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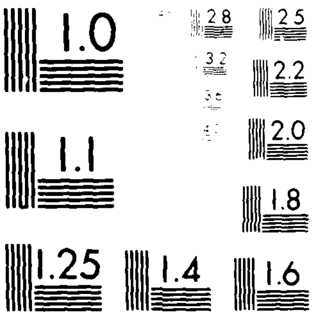

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STUDY OF CRYOGENIC TECHNIQUES FOR OPERATING HYDROGEN MASERS

Contract N00014-77-C-0777

Interim Report
For the period from 1 May 1981 to 31 March 1982

MARCH 1982

Prepared for
OFFICE OF NAVAL RESEARCH
800 N. Quincy Street
Arlington, VA 22717

Prepared by
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Cryogenic Techniques are applied to the Atomic Hydrogen Maser Frequency Standard to extend the storage time of the atoms and reduce the thermal noise accompanying the signal and within the resonance linewidth. One maser system is completed and installed in the cryostat. The wall coating gas handling system and the pulse and cavity measuring systems are now available for testing. A new cold dissociator has been built, tested and installed on the maser. In addition, two electronic control systems have been completed. Additional tests will be conducted. Stability at the 1×10^{-16} level in $\Delta f/f$ for averaging time intervals of 1,000 seconds is expected at temperatures below 30K.

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PROGRESS REPORT

STUDY OF CRYOGENIC ATOMIC HYDROGEN MASER OPERATION

O.N.R. Contract N00014-77-C-0777

Principal Investigator: Dr. R.F.C. Vessot
Co-Investigator: Dr. E.M. Mattison

1. INTRODUCTION

The purpose of this program is to build, operate and evaluate the short term frequency stability of two cryogenic hydrogen masers of the same design, and to study the interaction of hydrogen atoms when they collide with the surfaces of various materials. Funding for this study and experimental test series has been jointly provided by the Office of Naval Research, the Smithsonian Astrophysical Observatory, the Jet Propulsion Laboratory of the National Aeronautics and Space Agency (NASA) and in the last year, by NASA'S Marshall Space Flight Center. This recent support was for the development of an atomic hydrogen dissociator system to operate below 77K. The current status of this phase of the activity is given in Appendix I.

The composite program consists of :

(a) Designing and building 2 masers, each [illegible] own cryostat. This includes the electronics systems for controlling magnetic fields, temperature and atomic hydrogen flux. One unit would, as much as possible, be identified with the J.P.L. support of this effort.

(b) Building cold, low noise electronics to be housed in a third cryostat and later to be incorporated in each of the two maser cryostats.

(c) Developing a hydrogen atomic beam source to operate at or below 77K.

(d) Developing and implementing a test program for low temperature maser operation and operating the maser using various types of wall coatings in the atomic hydrogen storage volume.

The principal objective of the work is to study the interaction of atomic hydrogen on various surface coatings frozen in place at low temperatures. We are interested in seeing how the hyperfine structure of atomic hydrogen is altered by the collision process and to relate this structure to the interatomic potential function developed during collisions. We will determine the average phase advance (or retardation) of the oscillating dipole moment of the hydrogen atom and its phase dispersion by measuring the wall frequency shift and line broadening of the (F=1 m_F=0) to (F=0, m_F=0) transition using the maser technique under two conditions: (1) with the maser oscillating and (2) under sub-threshold conditions where pulsing techniques will be used.

Our plan is to operate the atomic hydrogen maser at temperatures between 4K and 77K and apply storage surface coatings by introducing into the storage volume gases that will freeze in place to form the storage surface. We will measure the wall collision frequency shifts and the relaxation processes as a function of temperature for various coatings.

During the last year the cold maser, the cryostat and the test setup were assembled. The system was evacuated and we have begun testing at cryogenic temperatures.

2. OBJECTIVES OF THE COLD MASER RESEARCH PROGRAM

The possible advantages of operating a hydrogen maser at the temperatures well below room temperature have been speculated upon for many years, but until recently the prospects for successfully operating such a device at temperatures significantly below 77K seemed marginal. In 1976 Kleppner and his co-workers[1] demonstrated that atomic hydrogen could be contained at 4K in a vessel whose walls were coated with frozen molecular hydrogen. This gave considerable impetus to investigate the behavior of the hyperfine resonance at temperatures below 77K, which was the temperature limit explored by M. Desaintfuscien[2] and others in their 1974 research into wall relaxation and wall coatings.

In 1977 work began at SAO on a very crudely lashed-up liquid helium cryostat that contained a TE_{111}-mode split storage volume resonator[3] with fluorinated ethylene propylene copolymer (FEP) Teflon coated walls. At first, oscillation could only be sustained down to temperatures of about 55K. Why it would not oscillate below this temperature was open to many questions -- were the walls of the storage volume contaminated because of the rather crude vacuum system we employed, or was there a more fundamental limit imposed by the nature of the atomic hydrogen in its collision with the FEP surfaces? To answer these questions we decided to try a different approach with the cold maser. This was to introduce carbon tetrafluoride (C_2F_4) gas through the hydrogen source structure and freeze a coating of this gas on the inside surfaces of the cavity storage volume. This technique provided a fluorine-bonded-to-carbon surface comparable to the long chain fluoride molecules of Teflon. The scheme worked and greatly to our delight, we were able to maintain oscillation down to temperatures of 26K.

This work was reported[4] and we continued theoretical studies to determine what advantages would accrue if we could operate at or below 26K.[5]. From theory we know that the stability would be well below 1 part in 10^{16} at 1000 seconds provided no new instability problem arose. However, we know that the large temperature-dependence of the wall shift is likely to cause difficult requirements for temperature stabilization in the cold maser.

The chief objective of this program is to measure the wall shift and wall relaxation parameters of atomic hydrogen on surfaces formed by freezing substances that are gaseous at room temperature onto the interior of the maser's atomic hydrogen storage vessel.

Making such measurements requires a far more carefully designed apparatus than the original system. Since there are a number of candidate substances to freeze in place, we felt it was desirable to have two separate systems so that tests on one system could be made while the other system was being modified.

Eventually two such devices would be required in order to make short-term stability data, since no other device than a similar maser could be expected to provide comparable short-term stability as a reference.

Support for construction of two masers was obtained from the Office of Naval Research[*], The Smithsonian Institution[**] and the Jet Propulsion Laboratories of the California Institute of Technology[***]. This long-term program was launched on 30 September 1977. The plan is to measure the properties of neon, carbon tetrafluoride, sulphur-hexafluoride, argon and coatings of other substances. The data to be measured are the frequency shift, oscillation level and line Q, from which will be calculated the phase shift per collision and the phase dispersion per collision. These parameters would then be related to the theoretical structure of the interactions of atomic hydrogen with solid surfaces.

[*] ONR Contract No. N00014-77-C-0777

[**] Smithsonian Institution Scholarly Studies Funds

[***] J.P.L. Contract No. 955633

3. MECHANICAL CONFIGURATION OF THE COLD MASER

The design of the maser cryostat required considerable effort and imagination to foresee the many uses to which it could be put in a cold maser testing program. First, it had to be reliable structurally. Secondly, it had to allow for a reasonably large volume of magnetically undisturbed space to house a variety of possible maser cavity and magnetic shielding configurations. We decided that if we had uncertainties in these dimensions it would be better to go to a larger, rather than smaller, volume. As an upper limit, we should be able to house the full size TE_{011} mode cavity and inner magnetic shield design as used in the lightweight space-probe maser.[6]

The question of the range of operating temperatures was also an issue. Our previous success in obtaining oscillation at temperatures as low as 26K suggested that we should cover the range from 77K to somewhere near 4.2K with provision for stabilization at any point between these temperatures. This was done by a constant-loss, slowly metered flow of liquid helium, whose latent heat of vaporization and gaseous heat capacity would be used to offset the heat leakage into the cavity system. Using a slightly greater flow of helium than required to maintain this balance, electrical resistance heating can be used in an active servo-control system to hold the temperature at its desired level.

For temperatures below the liquid-helium boiling point, we included provisions to change our method of cooling and can connect the cavity directly to the helium bath. By pumping on the helium gas, we can drive the temperature well below 4K.

Additionally, we wanted to have a reasonably large capacity for helium so that disturbances from filling would occur only after about 5 days of steady operation . Since the projected cavity and shielding structures that would be cooled tended to be quite massive and the apparatus itself would be rather large, we decided to use a liquid nitrogen guard region to surround the liquid helium container and the sample region. This reduces the cost of cryogens used for initial cooling and allows more flexibility of operation. It also eliminates the need for multi-layer reflective insulation (superinsulation) and the ensuing outgassing problems that could lead to surface contamination in the atomic hydrogen storage volume of the maser.

3.1 FINAL DESIGN OF THE CRYOSTAT

The final design of the SAO cold hydrogen maser cryostat is shown in Figure [1]. The fact that the liquid helium and nitrogen tanks are above the region to be cooled is dictated by the need for a gravity feed of cryogen to the cold region that lies below the tanks.

The annular 30 liter liquid nitrogen tank is thermally connected to an equipment mounting plate of copper beneath it and to a heavy copper shroud surrounding the working volume roughly 22 inches (56 cm) in diameter x 22 inches (56 cm) deep. Inside it is the 30 liter liquid helium tank which has a flat base plate for mounting equipment to operate at 4K. The cavity resonator is suspended from a sample holder connected to the liquid helium tank by a tube leading to a needle valve in the helium tank by which the flow of helium is controlled. The sample holder is thermally isolated by being attached to a point near the top of the helium tank, allowing it to operate at temperatures substantially above 4K. The magnetic shield assembly is suspended by thermally conducting rods from the nitrogen tank and is kept near 77K to prevent the excessive loss of magnetic shielding to the reduction of magnetic permeability at very low temperatures.

All the components are mounted on the 26 inch (66 cm) diameter top plate of the cryostat which is vacuum sealed by an "O" ring to the vacuum enclosure. Access is gained to the assembly by lifting the plate out of the enclosure using a crane as shown in Figures 2a and 2b.

To obtain reasonably fast pumping with good cleanliness to permit outgassing at the 10^{-8} torr level, we purchased a Leybold-Heraeus turbo-molecular pumping system with 450 l/second throughput. This is intended to operate the system when it is at or above 77K. When liquid helium is used, the 4 inch diameter Varian Associates gate valves are closed and the systems will cryopump so that all gases but helium will condense on the helium tank.

The forepump used to back up the turbo pump is a 17 liter/second Welch Model 1397 mechanical pump that can be directly opened to the cryostats for rough pumping. During this cycle of evacuation a smaller 2.6 liter/second Welch model 1402 mechanical pump is used as a forepump for the turbo pump. Thermocouple gauges in the forelines and a Varian model 973-5028 "Smart" gauge in the high vacuum lines provide vacuum diagnostics and aid in leak checking. To prevent a high positive pressure developing in the vacuum system when it is brought to room temperature, owing to the possible revaporization of large amounts of condensed gases on the liquid helium dewar, a pressure relief valve is installed in each cryostat.

3.2 FABRICATION OF THE CRYOGENIC DEWAR SYSTEMS

A preliminary design of the cryogenic maser was made in early January 1980 and with sketches of the design concept in hand, meetings were begun with dewar manufacturers to obtain suggestions and establish a realistic cryostat design to meet the goals of the cryogenic maser program. During the first quarter of 1980 we arrived at a preliminary concept for the dewar and made drawings for bidding purposes by vendors. In April 1980, requests for quotations were sent to a number of manufacturers and bids were solicited for a cryostat capable of long-term operation (3-4 days) at a fixed temperature (between 4 and 30K). In early May a vendor was selected and JPL approval was requested for purchasing one of the two cryostats on the JPL contract. On 19 May 1980 approval was received and the order was placed. Although the vendor's promised delivery was 19 September 1980, actual delivery to SAO was delayed until 1 December 1980. The cryostats were tested at the manufacturer's facility. Both units displayed excellent vacuum integrity and adequate hold times of several days for LN_2. From helium evolution tests, 4 to 5 days of liquid helium containment time have been estimated. The units were then shipped to SAO. A test area was prepared and the units were set in place.

3.3 CRYOGENIC MASER DESIGN, FABRICATION AND ASSEMBLY

Design of the cryogenic maser to be located within the cryostat proceeded in conjunction with the cryostat design. Once the cryostat design was established and the order placed in May 1980, the cryogenic maser design was subsequently established. Magnetic shield design was completed, vendor quotes were solicited in July and orders were placed in August 1980. The shields were received in October, 1980. The dissociator housing and glassware mounting hardware were ordered from the Harvard Model Shop in July. The housings were completed in early November, 1980 and the glassware mounting hardware in late October, 1980.

For the cavity resonator design in the first tests the approach taken used a 15 cm diameter x 18 cm long TE_{111} mode r.f. cavity (instead of the usual 28 cm diameter x 28 cm diameter long TE_{011} mode cavity). This cavity is equipped with a Teflon septum to separate the two regions of r.f. magnetic field that are 180 degrees out of phase. The remaining interior surfaces of the cavity are coated with FEP-120 (Fluorinated Ethylene Propylene co-polymer). The entry collimator is split by the septum, each side leading to one-half the cavity.

At the collimator entry we located the wall-coating gas entry tubes made in the form of hairpin loops of .020 inch diameter brass tubing that penetrate slightly into the cavity half sections. The tubing is pierced with fine holes to allow effusion of the gas to the inside of the cavity to spray the wall surfaces.

Each of the two hairpin tubes is kept electrically insulated from ground and each is separately led, via thin-walled stainless steel tubing, to an off-ground vacuum connection to a gas-handling system that is itself electrically insulated from ground. An electrical connection is made to each end of the hairpin tubes to permit a momentary electrical current to warm the tubes sufficiently to allow gas passage to coat the cavity interior.

The gas handling system consists of a ballast volume and a pressure-measuring and flow-measuring system. A mechanical scavenging pump allows control of the gas ballast tank pressure, as well as purging and cleaning of the system. This system has been built and leak checked and is ready for connection to the cryostat.

During October through December, 1980 the hydrogen dissociator/hexapole magnet assembly was designed and fabricated. This unit also provides for adjustment of the maser cavity resonator's mechanical tuner and is equipped with a 4 inch vacuum pumping port. The glassware of the dissociator was procured, the design of the r.f. excitation system was completed and the system was built, installed and tested.

In the first quarter of 1981, the focus of our work was on setting up the test area and vacuum pumping system. Once these were completed, assembly of the cold maser within the cryostat was begun in May, 1981. Cold maser assembly continued during

June. The cavity was completely assembled with magnetic shields, solenoid, control heaters, hexapole magnets and dissociator. A method of degaussing was devised and implemented to degauss the shields when in the assembled condition. The assembly was then evacuated and allowed to outgas. Figure 3 shows the lower portion of the cryostat with assembled dissociator housing and glassware assembly.

3.4 LABORATORY TEST AREA AND VACUUM PUMPING SYSTEM

Upon receipt of the cryostats in December 1980, a fixed position crane was installed to service the handling needs of both cryostats. By the end of February 1981 the test area was cleared and painted and the cryostats were set in place. Layout and design of the vacuum pumping system proceeded during March and April. At the end of April this system was essentially completed and leak checking was conducted in May. Leak checking included the cryostat with several cold cycles. The vacuum system leaks that were found were repaired and the system appeared to be ready by the end of May 1981. Figure 4 shows the test area, pumping system and cryostat setup.

3.5 ELECTRONICS FOR THE CRYOGENIC MASER PROGRAM

One of the necessary areas of support for the program is the development of cold, low noise electronics for making frequency comparisons between two cold masers. The design of this system has been completed and parts procured. Assembly of the low noise system was given a lower priority to the assembly and initial operation of the cold maser since the existing receivers are adequate for wall shift and wall relaxation measurements.

Each maser will have its own GaAsFET preamp housed in the LN_2 jacket of the dewar. This will set the excess noise temperature of the system somewhere between 50 and 70 K.

To operate the masers in the cryostats, two maser control systems, one for each cryogenic maser, have been designed and built and are ready for use. The controllers monitor and set the magnetic field of the maser, control and monitor the cavity temperature and control the hydrogen pressure in the hydrogen dissociator system that provides a beam of atoms to the cavity.

Tests of the cavity resonator and its tuning range show that the system can be kept tuned from 77K to 4K. The microwave cavity sweeping and the pulsed oscillation decay measuring systems for below-threshold measurements of line Q and frequency have been completed. These systems have been designed to permit making rapid changes in the microwave system configuration. We can operate the system to measure cavity frequency, coupling factor and resonance Q and rapidly change to operating the system to measure maser output frequency and power level or, if below oscillation threshold, the decrement of the pulsed oscillation.

4. SUMMARY OF PRESENT STATUS

The design and fabrication of the cold maser has been completed and the system has been assembled and tested in a preliminary way under vacuum with liquid nitrogen as the cryogenic material. These recent tests disclosed a number of vacuum problems that have since been overcome. The vacuum problems appear to be chiefly associated with brazed joints between 6 inch copper tubulation and stainless flanges. These have been sealed temporarily with vacuum epoxy and the brazing will eventually be reflowed. The first cold trials revealed mechanical problems in the cavity tuner mechanism that were seemingly rectified but persisted after the second cold test; the problem has since been found and we are ready to reassemble the maser. The r.f. dissociator and the temperature control system have been tested, though not yet in conjunction with the maser at temperatures near 77K.

During the first three months of 1982 we have designed and built an atomic hydrogen dissociator that will operate at about 77K. This is mounted directly to the heavy copper 77K thermal shield and greatly improves the mechanical alignment of the beam from the source to the cavity. Tests of its function under vacuum have been completed in a separate test system. A more complete account of this work is given in Appendix I.

We will continue the program of testing the masers under sponsorship from the Office of Naval Research.

5. CONCLUSION

We believe the apparatus is well designed and flexible in concept so as to provide a facility to perform a great variety of low temperature tests related to the hydrogen maser and that it will be useful for many years to come. With very little further modification it can be used to explore interactions at temperatures below 4K and ultimately there is room for a future stage of refrigeration to work in the 0.5K range, where wall coatings of liquid ^{4}He can be used as suggested recently by W. Hardy[7] and J. Berlinsky[8].

6. RECOMMENDATIONS AND SUMMARY

To date, the principal uncertainty in this techniq as it may be applied to a super stable oscillator (i.e. stability in the 10^{16} region and lower) is the expected very large temperature dependence of the output frequency of the oscillating maser. There is some, but admittedly slight possibility of relatively flatter dependence on temperature at temperatures where phase changes may occur in the crystal structure of the surfaces which would permit better stability. These, if they exist, are expected to show up in our data.

The progress we have reported thus far in the past contract period, has been slow owing to pressure in our laboratory personnel to deliver 2 VLG-11 series masers to NASA's Jet Propulsion Laboratory and one to the Tokyo Astronomical Observatory. During the past 8 months of the contract period, we have solved many vacuum and assembly problems and designed, built and tested the cold dissociator described in Appendix I. We have pressed forward on hardware procurement and fabrication so that concentration on operating and data taking can be done in the last 4 months (March-June) of this period.

We do not expect to have unspent funds by the end of June, 1982. We have no graduate students at work on this program. A list of all other Federal grants or contract support is appended.

Our recommendations are that we should continue to press the maser program forward with whatever funding we have or can raise in the future. The prospects for a substantial improvement in frequency stability using cold maser techniques continue to be excellent.

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8. J. Berlinsky - to appear in Proceedings of 1981 Precise Time and Time Interval Conference

FIGURES

OTHER SUPPORT TO SAO

GRANT NAG-8006	NASA - MARSHALL SPACE FLIGHT CENTER	TIME & FREQUENCY TRANSFER STUDY
GRANT NAG-8012	NASA - MARSHALL SPACE FLIGHT CENTER	DISSOCIATORS FOR LOW TEMPERATURE ATOMIC HYDROGEN MASERS.
CONTRACT N00014-79-C-0718	ONR-NRL	1. DEVELOP NON-EVAPORABLE GETTERING SYSTEM FOR VLG-11 MASERS. 2. DEVELOP MASER CAVITY FREQUENCY STABILIZATION SYSTEM.
CONTRACT 954938	JPL - PASADENA, CA	BUILD HYDROGEN MASERS AND MASER R&D.
CONTRACT TKK801	UNIVERSITY OF TOKYO, JAPAN	BUILD ONE HYDROGEN MASER SYSTEM - DELIVERED 22 MARCH 1982.

SUPPORT BY SMITHSONIAN INSTITUTION

SI RESTRICTED	FOUR-LINK TIME CORRELATED DOPPLER SYSTEM FOR GRAVITATIONAL WAVE DETECTION, AND STUDY OF SOLAR PROBE MISSION TO MEASURE THE SECOND-ORDER REDSHIFT.

SUPPORT BY HARVARD/SAO CENTER FOR ASTROPHYSICS

NSG-7176	NASA CORE GRANT	GRAVITATIONAL WAVE DETECTION USING DEEP SPACE DOPPLER TECHNIQUES.

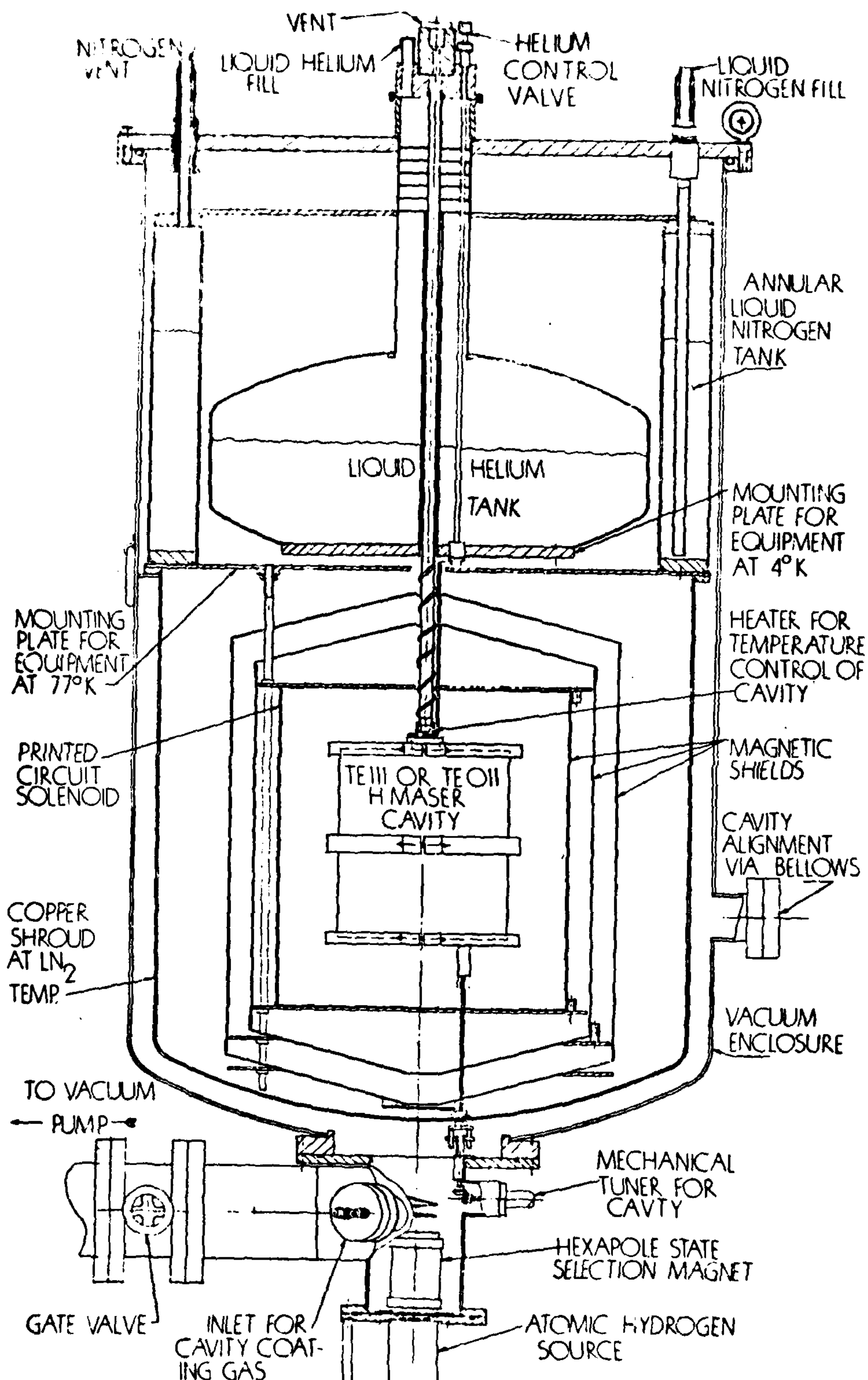

FIGURE 1 DESIGN OF CRYOGENIC MASER
WITH ROOM TEMPERATURE DISSOCIATOR

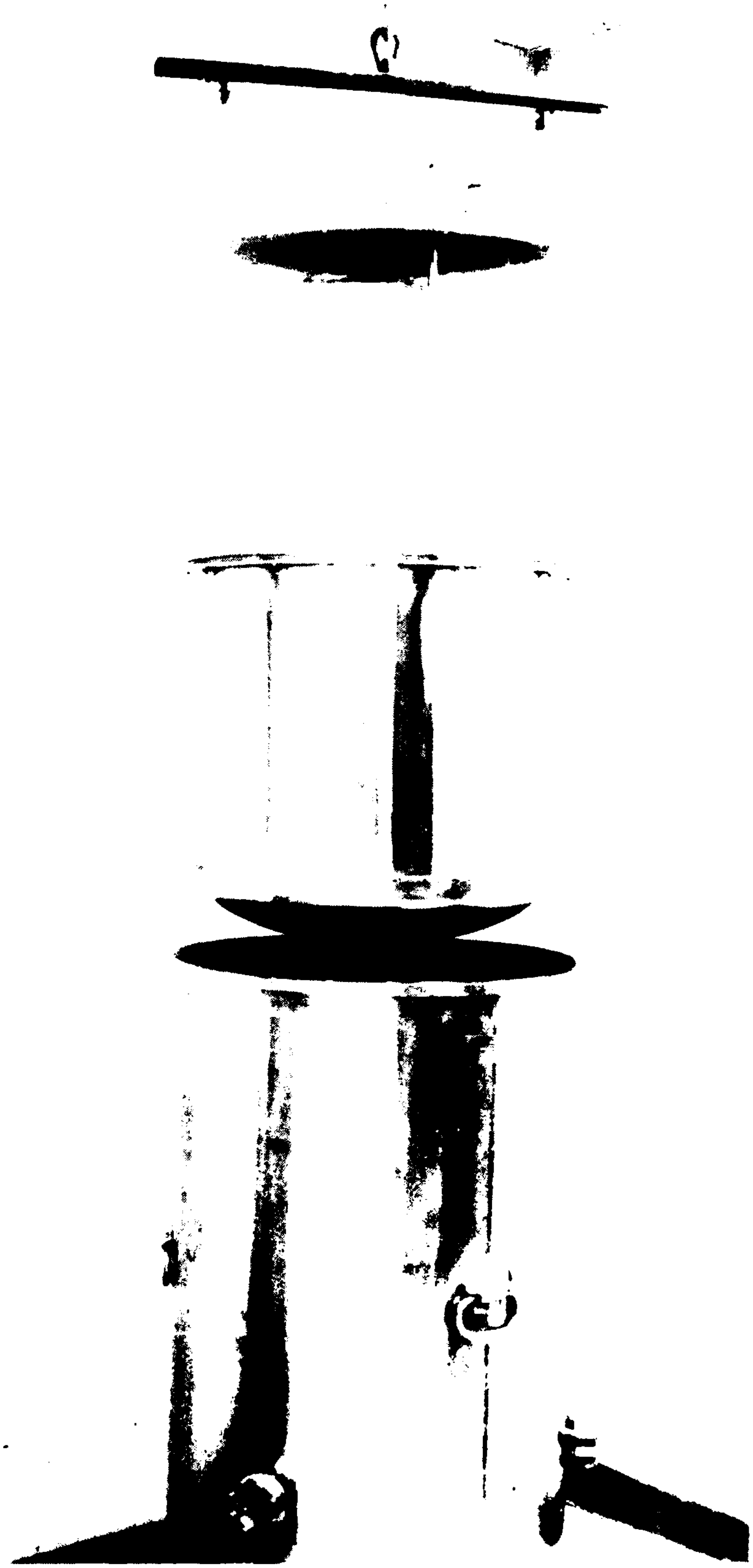

Figure 2a. Maser assembly lifted from cryostat vacuum enclosure.

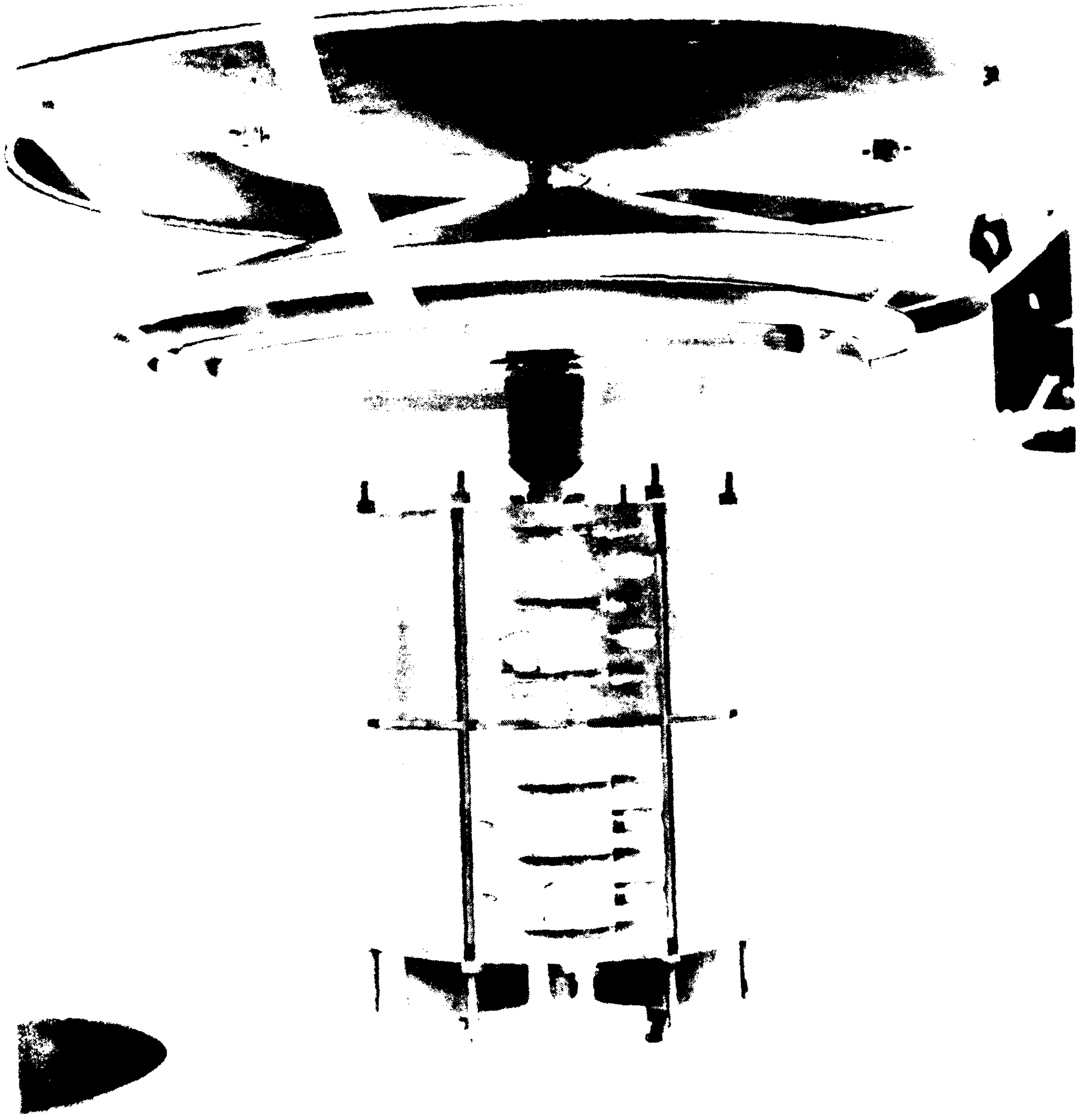

Figure 2b. Maser cavity assembly.

Figure 3. Lower portion of the cold maser cryostat showing the dissociator housing and glassware.

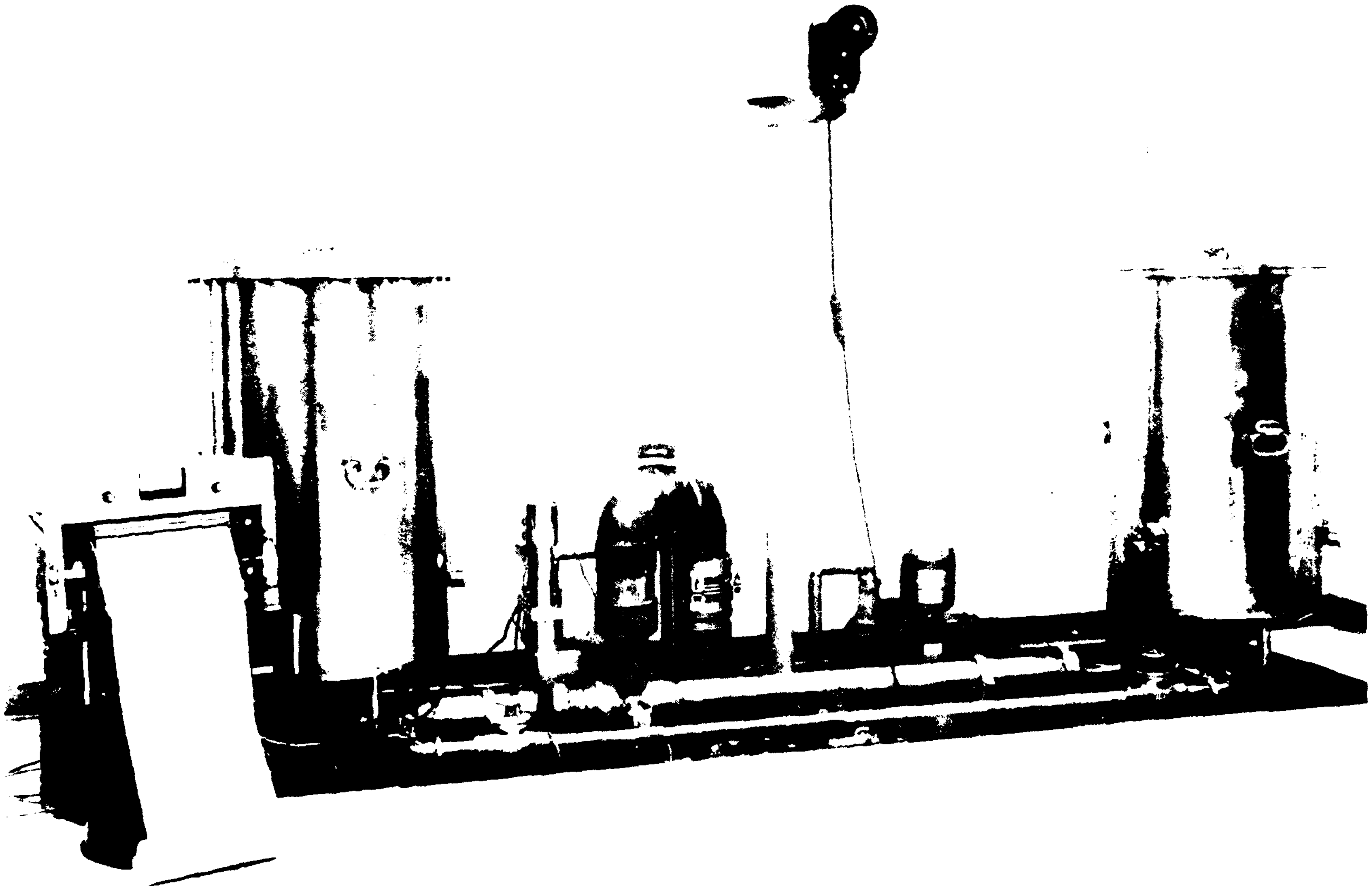

Figure 4. Test area, pumping system and cryostat setup.

APPENDIX I

THE CRYOGENICALLY COOLED ATOMIC HYDROGEN BEAM SOURCE STRUCTURE FOR COLD HYDROGEN MASERS

APPENDIX I

THE CRYOGENICALLY COOLED ATOMIC HYDROGEN BEAM SOURCE STRUCTURE FOR COLD HYDROGEN MASERS

This project has been supported by the National Aeronautics and Space Administration, Marshall Space Flight Center, under M.S.F.C Grant NAG-8012.

INTRODUCTION

Hydrogen masers require a source of hydrogen atoms in the form of a directed beam. In conventional masers operating at room temperature the source of atoms is nearly in thermal equilibrium with the storage region. In the cold masers, however, a conventional atomic hydrogen source would be much hotter than the storage volume. This can cause at least two types of problems. First, there is radiative heat transfer from the source to the cold cavity and second, there is the question of thermal equilibration of the hot, fast-moving hydrogen atoms after they enter the cold cavity and the effect they can have dislodging the wall coating atoms frozen to the surface. A beam source cooled at least to the liquid nitrogen temperature helps to diminish these problems.

The object of this project is to study the operation of a cryogenically-cooled hydrogen maser using an r.f. plasma dissociator operating at liquid nitrogen temperature (77K) in conjunction with a state selector magnet whose dimensions are suitable for slow atoms. The focusing characteristics for a hexapole state selector magnet with maximum fields at the pole tips, H_m, provide a maximum acceptance angle for atoms at the most probable velocity in the beam given by

$$\theta_m = \left(\frac{2\mu_o \quad H_m}{3 \; kT} \right)^{\frac{1}{2}}$$

where μ_o is the Bohr magneton and kT is the thermal energy per unit bandwidth, k is Boltzmann's constant, and T is the absolute temperature of the beam source.

Since the acceptance solid angle is proportional to $\theta_m{}^2$, the magnet is approximately 4 times more effective at 77K than at 300K. Furthermore, (though this is not a very important consideration) the magnet's length is reduced by about one-half.

By thermally isolating the r.f. circuitry from the dissociator glassware, only dielectric losses in the glass and the energy coupled to the plasma will result in the boil-off of liquid nitrogen. We estimate that this is about one watt and thus anticipate a loss rate of approximately .022 litres per hour. This rate can easily be accommodated in the presently available experimental setup.

THE EXPERIMENTAL LIQUID NITROGEN COOLED R.F. DISSOCIATOR

During the past three years, S.A.O. has had an ongoing r.f. hydrogen dissociator program supported by NASA in which different types of dissociator enclosures are being life tested under various conditions of r.f. excitation and cooling. Several conclusions have so far been drawn.

1. The glasses that seem to work best are borosilicate glasses, Corning 7070 and 7740.

2. The dimensions of the dissociator bulb should be on the order of 4 cm; smaller tubes seem prone to excessive surface recombination.
3. The glass can run fairly hot, 50-60°C without any obvious loss of performance.
4. Because of the non-critical cooling requirements, a dissociator can be operated within the vacuum enclosure rather than being in the atmosphere. Conductive cooling of the glass to a heat conducting "sink" is all that is required. This means that for operation in the vacuum of space there is no need for an active cooling system as used in the 1976 Redshift space probe maser. It also means that difficult and costly glass-to-metal vacuum seals are not required; simple ground joints will suffice since hydrogen leakage from the low pressure (< 1 Torr) dissociator to the vacuum system is negligible when compared to the high beam flux from the collimator.

The design of the dissociator which was used in the test system was particularly simple. It was later used in the four experimental and advanced development models of XDM and ADM passive hydrogen masers, developed and tested for the U.S. Naval Research Laboratory. As with the other systems, these operated from an external r.f. supply at 80-100 MHz, capable of delivering about 5 watts to loads of highly variable impedance resulting from the fact that the hydrogen presents very different electrical characteristics to the generator when it is ionized in a plasma state.

This type of dissociator, with the bulb outside of the vacuum enclosure, was originally adopted for the cold maser, as shown in Figure 1. However, it soon became obvious to us that we were headed for trouble with this structure. First, it was very difficult to maintain the alignment of the dissociator, which was attached to the outer vacuum enclosure, with the internal cryostat structure. Second, the heat leakage to the inside system was not insignificant. We therefore decided to equip the maser with the cold dissociator before making any further maser measurements at low temperatures.

The glass is thermally connected to a liquid nitrogen reservoir and enclosed in the vacuum system. A hexapole state selector magnet and beam stopping disc with dimensions suitable for the cryogenically cooled maser are attached to the cold structure. (See Figure 1a).

Figure 2 shows the device as it is built into the cryogenic maser. The liquid nitrogen cooled attachment ring is bolted to the cooled copper shroud as shown in Figure 3.

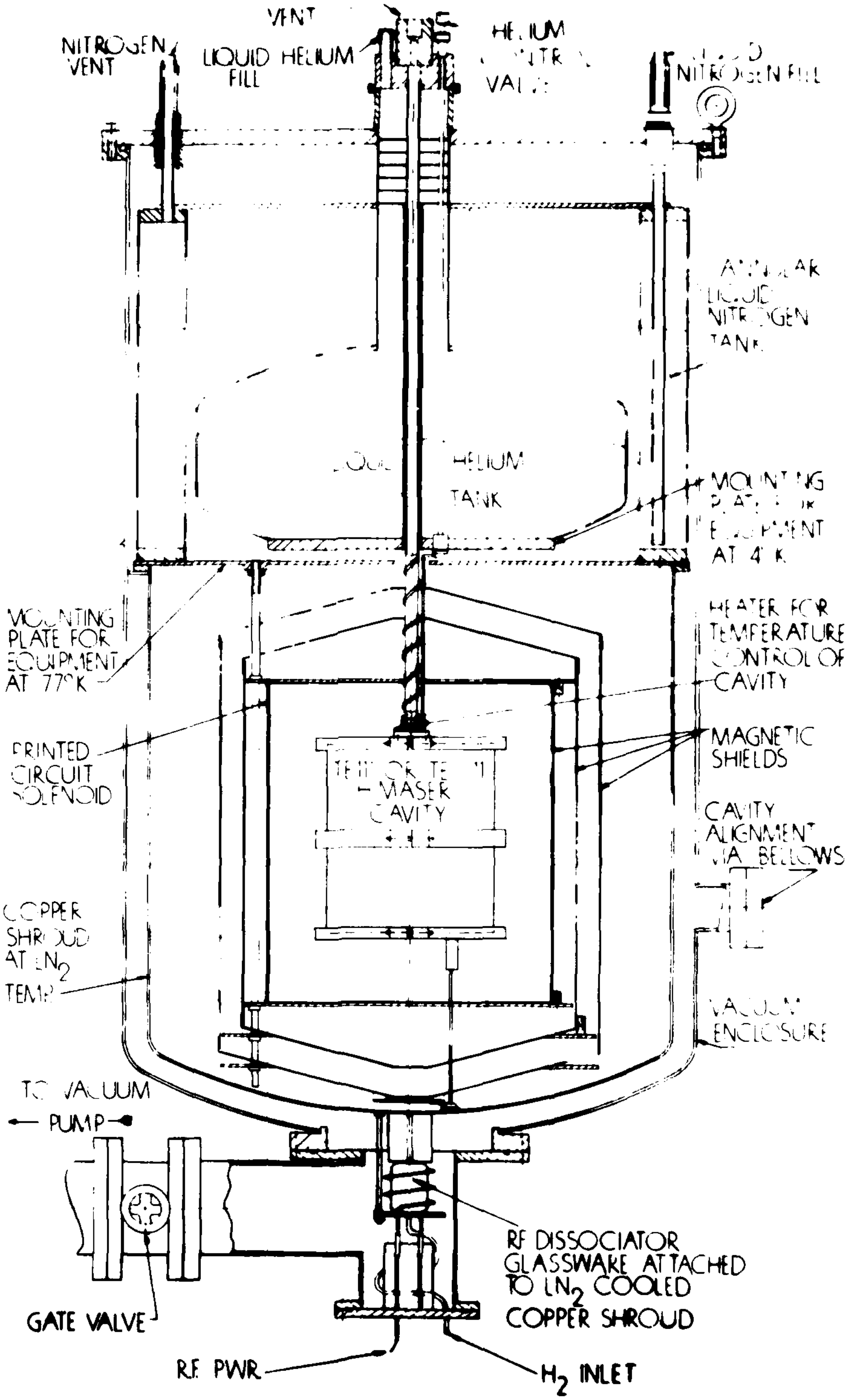

FIGURE 1a SAO COLD MASER ASS'Y WITH COLD RF. DISSOCIATOR

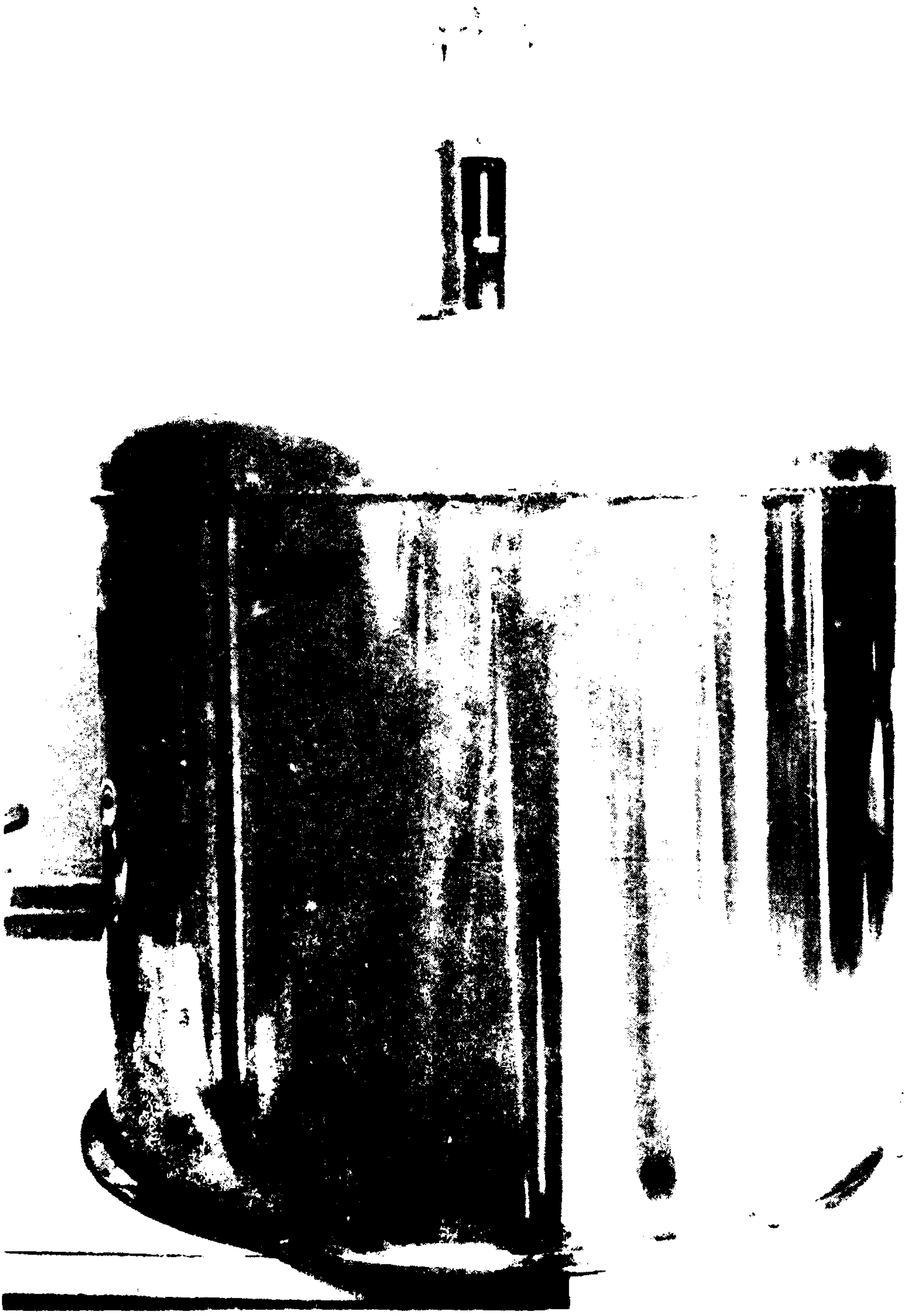

Figure 2. Cryogenic Dissociator Mounted on Copper Shroud.

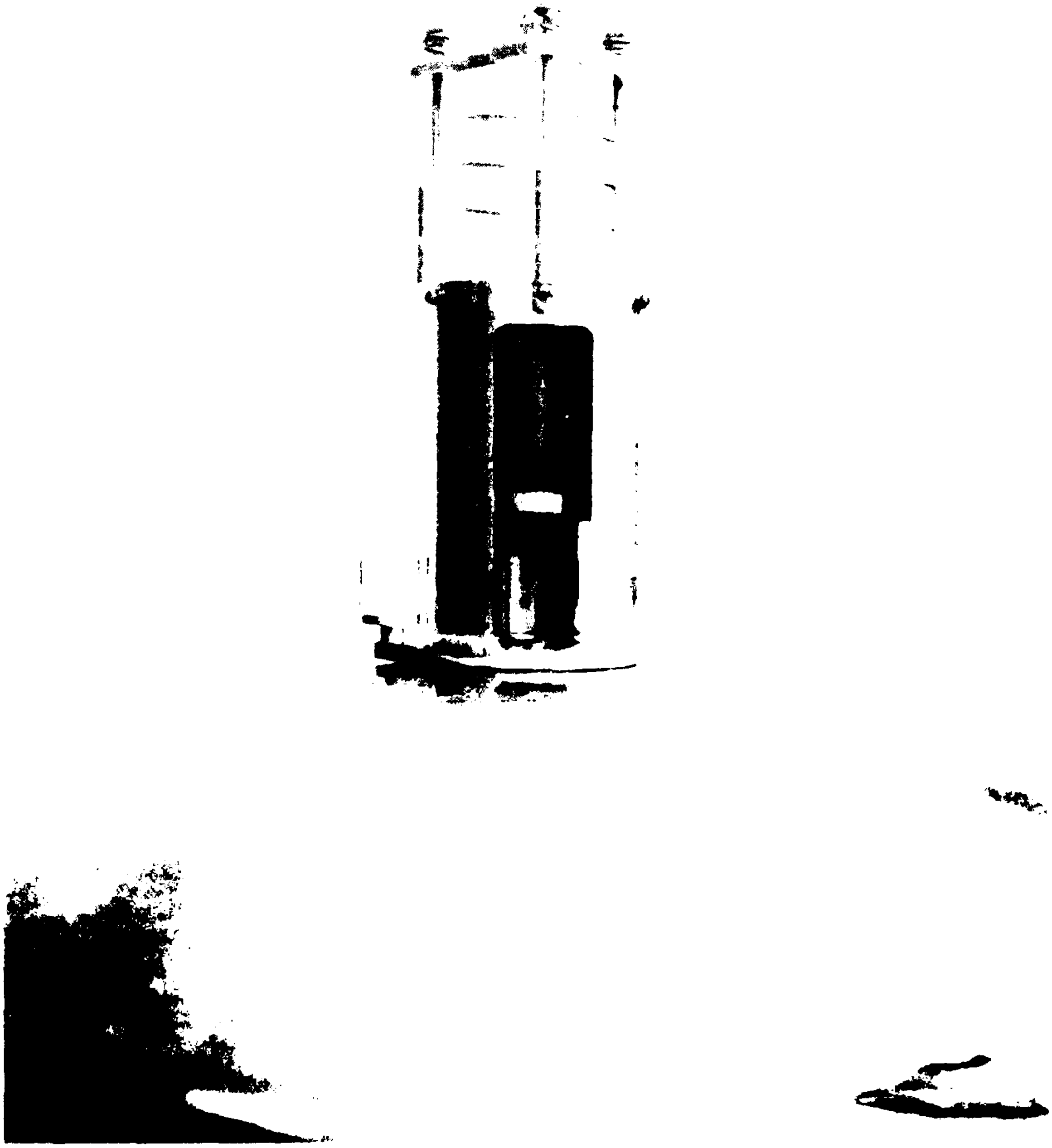

Figure 3. Closeup Showing LN Attachment Ring Bolted to Copper Shroud.