Frequency and Time Division-East
Salem Road, Beverly, Massachusetts 01915

HEWLETT PACKARD

Technical Report

HYDROGEN MASER FOR FIELD USE

Task M
Contract NAS8-2604

HEWLETT-PACKARD COMPANY

Frequency and Time Div. - East
Beverly, Mass.

HYDROGEN MASER RESEARCH

TECHNICAL REPORT ON
CONTRACT NAS8-2604 (Task M)

Dated: February 26, 1968

Period Covered: June 27, 1966 to January 30, 1968

Prepared by: R. Vessot and L. Mueller

Prepared for:

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NASA, Huntsville, Alabama

Distribution (11 copies)

Code	No. Copies
PR-RC	1
MS-IL	1
MS-T	1
MS-I	2
R-ASTR-ZI	1
R-ASTR-IRT (B. Reed)	4
R-ASTR-S (J. Gregory)	1

TASK M REPORT

I. INTRODUCTION

The objective of this task was to design and build a complete maser suitable for field use. This maser would incorporate the present cavity and bulb design of the maser for satellite applications being developed for NASA under Contract No. NASW-1337. A set of specifications was laid down that was to be followed as closely as possible. It is as follows:

Electrical

Output Frequency:	1420,405,751 Hz
Output Stability:	1×10^{-13} rms
Power Output:	-97 dbm ± 3 dbm
Prime Power:	115 V a.c. 60 cycle
Operating Temp. Range:	$26^0C \pm 5^0C$

Mechanical

Height:	42 inches max., 30 inches design goal
Width:	21 inches maximum
Depth:	26 inches maximum
Weight:	600 lbs. max., 400 lbs., design goal

Rack space shall be provided for additional electronics (installed by Government) 19 inches wide times 20 inches high times 3 inches deep.

Electronics for thermal and pressure control, high voltage for the ion pump, and r.f. power at 100 MHz for the atomic hydrogen dissociator were all to be contained within the cabinet. Space was allowed in the cabinet to enclose a 3-inch deep by 21-inch high electronics module for the maser synthesizer system. The maser is shown in Figure 1.

The general design philosophy was as follows. The maser would incorporate the latest developments in structure and electronics to provide as rugged and reliable an instrument as possible. Solid state circuitry would be used throughout. No moving parts, such as fans or blowers, would be incorporated. There would be serious consideration of r.f. shielding

Fig. 1. Completed Atomic Hydrogen Maser for Field Use.

HOUSE OF HINLIN
COMMERCIAL PHOTOGRAPHY
TEL. 356-3844
3 ELM STREET IPSWICH, MASS.

727/3

problems to minimize stray r.f. radiation. The r.f. discharge would be operated in a reliable manner with air convection cooling through r.f. tight apertures. The pressure control would be faster than in the previous designs to facilitate tuning.

Source pressures would be pre-set at two levels to allow tuning. A convenient panel with a multi-position switch and a single meter would allow monitoring of the essential voltages and currents. The magnetic field solenoid would be controlled by calibrated multi-turn potentiometers in the three windings that constitute the main solenoid. The cavity tuning varactor diode, located inside the cavity, would be controlled by a precision voltage divider operating from a separately controlled voltage supply.

In the design of such an apparatus as described above, thermal control of the cavity is necessary to prevent pulling the hydrogen output frequency by thermal mistuning of the cavity. A first order correction for temperature dependence of the cavity resonance frequency can be made by designing the cavity so as to be temperature compensated by having a thermally moved end plate that decreases the length of the cavity sufficiently to compensate for the radial expansion of the cavity. Due to the dielectric loading of the cavity by the quartz storage bulb, it is difficult to calculate the required rate of compensation; further, the presence of temperature gradients will degrade the compensation.

The present design has a double oven enclosing the cavity; the inner oven runs at 46^0C, the outer at 43^0C. To prevent changes in cavity temperature due to heat leakage through the cavity supporting structure, the main mounting plate is temperature controlled. This main structural member attaches the maser to the cabinet enclosure which has an insulated zone that surrounds the oscillator assembly. Insulating spacers are used to mount the maser in the cabinet. Calculations of thermal conductivity of the structure predict that if the temperature of the mounting plate is kept within $\pm 0.3^0$C, the bell jar enclosure should not vary more than $\pm .012^0$C. With the present cavity design, the fractional frequency shift due to these temperature changes will not exceed 1×10^{-13}.

By keeping such an enclosure at constant temperature, it is possible to stabilize the low level temperature sensing electronics, the pressure sensing electronics and the voltage control system for the varactor tuner. The pirani gauge for sensing the hydrogen pressure in the atomic hydrogen dissociator also operates in this stabilized enclosure.

II. CONSTRUCTION

At the time of the beginning of Task M the design of the satellite maser had progressed to a point at which the construction of a laboratory prototype was begun. It was decided that the successful test oscillation of this prototype at low magnetic fields would be the signal for beginning the layout of the maser for this contract. On April 3, 1967, the satellite maser prototype was oscillated at low fields (less than 1 millioersted) and at this point the cavity, bulb, magnetic field and oven structure was adopted. The remaining structure, consisting of an ionization-type vacuum pump (or VacIon® pump), was somewhat different in that a heavier pump having more capacity was used. Since there was no weight problem in this maser, an eight-element Ultec pump (Model No. 20-185) was used as the basis for the vacuum chamber. The length of this pump was cut down and the high voltage connections and other vacuum feed-throughs were redesigned. The diameter of the pump, including the necessary magnetic shields, could still be made close to the diameter of the magnetic shields of the maser cavity section and no increase in overall size of the package resulted.

A schematic of the oscillator portion of the maser is shown in Figure 2 and in a cutaway drawing, Figure 3. Structurally, the whole system is fastened to a stiff mounting plate located between the cavity and pump assemblies. The vacuum envelope consists of the eight-element pump joined to the cavity enclosure by a thin-walled flexible neck that goes through the mounting plate. The pump is held to the mounting plate by four studs with spacers to allow two layers of magnetic shielding about the pump magnets. The inner shield is a capped cylinder made of Armco. The outer shield is a concentric canister spaced three-fourths of an inch from the inner shield and is made of .030 inch moly-permalloy. Both shields are open at the hydrogen dissociator end to allow access to the hexapole magnet via a flanged part that mates with the flange that incorporates the glass r.f. discharge structure and the gas handling system.

® Varian Associates.

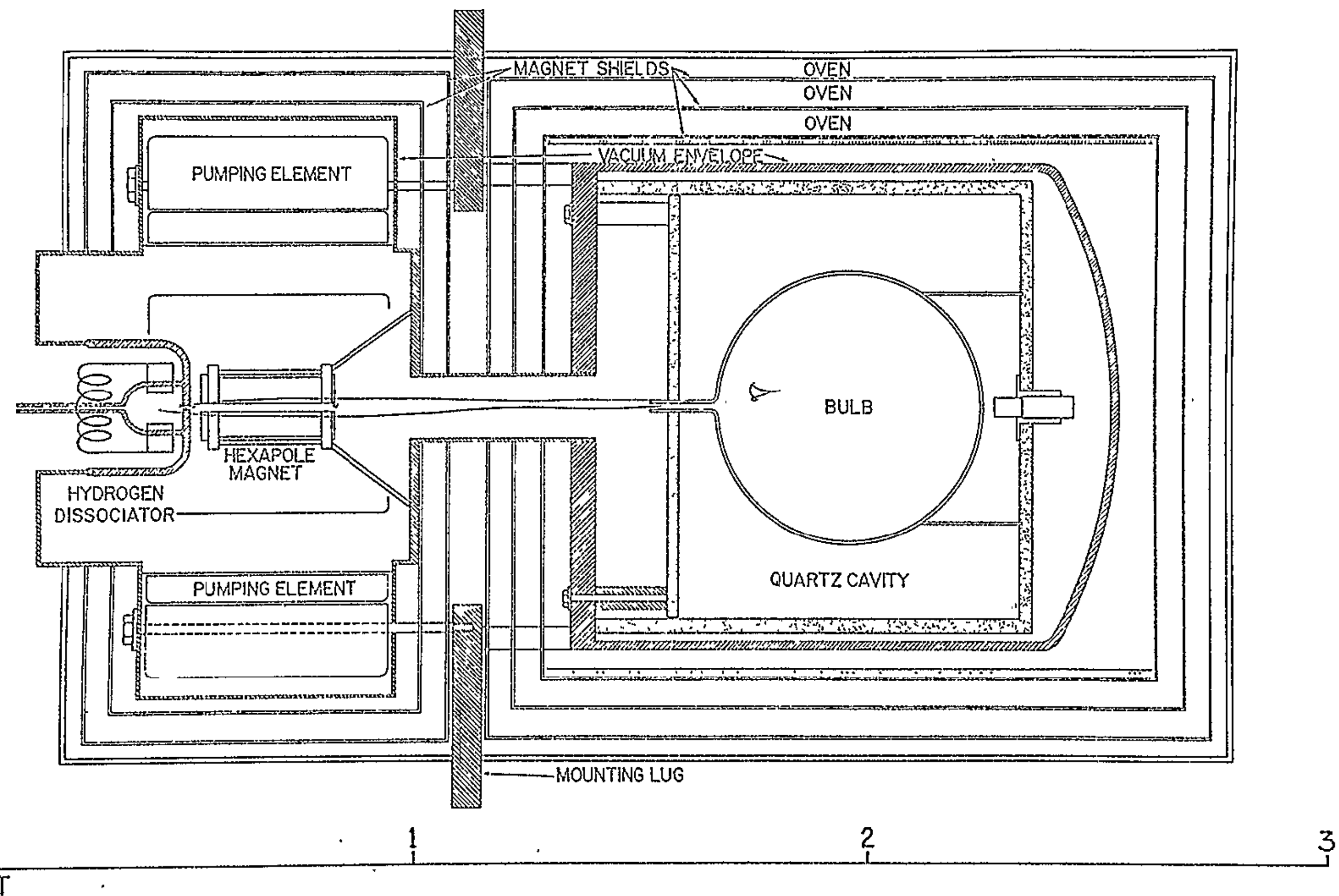


Figure 2. Schematic View of Maser Oscillator.

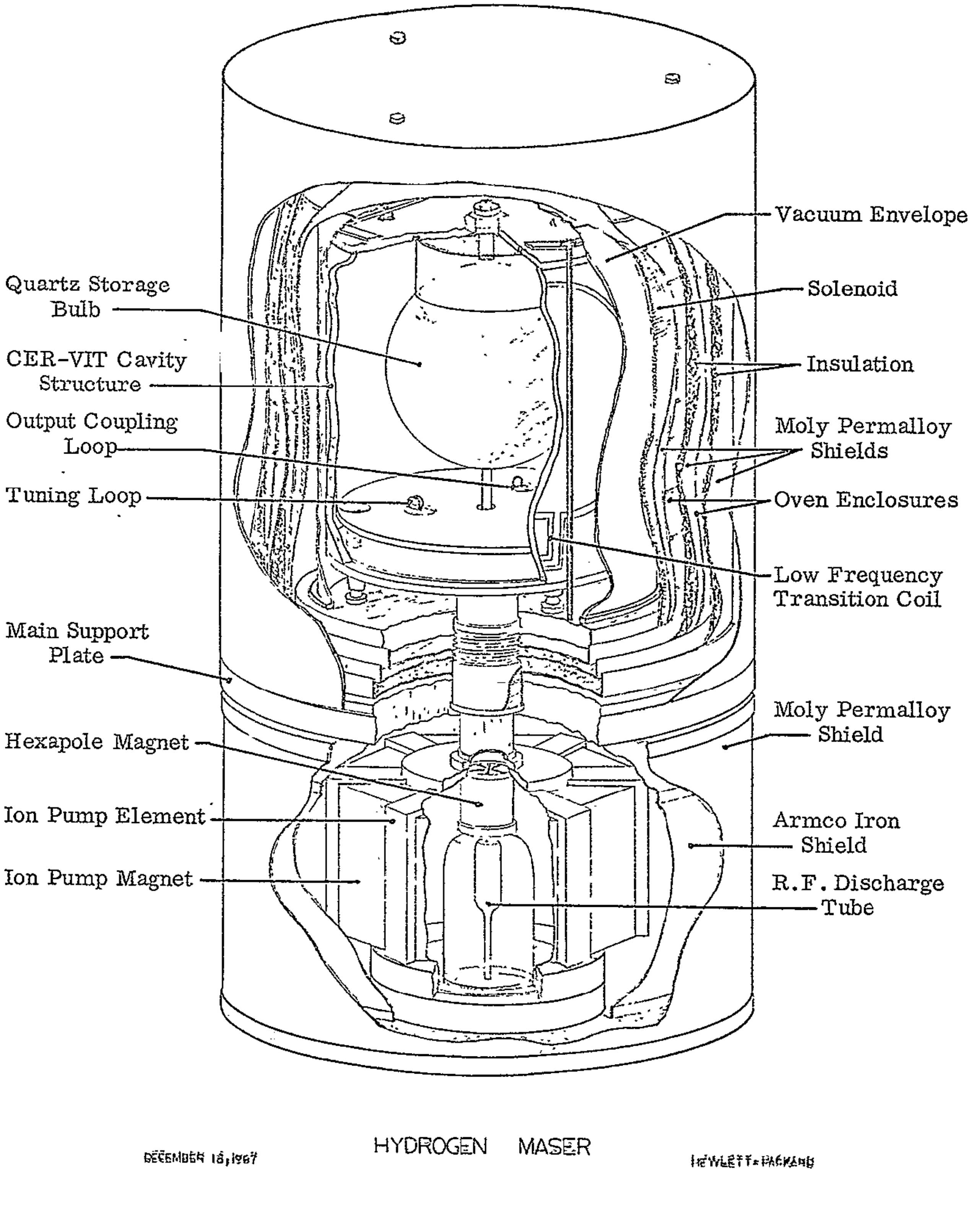


Figure 3. Cutaway View of Maser Oscillator.

A. The Hexapole Magnet

The hexapole magnet is fastened to the end of the pump nearest the cavity using studs and an adjustable three-point mounting flange to permit aligning the magnet between the source aperture and the bulb aperture. The state selector is a 1/8" diameter hexapole magnet 3½" long, made as shown in the sectional diagram, Figure 4. The exit aperture of the magnet incorporates a stopping disc .060" in diameter that prevents atoms from the wrong states entering the bulb. It is also meant to scatter the molecular hydrogen that results from the incomplete dissociation at the source and to keep it from being beamed into the bulb. The magnetic field strength at the pole tips is about 8000 gauss and the length is chosen so as to be optimal for focussing the atoms having the most probable velocity in the beam emerging from the dissociator.

B. The R. F. Discharge and Gas Handling System

The r.f. discharge structure is made of Corning 7740 Pyrex glass graded to 7052 glass that in turn is sealed to a Kovar sleeve welded into the stainless steel flange. It is excited by about 15 watts of r.f. power at 100 MHz. The excitation is obtained by electric coupling to the electrons in the plasma by a resonant step-up transformer. About 300 volts rms at 100 MHz is applied to the discharge tube. Since the r.f. structure is at the top of the maser, cooling by natural convection of air is possible. R. F. leakage is minimized by a special multi-channel cover over the flange that admits air but prevents r.f. leakage due to the waveguide beyond cut-off behavior of the channels. The atoms leave the source structure through an aperture .030" in diameter leading to a multi-tube collimator array. The pore diameter is 0.001", collimator length is 0.020" and the net transparency of the array is about 75%.

Hydrogen flow control is obtained by the usual heated palladium valve operating at a pressure of about 1000 p.s.i. An improved design of this valve allows changes of pressure to be made in about 40 seconds. The design is reproducible and makes use of a ceramic cup-shaped heater that gives improved efficiency over the previous type of hydrogen controller. Pressure sensing is

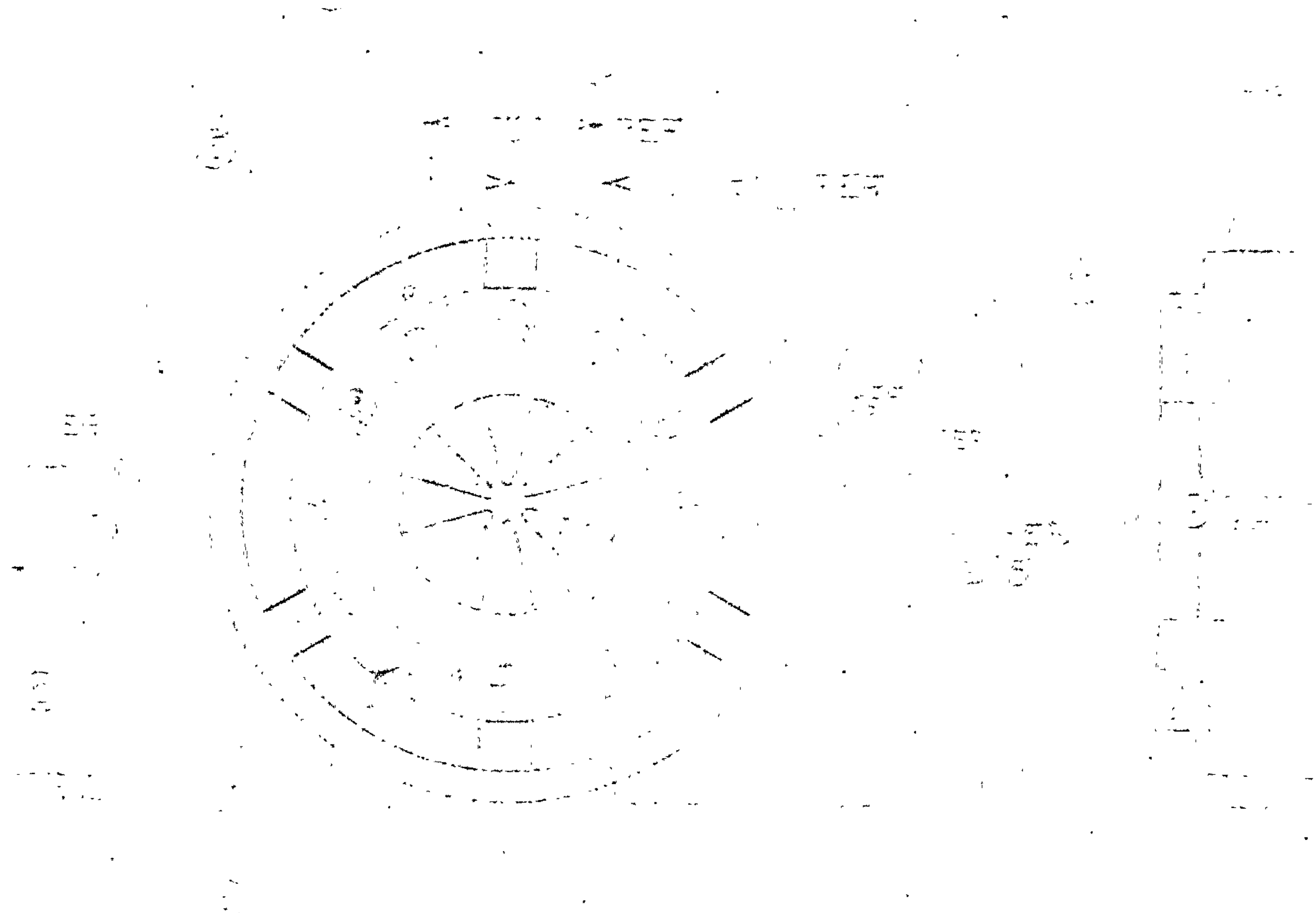


FIG. 4

ABSTRACT:
C-34965-

performed by a Fenwal Type No. GA51 T4 thermistor bead pirani gauge in a demountable metal sealed vacuum joint. The temperature reference for the pressure sensing pirani gauge is provided by the cabinet temperature control.

C. <u>The R. F. Cavity and Bulb</u>

The r.f. cavity and bulb configuration is basically the same design as made for the first development of the satellite maser under Contract No. NASW-1337. A 7-inch diameter spherical bulb is used as it is reasonably near the optimum filling factor for a cavity whose length and diameter are equal. The fused silica bulb is fastened to the cavity end plate by means of a 6-inch diameter cylindrical skirt made of fused silica. The cavity cylinder is made of opaque fused silica. The cavity is constructed to allow frequency compensation by thermal expansion of three posts supporting the end plate nearest the source. These posts are referenced to the end of the cavity cylinder by a fused silica ring that serves as the support for a three-ball kinematic mounting structure connecting the cavity to the bell jar base. A calculated pre-load force is applied to the top of the cavity from the base plate by six silicon bronze rods and six springs.

The cavity can be coarsely tuned mechanically by means of metal shims at the three compensating posts; finer tuning is performed by an axial plunger at the other end of the cavity. These mechanical adjustments are made prior to assembling and pumping down the maser. The resonance frequency is set to mid-range on the electronic tuner using these mechanical adjustments.

Electronic tuning is performed by magnetically coupling a variable capacitor to the fields in the cavity using a small, one-turn loop across a varactor diode. The range of cavity tuning is adjusted to be 3 Kc. for a voltage range from 1 to 10 volts. The diode voltage is brought through the vacuum envelope at the pump and care is taken to prevent grounding the diode circuit to the cavity surface.

The cavity output coupling loop is connected via coaxial cable to a vacuum feed-through at the pump. The outer conductor provides the only ground connection to the cavity.

Magnetic field intensity averaged over the volume of the bulb is measured by making transverse r.f. magnetic transitions excited from a two-turn low frequency coil made by a conducting silver coating in the form of two loops painted on the exterior of the cavity cylinder. Connections are made to a vacuum feed-through at the pump.

The cavity is enclosed in an aluminum bell jar that is clamped to a captured viton "O" ring joint at the bell jar base. A vacuum connection from the base to the pump is made via a thin-walled silicon bronze bellows 2 inches in diameter. The mechanical connection of the base to the main mounting structure is made by six 1/4" titanium studs and Stycast® bushings to space the three oven and magnetic shield end caps.

Surrounding the bell jar and mounted to the bell jar base is the C-field solenoid coil form. Windings are distributed on this form to provide a uniform magnetic field over the volume of the bulb. Three separate coils are wound taking care to locate go and return wires close together.. The solenoid is surrounded by a close fitting moly-permalloy magnetic shield which is in turn surrounded by a close fitting aluminum can. This serves as an isothermal layer onto which the heaters are wound. A similar combination of aluminum and moly-permalloy cylinders form the outer oven and second magnetic shield combination. The magnetic shields are spaced 3/4" apart and the gap is filled with fiberglass wool insulation. A third set of aluminum and moly-permalloy cylinders encloses the maser and is spaced to obtain 3/4" between magnetic shields and is insulated, as before, with fiberglass wool. The end caps have thermal insulating bushings as spacers and are held in place by 1/4" titanium rods.

The overall dimensions of the oscillator package are 19" diameter by 33" long. This package is bolted onto a set of rails in a standard steel cabinet 42 1/2" high by 21" wide by 27" deep made by EMCOR. Thermal and electrical isolation of the oscillator from the cabinet is obtained by Stycast® spacers. The space remaining leaves ample room for the 19" by 20" by 3" enclosure specified in the contract for synthesizer electronics and for maser electronics systems.

® Emerson & Cuming, Inc.

III. MASER ELECTRONICS SYSTEMS

To support the operation of the maser the following control systems and power supplies are required:

1. Power supplies:
    a) 28 volt d.c. unregulated;
    b) 3 K volt unregulated VacIon supply;
    c) + 15 volt d.c. regulated;
    d) - 15 volt d.c. regulated;
    e) 20 volt regulated;
2. 100 MHz r.f. amplifier oscillator;
3. Varactor diode voltage control;
4. Magnetic field current control;
5. Hydrogen pressure control;
6. Inner oven thermal control;
7. Outer oven thermal control;
8. Cabinet and midriff thermal control.

A. Electronics Packaging

The power supply and all the low power dissipation components are located within the thermally controlled enclosure. External to this enclosure are located the power supply rectifiers, r.f. oscillator, amplifier and its power supply regulator, and the current controlling transistors for the inner oven, outer oven, cabinet temperature and pressure controller.

Construction of the inner oven, outer oven and cabinet temperature controllers is in aluminum modules that plug into a chassis that pivots outward near the bottom of the access panel. The r.f. power supply is located at the top of the maser and uses part of the top panel as a heat sink. The steel rear door of the cabinet is faced with an aluminum panel for heat sinking the remaining current control transistors.

B. Power Supplies (C-350259)

The power supplies shown are the + 28V, ~10 ampere supply with capacitor filter, two 24V, 1.5 ampere supplies with Pi network LC filters used for the precision positive and negative 15 volt regulators, and the 2.4 KV supply for the ion pump.

The 2.4 KV supply utilizes a "soft" transformer which has a short circuit current limit of approximately 300 ma. that provides protection for the ion pump during pump start and in the event of an oversupply of hydrogen.

The +15 volt and - 15 volt supplies (B-350262 and B-350310) are used to supply regulated voltages to all the circuits (except the r.f. circuits) in the maser electronics. The Pi network filters in the rectifier assembly reduce the 120 Hz ripple to approximately .1 volt, and the regulator circuit filters reduce the ripple to less than 1 mv. In addition to providing line and load regulation of approximately .05%, the regulators also provide current limiting at 200 ma.

The - 15 volt supply is designed to track the +15 volt supply so that any change in the output voltage of the positive supply is compensated by an equal but opposite change in the negative supply, thus providing improved stability in the differential amplifiers used in the control circuits.

A separate regulator circuit (C-350276) is provided for the r.f. amplifier and oscillator. The circuit for this regulator is similar to that used in the +15 volt regulator with the following exceptions: the output current is a maximum of approximately 2 amperes, the output voltage is adjustable from 17.5 to 22.5 volts, and the current limiter is adjustable. These adjustments were designed to permit greater flexibility in the use of the r.f. amplifier and oscillator circuits. This regulator operates from the +28 volt supply and is separately controlled from the r.f. switch on the control panel.

Power to the r.f. switch is interlocked through the hydrogen switch so that the r.f. may not be applied when hydrogen cannot be present in the discharge tube.

The 100 MHz r.f. amplifier-multiplier manufactured by American Electronics Corp. requires a 5 MHz, 1 volt rms input which is supplied by an Accutronics crystal controlled oscillator. The output of the r.f. amplifier is fed to a lumped constant circulator which protects the amplifier from the severe mismatches which may be encountered in operating an r.f. discharge.

The varactor diode voltage control module (A-350296) consists of a .001%/^{0}C temperature compensated reference diode, which operates inside the temperature controlled cabinet, from the +15 volt supply. The nominal 11.4 volt output from this reference is applied across the input terminals of an E.S.I. Model 1211, .003% resolution Kelvin-Varley voltage divider. The output voltage from this source is connected to the tuning varactor in the maser cavity.

The field control circuits (C-350277) use a potentiometer operating from the +15 volt supply to provide an adjustable voltage to supply the field coils. Series resistors are used with the coils to limit the maximum current which can flow for each range switch position. A reversing and off switch is provided, as is a three-digit readout on the potentiometer setting.

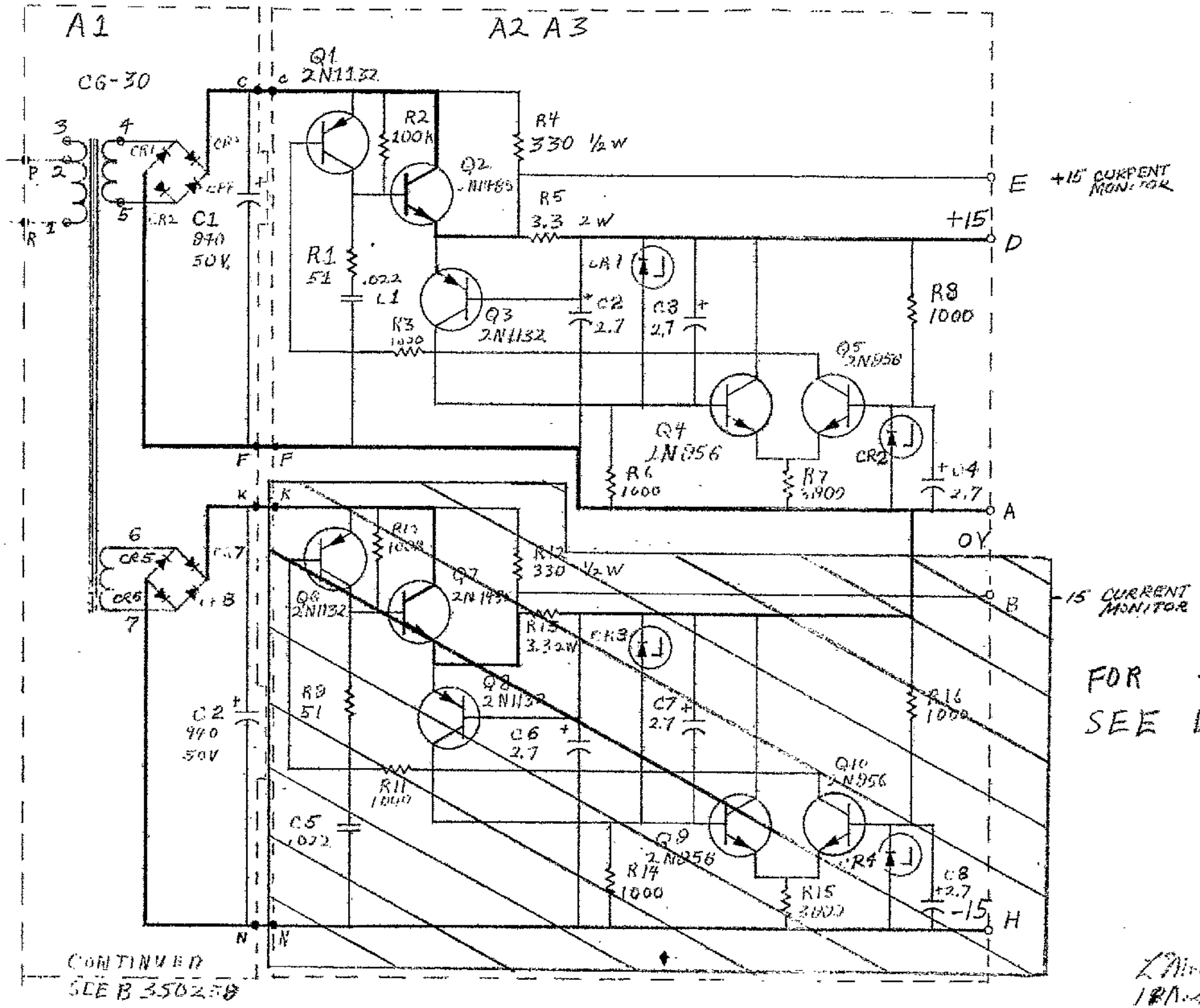
The pressure controller (C-350299) circuitry continuously monitors the pressure in the discharge region. To accomplish this a small thermistor (.010" bead) is mounted inside the vacuum envlope so that the thermistor bead is cooled by gas at the discharge region pressure. A servo circuit (Z1) is connected to this thermistor in such a way that the voltage across the thermistor can be varied by the servo output. An effect of changing this voltage is to change the self-heating of the thermistor and thus its temperature and resistance. The input to the servo circuit requires that the resistance of the thermistor be constant. Thus the output voltage of the servo is an indication of the amount of power required to keep the thermistor at a constant temperature. The removal of heat from this thermistor by the gas in the discharge pressure region then changes the voltage necessary to keep the thermistor temperature constant. This output voltage is metered to give a pressure indication. Z3 is used as a voltage reference which is adjusted so that the output voltage from the pressure monitor servo is 0 volts when the pressure in the maser is less than 10^{-5} torr.

Z2 is the servo control amplifier which compares the measured pressure with the desired operating pressure setting (A3 R3 or A3 R4) and changes the heater power for the palladium valve to cause hydrogen to be admitted to the system at the proper rate to maintain the set pressure in the discharge region. The two pressure set potentiometers have been previously mentioned. The relay A3 K1 and push-button switch lights are arranged with the two controls so that only one control is used at a time. In the nonenergized position of the relay, the green low pressure lamp is lighted, and the low pressure control is operative. Pressing the high pressure button energizes the self-holding relay circuit, lights the red high pressure lamp and connects the high pressure control to the controller servo. Subsequent pressing of the low pressure button will de-energize the relay, etc.

A positive off is provided for the hydrogen input system. The hydrogen switch on the control panel removes power from the palladium valve and the r.f. circuits, turns off the pressure indicator lamps and resets the relay logic to the low pressure mode. Thus any interruption of power to the maser will cause the control logic to set for low pressure.

The inner oven controller (C-350273) is a d.c. proportional control servo designed in such a way that the thermistor self-heating is used in the Z1 servo loop to provide anticipation of the set operating temperature. This is used to improve the response time and transient stability of the control circuit. Z2 is used as a voltage amplifier to provide the correct gain for the designed stabilization factor, and to drive the output amplifiers.

The outer oven (C-350267) and cabinet heater (C-350309) controllers are quite similar to each other, differing only in the heater load connections. These controllers are similar to the inner oven controller in operating principle, the differences here being in the lower gain required and in the details of the voltage and output amplifiers.



CAPACITORS IN μF, 25V TANTALUM EXCEPT AS NOTED. (A2A3) C1, C5 CERAMIC (A1) C1, C2 ALUM. ELECT

RESISTORS ¼W 5% except as noted.

(A2A3) CR1, CR2 & (A2A3) CR3, CR4 MATCHED AS PAIRS SUCH THAT SUM OF VOLTAGES @ 7ma = 15.0V

FOR -15V REGULATOR SEE DWG B 350 310

CONTINUED SEE B 350258

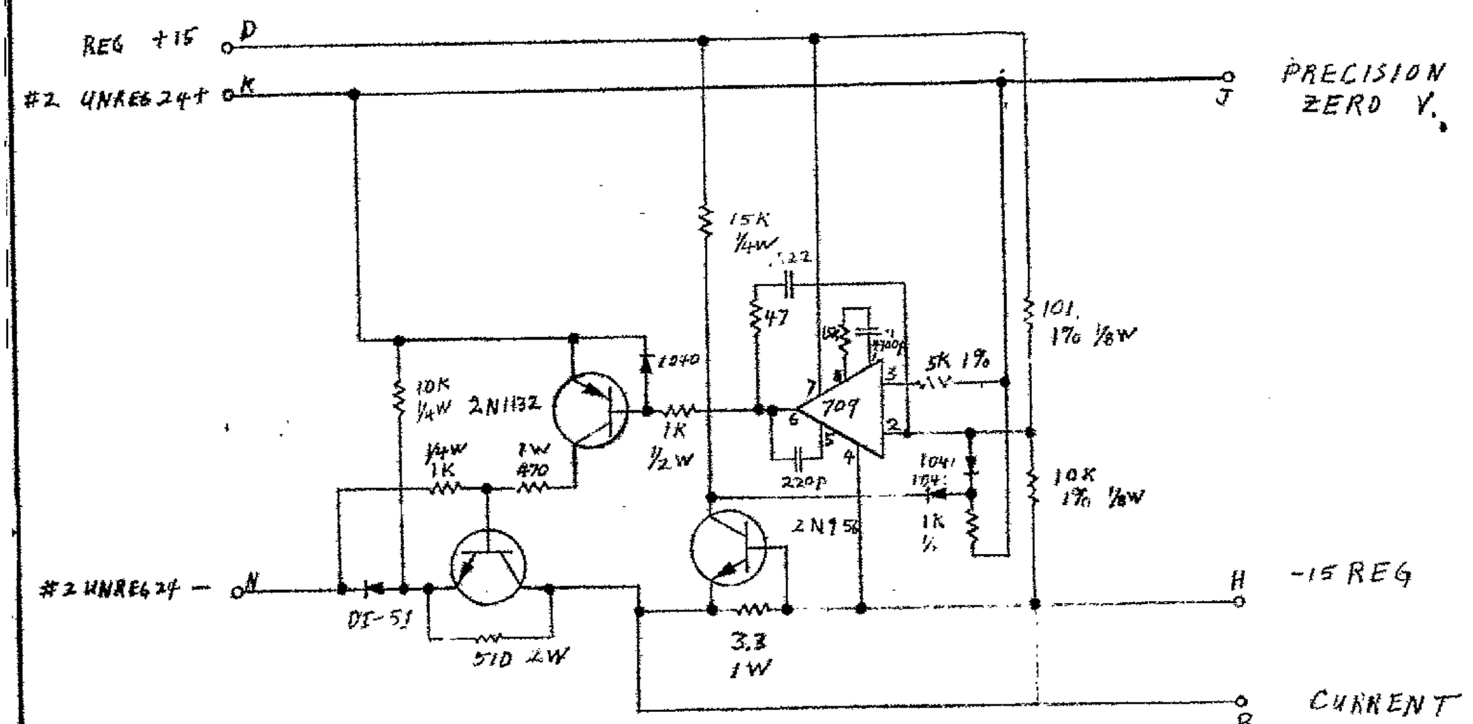
SCHEMATIC
POWER SUPPLY
+/- 15 VOLT

1-4-67

B 350262

B-350-310 -

SYM	REVISIONS	APPROVED	DATE



ENG. RESP. — DIV.	ITEM	QTY	DESCRIPTION	PART NO.	DWG. NO.	MAT'L SPEC.

UNLESS OTHERWISE NOTED
— TOLERANCES —

0.XX ±0.02 0.XXX ±0.005

ANGULAR ±

MACHINED SURFACES 63

— DO NOT SCALE —

DRAWN	DATE	TITLE
ENGINEER		SCHEMATIC, NEGATIVE 15 VOLT POWER SUPPLY
APPROVED		
SUPERSEDES B-350-310	1/3/68	FINISH / SCALE

HEWLETT PACKARD
LABORATORY INSTRUMENTS

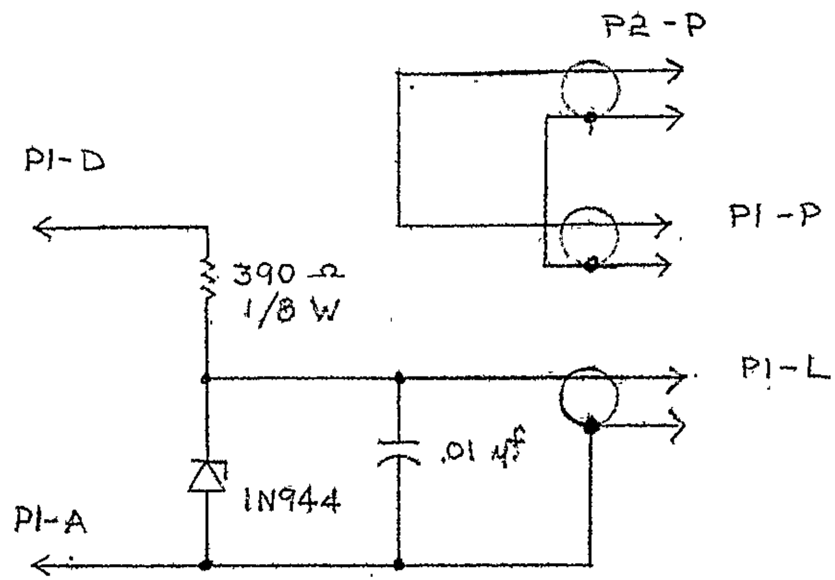
NEXT ASSY.

B-350-310 -

SHEET —

A-350 -296 -

SYM	REVISIONS	APPROVED	DATE



ENG. RESP. — DIV. F. & T. EAST

ITEM	QTY	DESCRIPTION	PART NO.	DWG. NO.	MAT'L SPEC.

UNLESS OTHERWISE NOTED
— TOLERANCES —
0.XX ±0.02 0.XXX ±0.005
ANGULAR ±
MACHINED SURFACES 63
— DO NOT SCALE —

DRAWN	DATE	TITLE
[signature]	1/2/68	VARACTOR CONTROLLER A2A4
ENGINEER		
[signature]	2 Jan 68	
APPROVED		
SUPERSEDES		FINISH / ~~SCALE~~

HEWLETT PACKARD
LABORATORY INSTRUMENTS

NEXT ASSY.
A-350 -296 -

SHEET —