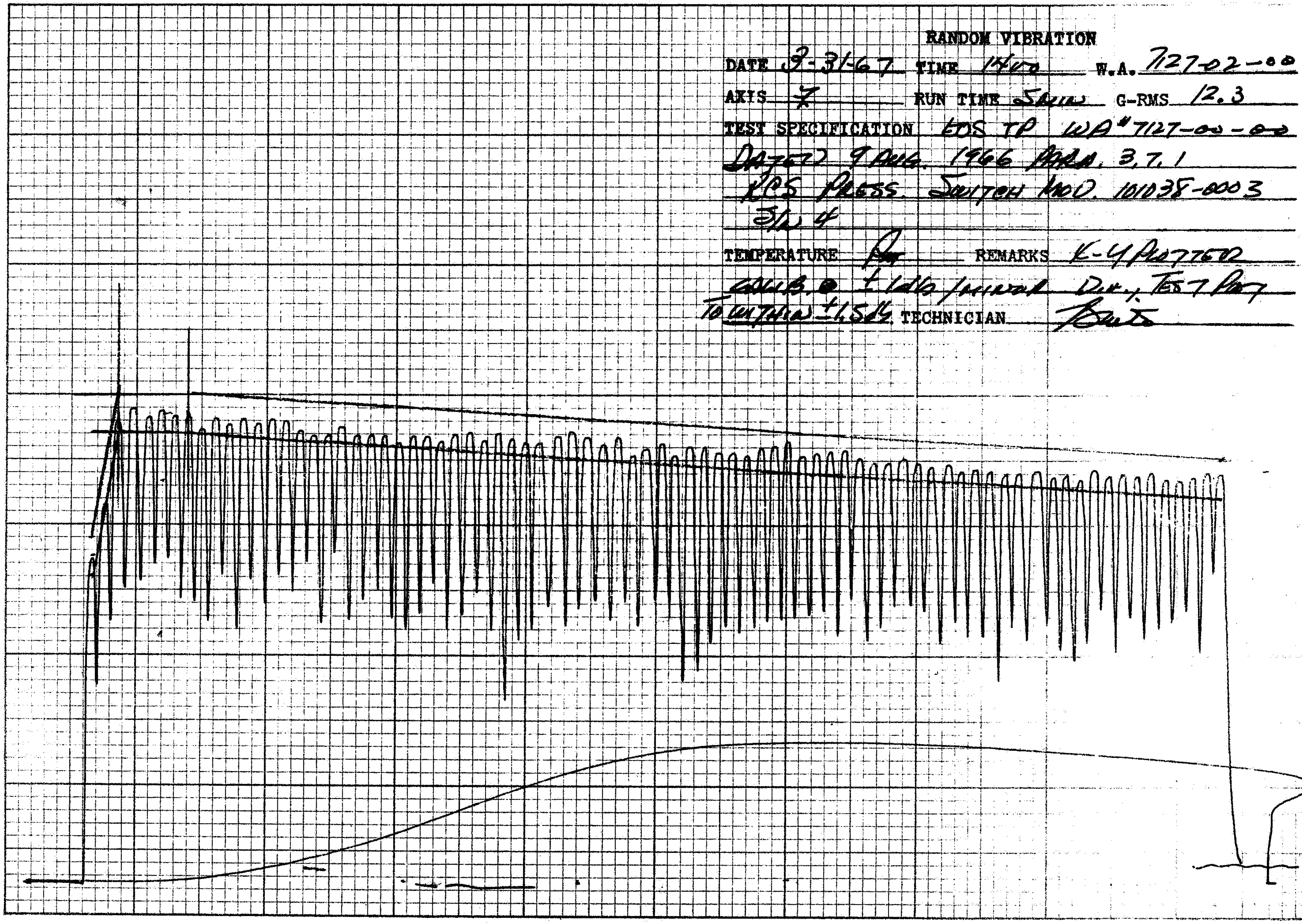
RUNNING TIME 5 MIN.

REMARKS FIXTURE EQUALIZATION NOT NECESSARY. TEST PLOT.

OPERATOR [signature]

EOS FORM No 304 7127-Final

K+E 10 X 10 TO THE INCH 7 X 10 INCHES KEUFFEL & ESSER CO. 46 0782 MADE IN U.S.A.



13.

SINE WAVE VIBRATION

DESCRIPTION OF TEST SPECIMEN (P/N & S/N) RCS PRESSURE SWITCH
MOD. 101038-0003 S/N 4 WO# 7127-02-00

DATE	TIME	AXIS	AMB. TEMP.	FREQUENCY (cps)	D.A. (in)	ACCEL (g's)	RUN TIME	REMARKS	TECH.
3-31-67	1109	X	Rm	5-16	.2	–		START SINE SWEEP.	
				16-90	–	2.5			
				90-140	.006	–			
				140-350	–	6.0			
				350-500	.001	–			
				500-2000-500	–	11.0			
				500-350	.001	–			
				350-140	–	6.0			
				140-90	.006	–			
				90-16	–	2.5			
	1127	X	Rm	16-5	.2	–	18 MIN.	COMPL. SWEEP.	B
	1325	Y	Rm	5-16	.2	–		START SINE SWEEP.	
				16-90	–	2.5			
				90-140	.006	–			
				140-350	–	6.0			
				350-500	.001	–			
				500-2000-500	–	11.0			
								CONT.	

EOS FORM NO. 302

SINE WAVE VIBRATION

DESCRIPTION OF TEST SPECIMEN (P/N & S/N) RCS Pressure Switch
Mod. 101038-0003 S/N 4 WA# 7127-02-00

DATE	TIME	AXIS	AMB. TEMP.	FREQUENCY (cps)	D.A. (in)	ACCEL (g's)	RUN TIME	REMARKS	TECH.
3-31-67								Cont. Y-Axis.	
		Y	Rm	500-350	.001	—			
				350-140	—	6.0			
				140-90	.006	—			
				90-16	—	2.5			
	1343	Y	Rm	16-5	.2	—	15 min.	Compl. Sweep.	B
	1405	Z	Rm	5-16	.2	—		Start Sine Sweep.	
				16-90	—	2.5			
				90-140	.006	—			
				140-350	—	6.0			
				350-500	.001	—			
				500-2000-500	—	11.0			
				500-350	.001	—			
				350-140	—	6.0			
				140-90	.006	—			
				90-16	—	2.5			
	1423	Z	Rm	16-5	.2	—	15 min.	Compl. Sweep.	B

EOS FORM NO. 302

ELECTRO-OPTICAL SYSTEMS, INC.
A Subsidiary of Xerox Corporation

ENVIRONMENTAL TEST REMARKS

DATE 3-31-67 W.A. NO. 7127-02-00 PAGE 16 OF 16

RCS PRESSURE SWITCH MODEL # 101038-0003
S/N 4
SINE & RANDOM VIBRATION

3-31-67	0925	START FIXTURE EQUALIZATION @ 12.3g RMS	
	0955	COMPL. EQUAL.	
	1000	START INST. CALIB.	
	1050	COMPL. INST. CALIB.	
		CH. 1 = 28V/1.5 INCH CH. 2 = 150MV/INCH -	
		SPEC. MOUNTED IN X-AXIS.	
	1055	START X-AXIS RANDOM	
	1100	COMPL. RANDOM.	
	1109	START X-AXIS SINE SWEEP.	
	1127	COMPL. SINE SWEEP.	
	1138	START Y-AXIS EQUAL @ 12.3g RMS.	
	1141	COMPL. EQUAL.	
	1150	START Y-AXIS RANDOM.	
	1155	COMPL. Y-AXIS RANDOM.	
	1325	START Y-AXIS SINE SWEEP.	
	1343	COMPL. SINE SWEEP.	
	1355	START Z-AXIS RANDOM - EQUAL NOT NECESSARY.	
	1400	COMPL. Z AXIS RANDOM.	
	1405	START Z AXIS SINE SWEEP.	
	1423	COMPL. Z-AXIS SWEEP.	EOS 7 3/31/67
		VIB. TEST COMPL.	

OPERATOR Burto

EOS FORM NO. 4625 (1) (REV. 1-67) 7127-Final

APPENDIX E

RCS PRESSURE SWITCH S/N 4

Effects of 100,000 exposures to O&R internal combustion engine* pressure cycles

Speed = 6000 rpm; hp rating = 1

Mean effective pressure generated: 125-130 psi

Cylinder head temperature > 300°F

Combustion temperature >> 1200°F

Test duration = 18 minutes

Fig.		Fig.	
E-1	Test setup	E-1-1	Test fixture (O&R cylinder head modification)
		E-1-2	Sketch of cylinder head modification required for PT 150 instrumentation
		E-1-3	Shape of pressure pulse in O&R engine
E-2	Calibration charts	E-2-1	
		E-2-2	

*Model III Base Mount
O&R Engines Inc.
3340 Emery St.
Los Angeles, Calif.

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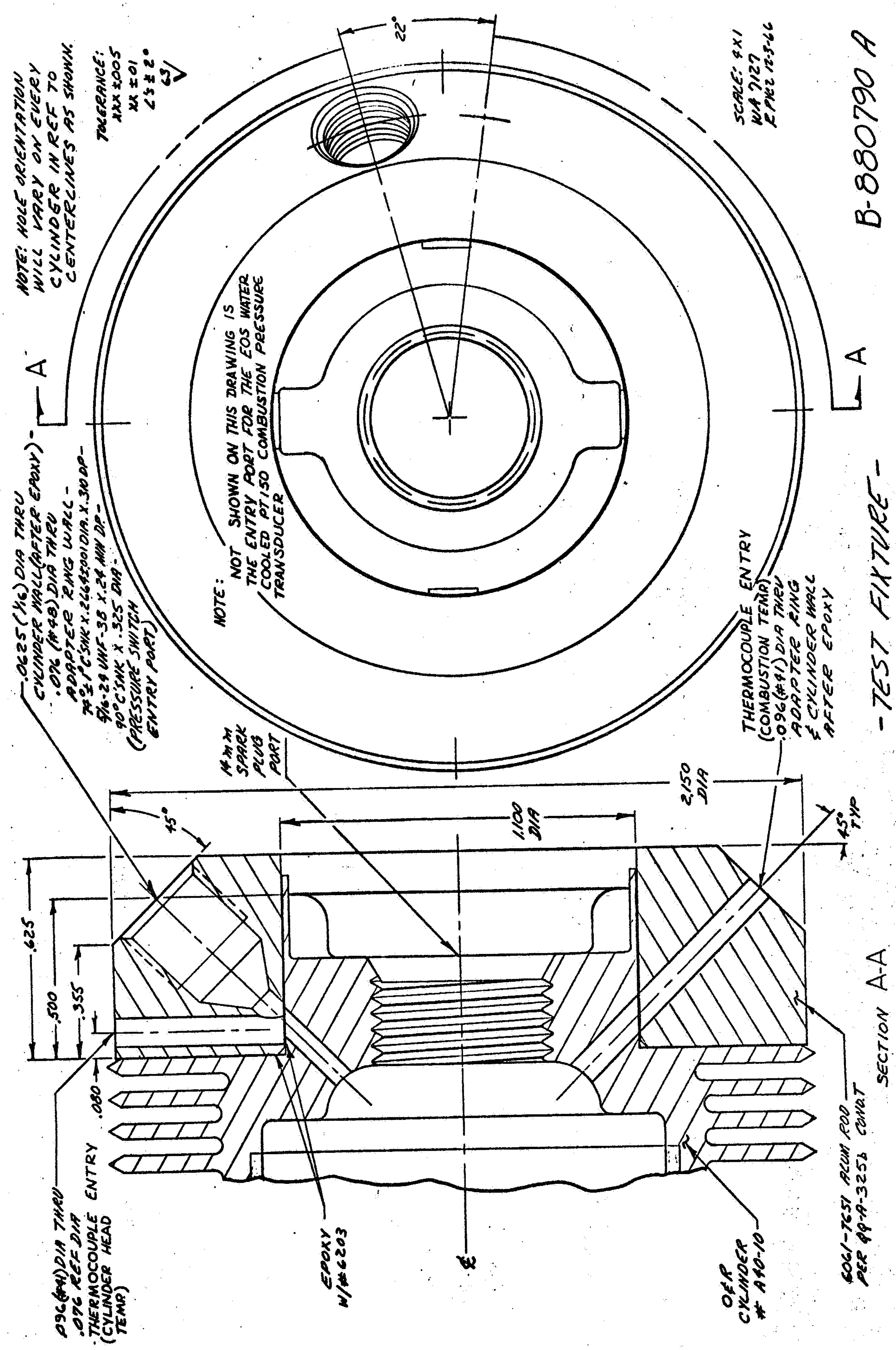


Figure E-1-1. Test Fixture, Cylinder Head Modification

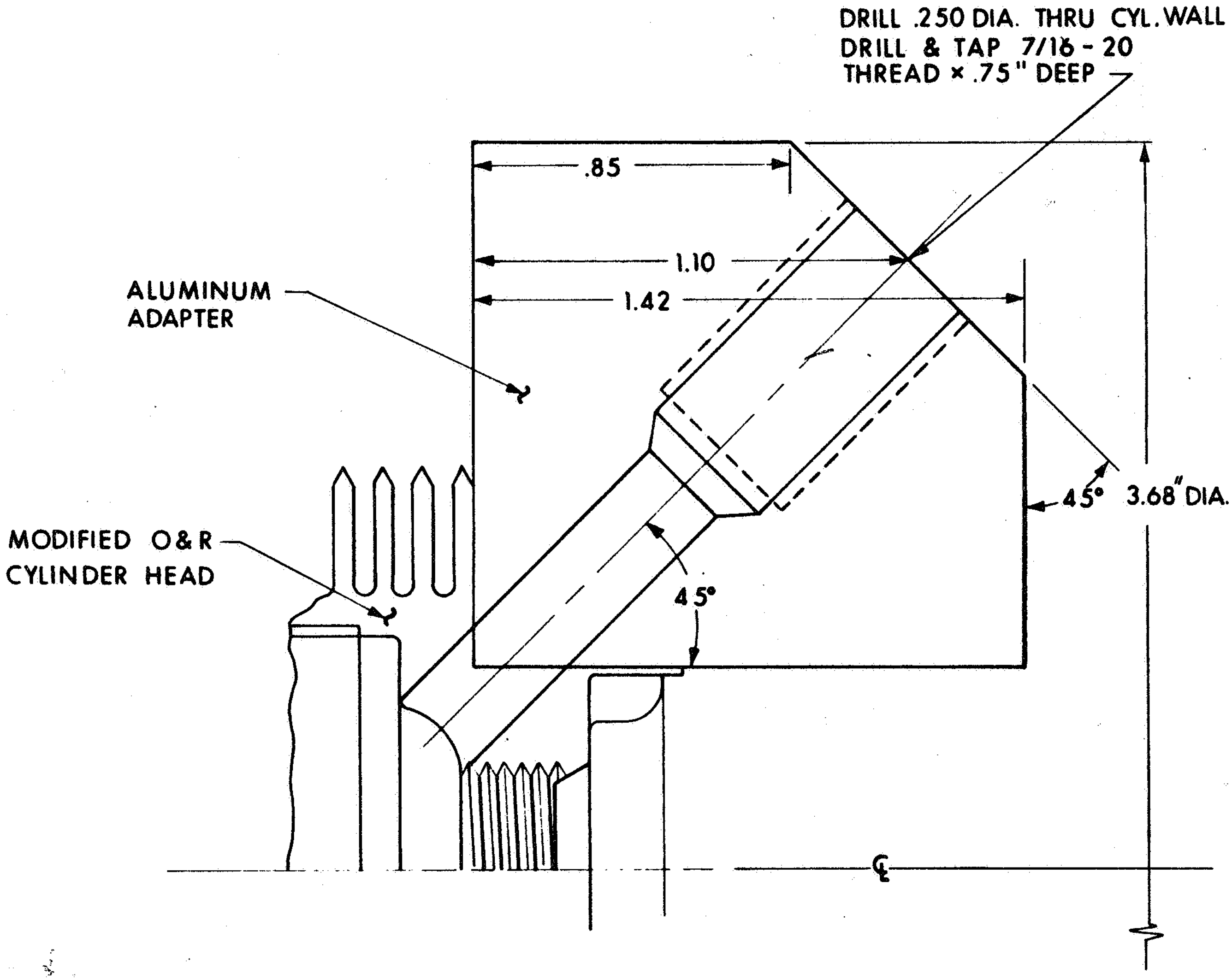
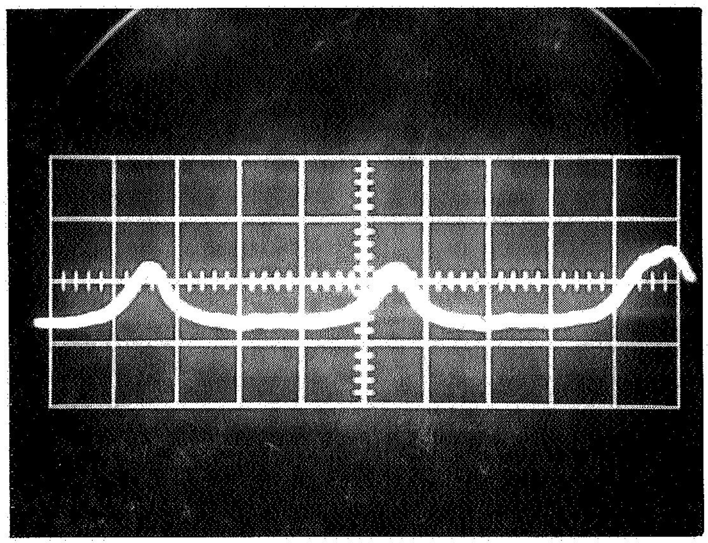


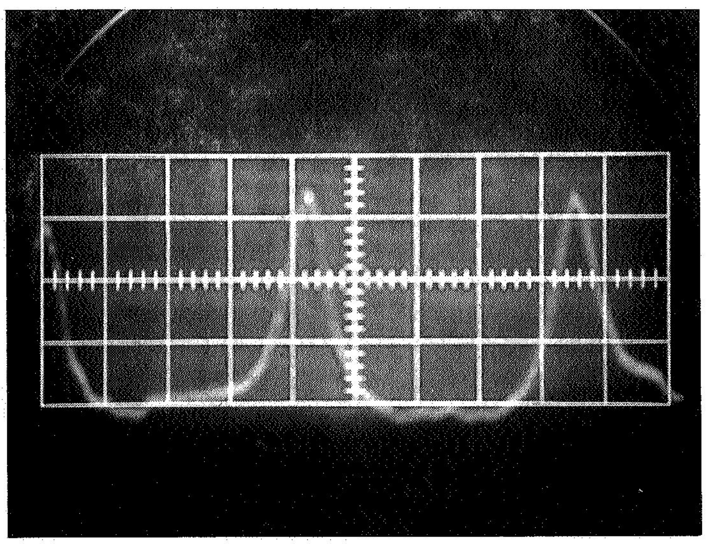
Figure E-1-2. Cylinder Head Adapter for O & R Engine for PT 150 Water Cooled Combustion Pressure Transducer



SENSITIVITY

HORIZONTAL =
2 ms/cm

VERTICAL =
20 mV/cm



HORIZONTAL =
2 ms/cm

VERTICAL =
5 mV/cm

'SCOPE = 541 A
"D" PLUG - IN

Figure E-1-3. Shape of Pressure Pulse in O & R, 1-HP, 2 Cycle Gasoline Engine

RCS
Pressure Switch

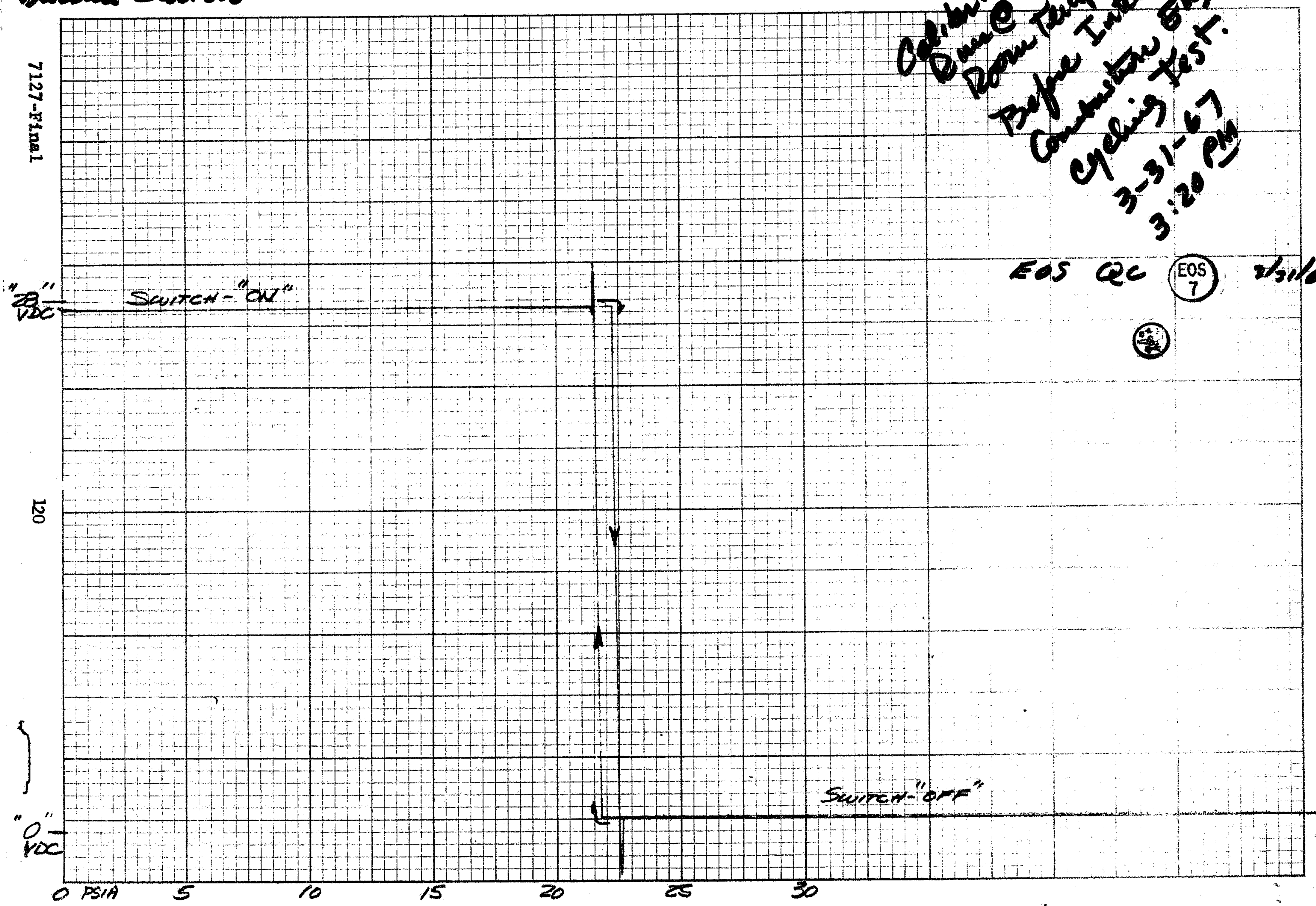


Figure E-2-1. S/N 4

10 X 10 TO THE INCH 46 0782
7 X 10 INCHES
KEUFFEL & ESSER CO.

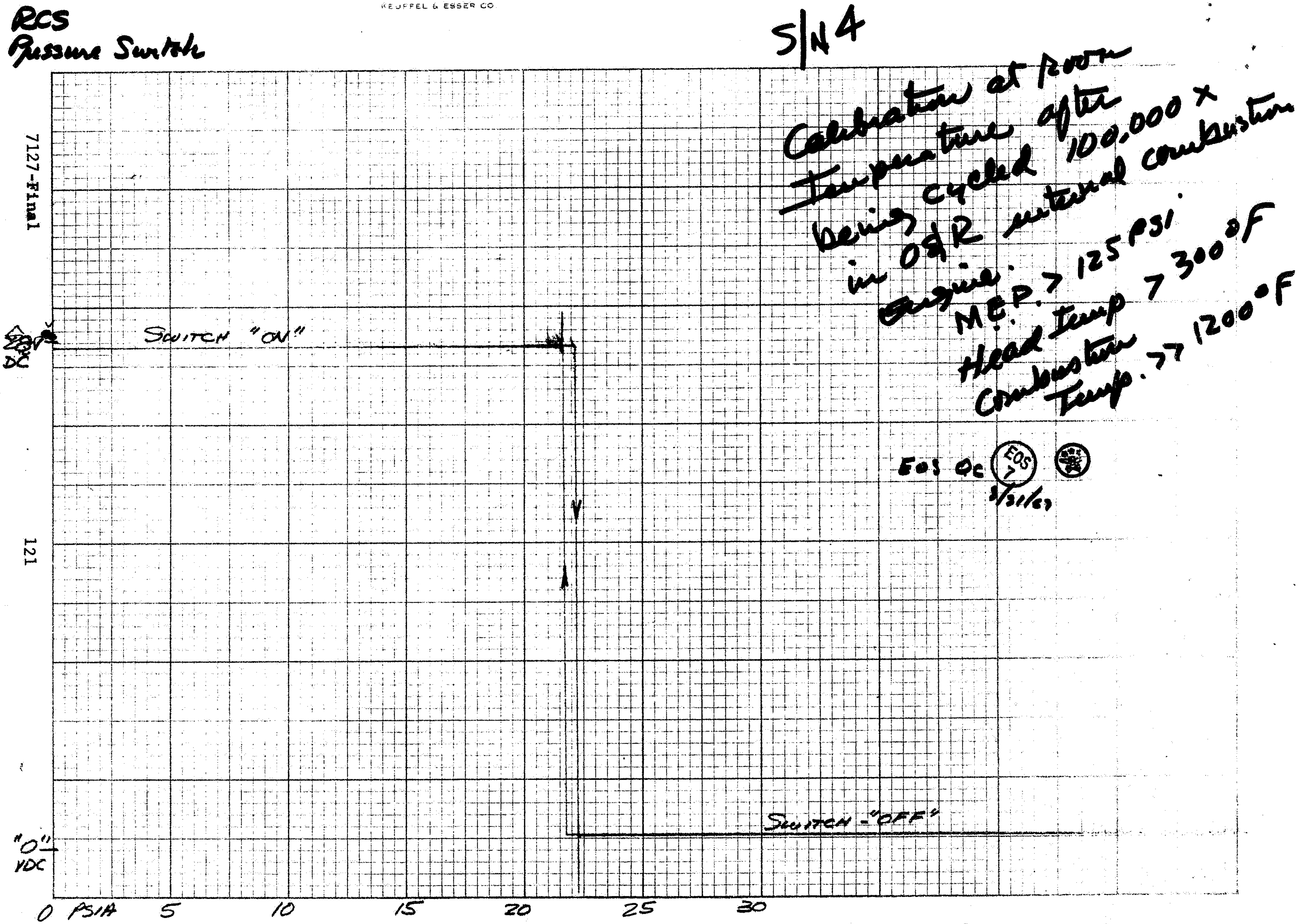


Figure E-2-2. S/N 4

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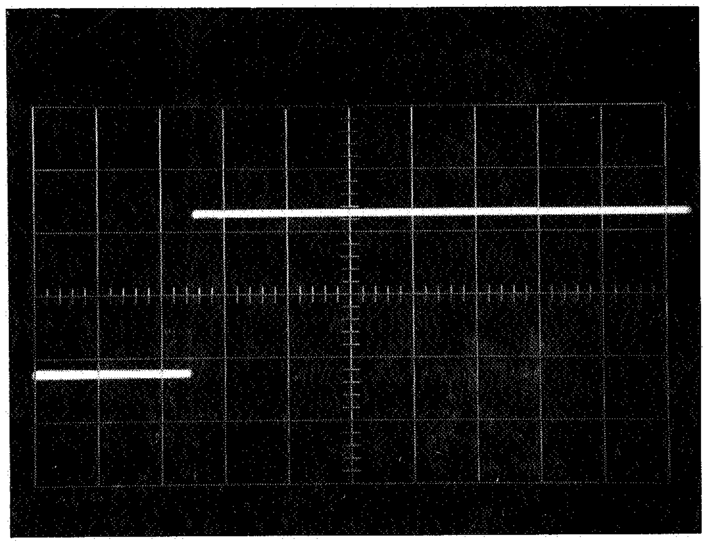
APPENDIX F

RCS PRESSURE SWITCH S/N 4

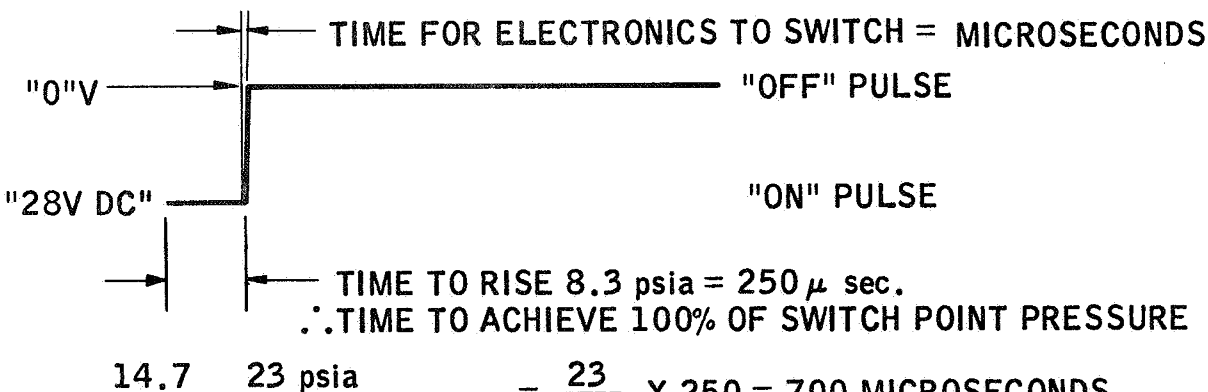
Effect of shock wave pressure pulses on switch point



OSCILLOSCOPE = TEKTRONIX 543 WITH TYPE "H" PLUG-IN

VERTICAL = 10 V/cm

HORIZONTAL = 0.1 ms/cm



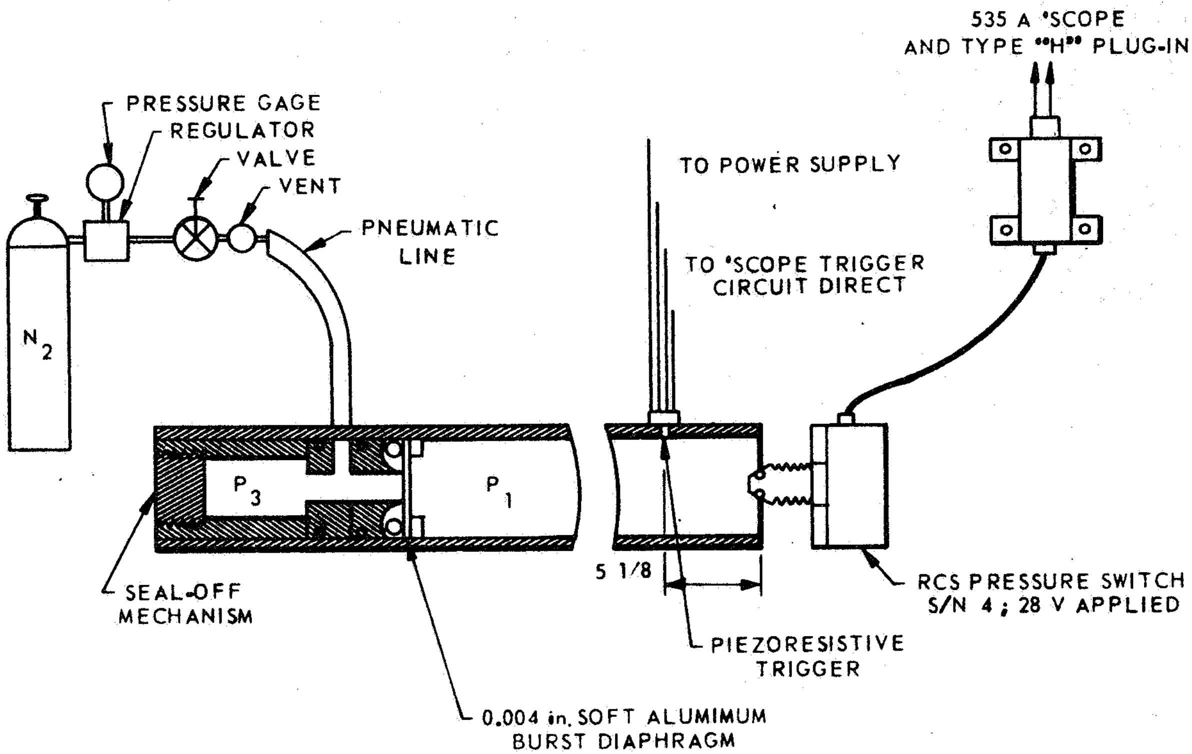
∴ TIME TO ACHIEVE 100% OF SWITCH POINT PRESSURE

$$= \frac{23}{8.3} \times 250 = 700 \text{ MICROSECONDS}$$

(LESS TIME FOR SHOCK WAVE TO TRAVEL 5 1/8 inch $= 5\ 1/8 \text{ inch} \times \dfrac{40\mu \text{ sec}}{\text{inch}}$

$= 500\,\mu\,\text{sec}$

Figure F-1. Shock-Tube Setup Used Open-Ended



1. PRESSURE $P_3 = 554$ psia

2. PRESSURE $P_1 = 14.7$ psia

3. PRESSURE RATIO = $\dfrac{P_3}{P_1} = 37.7$

   ∴ THEORETICAL AIR TO AIR SHOCK STRENGTH $\dfrac{P_2}{P_1} = 4.2$

   AND ∴ M = 1.9 ON THE ASSUMPTION THAT PERFECT GAS LAWS APPLY, THAT SPECIFIC HEATS ARE CONSTANT AND THAT FLOW IS ADIABATIC.

   AMBIENT TEMPERATURE = 77 °F

4. AT M = 1.9 SPEED OF SOUND IN AIR $\sim \dfrac{76 \text{ microseconds}}{\text{inch} \times 1.9} = \dfrac{40\mu \text{ sec}}{\text{inch}}$

Figure F-2. RCS Pressure Switch Response Data

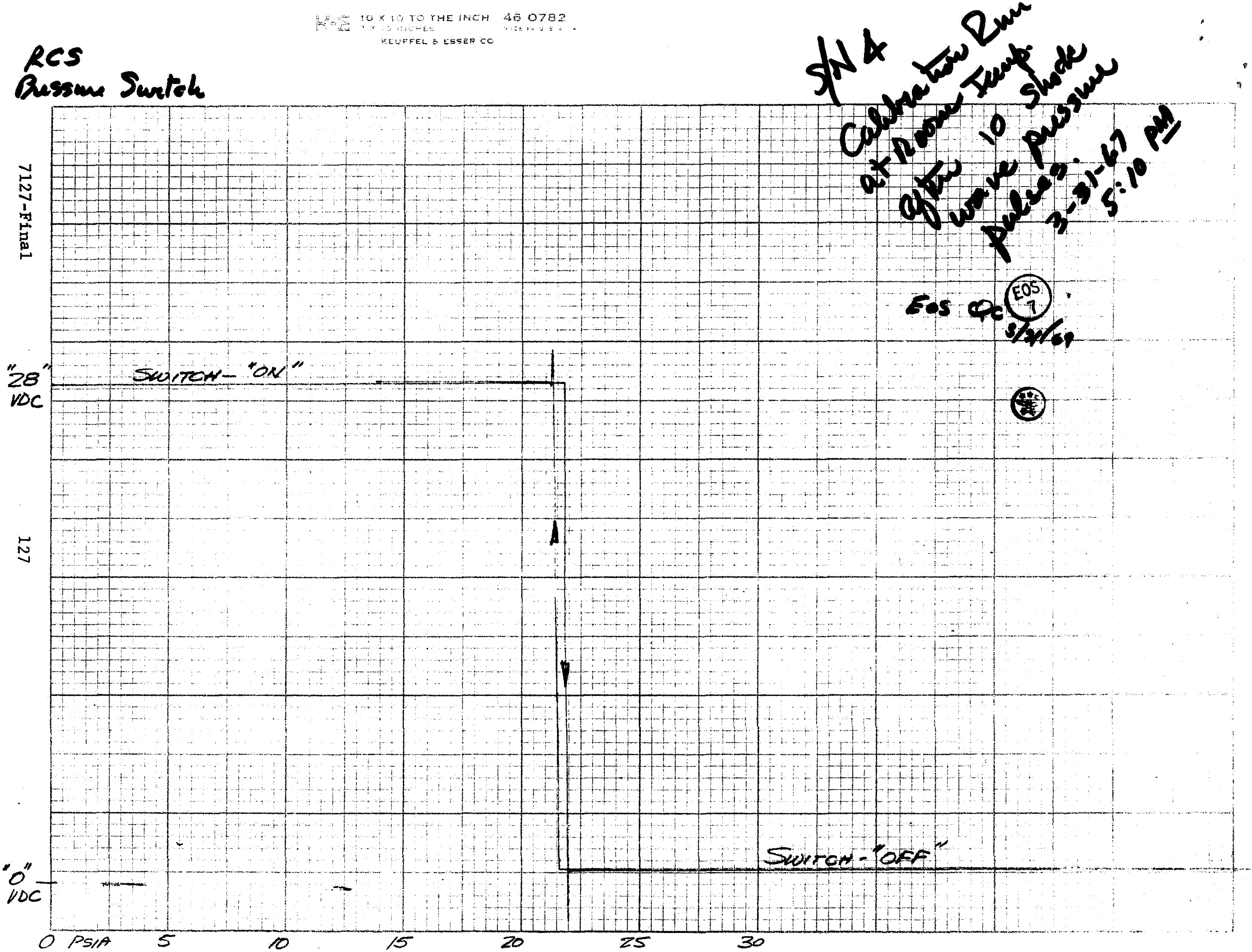


Figure F-3. S/N 4

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APPENDIX G

ACCEPTANCE TEST PLAN, TEST RESULTS, AND REFERENCED DOCUMENTS

A. Summary

B. Referenced Documents

		Same as
1.	Attachmend No. 1	Fig. 3
2.	Attachment No. 3	See Fig. G-1, Drawing 204154
3.	Attachment Nos. 4A, 4B, 4C, and 4D	See Appendix B: Figs. B-1 through B-4
4.	Attachment Nos. 5A, 5B, 5C, and 5D	See Appendix C: Figs. C-1 through C-4
5.	Attachment No. 6	See Appendix F
6.	Attachment No. 7	See Appendix A (36 items)

A. SUMMARY

31 March 1967

ACCEPTANCE TEST PLAN CONDUCTED AT EOS
and
RESULTS ON RCS PRESSURE SWITCH MODEL 101038-0003, S/N's 1, 2, 3 & 4

---

1. Mechanical Configuration:

   Reference Installation Drawing No. 101038-0003 Rev. B, attachment #1.

2. Weight:

   2.1 Pressure sensor 19 grams

   2.2 Signal conditioner 59 grams

   Total, including cable = 83 grams

3. Connector:

   Reference Drawing No. 101038-0003 (see attachment #1).

4. Workmanship:

   Reference S/N 1 through S/N 4, "Traveller Sheets".

5. Identification Markings of Product:

   Reference "Engraving" Drawing No. 204154-0001, attachment #3.

6. Overpressure Rejection for Type I Pressure Switch (23 PSIA)

   6.1 Completed as part of Verification Test Plan; raw Xeroxed data included as attachment #4A, 4B, 4C, 4D.

7. Sensitivity of Switch Point to Variations in Supply Voltage:

   7.1 See attachment #5A, 5B, 5C, 5D.

   7.2 Maximum current drain (@ 37 Vdc supply voltage).

   S/N 1 4.74 MA.

   S/N 2 4.74 MA.

   S/N 3 4.76 MA.

   S/N 4 4.7 MA.

8. Transducer Characteristics:

8.1 Switching output signal:

S/N	"ON"	"OFF"
1	28 VDC	0.7 VDC
2	28 VDC	0.7 VDC
3	28 VDC	0.7 VDC
4	28 VDC	0.7 VDC

8.2 Output impedance:

Connector Pins:	BETWEEN B & C	BETWEEN B & D TIED TO C
S/N 1	40 K Ω	39 K Ω
S/N 2	51 K Ω	51 K Ω
S/N 3	45 K Ω	43 K Ω
S/N 4	13 K Ω	13 K Ω

8.3 Transducer response time:

Completed as part of Verification Test Plan; response of a typical Type I transducer ≪ 1.0 MS response from zero to peak pressure, from a shock wave front. Raw Xeroxed copy of Polaroid of output included as attachment #6.

8.4 Transducer insulation resistance:

S/N 1	>	Megohms	at	100 Vdc	= ∞
S/N 2	>	"	"	"	= ∞
S/N 3	>	"	"	"	= ∞
S/N 4	>	"	"	"	= ∞

8.5 Transducer "isolation" resistance (usually "input" from "output").

NOTE: All units have a common input and output pin: Terminal B. See attachment #1.

9. Threshold Variation with Temperature:

Data completed as part of Verification Test Plan. Thirty-six pages of raw data are included as part of attachment #7.

Witnessed by

EOS 7 4/4/67

J. Delmonte
J. Delmonte
Project Engineer 4.4.67

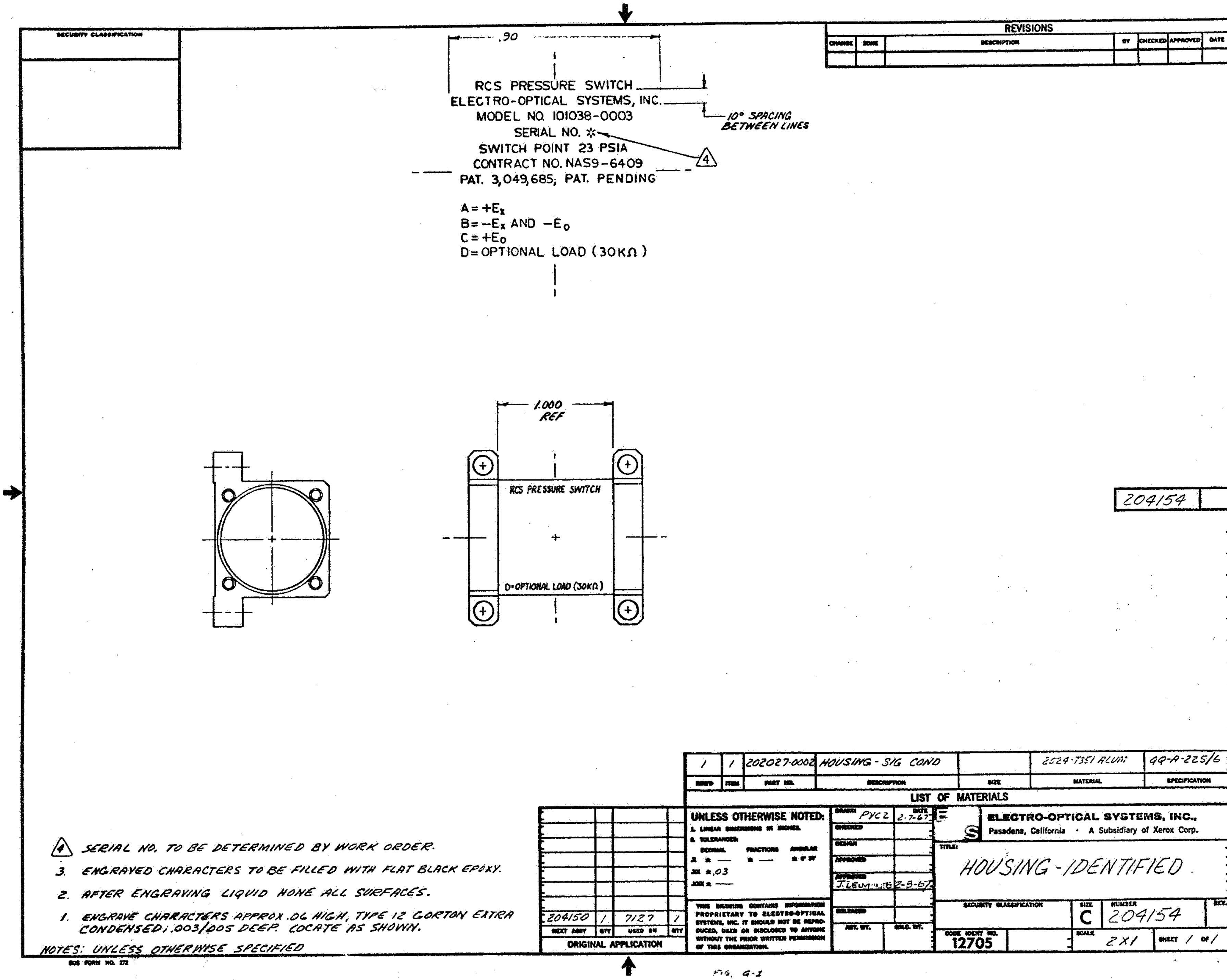

Figure G-1. Housing Identified