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Memorandum of Project MICHIGAN

RADIO-ASTRONOMY MASERS: TEST AND OPERATIONAL FACILITY

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Willow Run Laboratories

THE UNIVERSITY OF MICHIGAN

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PREFACE

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Project MICHIGAN, which engages in research and development for the U. S. Army Combat Surveillance Agency of the U. S. Army Signal Corps, is carried on by the Willow Run Laboratories as part of The University of Michigan's service to various government agencies and to industrial organizations.

Robert L. Hess
Technical Director
Project MICHIGAN

CONTENTS

FIGURES

RADIO-ASTRONOMY MASERS: TEST AND OPERATIONAL FACILITY

ABSTRACT

A low-noise radiometer using a maser preamplifier has been developed for radio-astronomy measurements. This radiometer uses a reflection-type cavity maser with the highest known gain-bandwidth product in practical use. Satisfactory gain stability and dependable performance are presently obtained with a gain-bandwidth product of 200.

This memorandum contains a discussion of the electrical and physical aspects of the maser facility together with its proposed uses and operation. Significant diagrams, circuits, and component characteristics are included.

1
INTRODUCTION

The first successful operation of a ruby maser occurred at Willow Run Laboratories of The University of Michigan on December 20, 1957. Immediately following this event, possible applications were considered which would provide much-needed experience in the designing, packaging, and operation of these new devices. Of the several possible applications, the use of the ruby maser in radio astronomy appeared to be the most attractive for two reasons: first, in such an application, full use would be made of the maser's low-noise properties; and second, a radio telescope with a paraboloidal reflector 85 feet in diameter was being installed by The University of Michigan's Radio Astronomy Project at a site near Ann Arbor, Michigan. This radio telescope has the highest antenna gain of any steerable antenna in the world and is usable at X-band frequencies. As a result of the interest shown by Professor F. T. Haddock of the Departments of Astronomy and of Electrical Engineering, a cooperative program was started in the summer of 1958. Under this program, the Solid-State Physics Laboratory of Willow Run Laboratories assumed the responsibility for the installation and initial operation of an X-band ruby maser system.

The first objective will be an attempt to detect the extraterrestrial helium line at 8.665 kmc.

The helium atom He^3 II State $1^2 S_{1/2} F = 0 \rightarrow 1$ transition should occur at this frequency (Reference 1). As a further objective, an attempt will be made to detect the hydrogen line at 9.869 kmc. Because of the expected width of this line, any investigation is contingent upon obtaining a maser bandwidth of 50 to 100 mc. Results of these investigations will be reported as soon as possible.

Operation of the maser radiometer as a radar receiver, and in other possible combat-surveillance applications, will further extend the mobile maser program (Reference 2) of the Solid-State Physics Laboratory of Willow Run Laboratories.

The test and operational facility has now been developed and will be in operation on the 85-foot antenna in the very near future. The purpose of this report is to describe this facility. Much of the description is of the X-band reflection cavity-type maser now in use. However, future plans include operation at other frequencies and with traveling-wave masers. Consideration has been given to these possibilities in the design of the present facility. In general, any foreseen changes would involve only the microwave portion of the existing system.

2
GENERAL DESCRIPTION OF THE FACILITY

The 85-foot reflector is shown in Figure 1. This unit provides a solid surface and equatorial mount. One mechanical specification is that the focus be maintained within 5/16 inch as the antenna, carrying a 500-pound load, is rotated. When the reflector is directed toward the zenith, the focus is 110 feet above the ground. The equipment is serviced by rotating the antenna to point due east and utilizing a 55-foot service elevator.

In order to provide the greatest flexibility of purpose while satisfying the primary radio-astronomy requirements, it was decided to install the test and operational maser unit in a modified SCR-584 radar van (Figure 2). Although this facility was designed and constructed primarily as a test unit for the radio-astronomy maser program, it also serves the purposes of extending the existing mobile-maser program and providing an elementary radio-astronomy research tool.

In its primary function, the facility will provide important data for possible radio- astronomy maser systems, without limiting the operation of the 85-foot antenna. By extending the mobile-maser program, this unit will further demonstrate the use of the ruby maser as a radar receiver (Reference 2), and as a mobile field unit with possible combat-surveillance applications. As a research tool it will be used in extensive noise measurements. Present plans in this

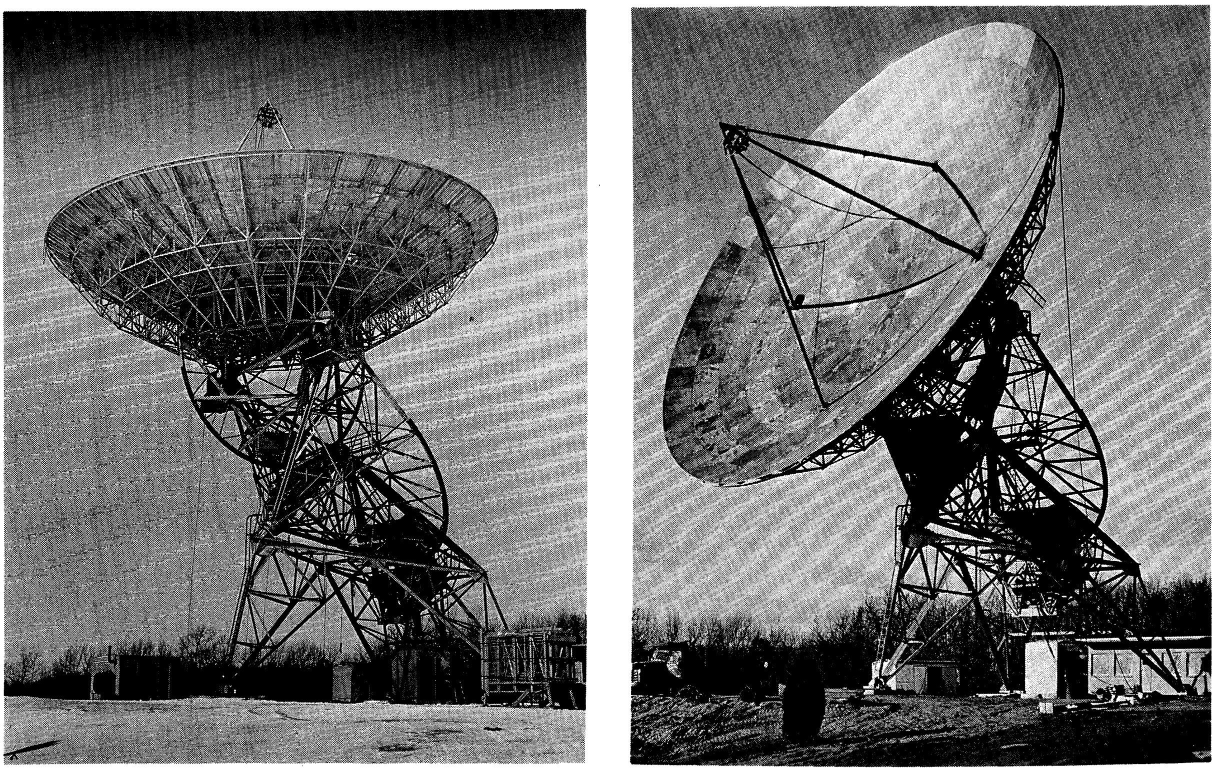

FIGURE 1. RADIO TELESCOPE

application call for determining noise figures of the maser system, studying methods of optimizing the maser to specific applications, as well as making extraterrestrial measurements. These activities will be reported as soon as possible.

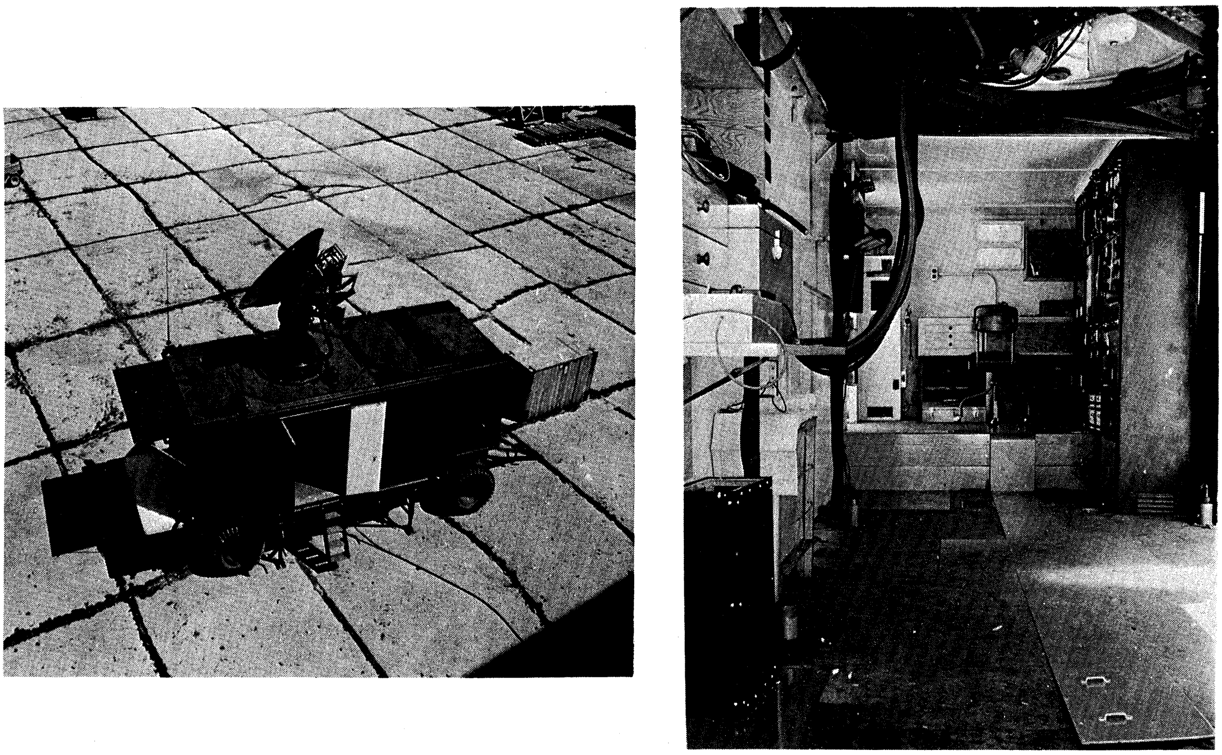

FIGURE 2. MODIFIED SCR-584 Van. (a) Exterior View. (b) Interior View.

The test and operational facility provides a 6-foot antenna and positioning system which satisfies the radio-astronomy requirements while being versatile and mobile to comply with both research and field-unit needs. The antenna mount may be lowered into the van, where initial adjustments and servicing can be performed alongside the control equipment. A simplified block diagram of the van appears in Figure 3 (inside dotted line). Power is fed into the antenna-mounted maser system, and the received signal is returned through cables to a terminal panel in the van floor. The signal is detected by a synchronous detector and displayed on a recorder.

The maser system is shown in simplified block form in Figure 4. The received signal is transmitted to the ruby-filled cavity through a ferrite circulator. The amplified maser output is returned through this circulator into a balanced mixer and then sent to a detector. Figure 5 shows a more detailed diagram of the microwave system.

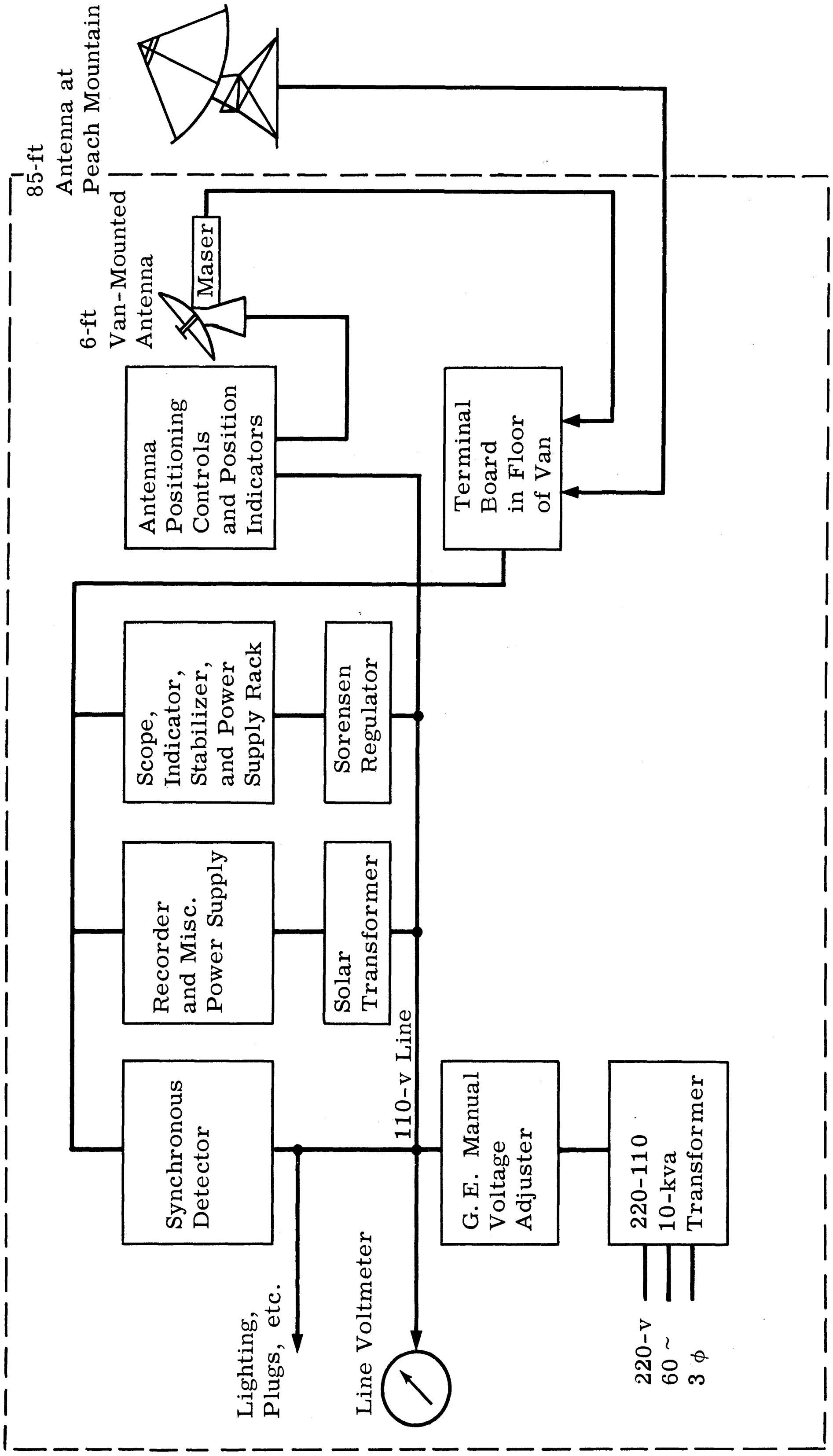

FIGURE 3. BLOCK DIAGRAM OF ENTIRE TEST FACILITY

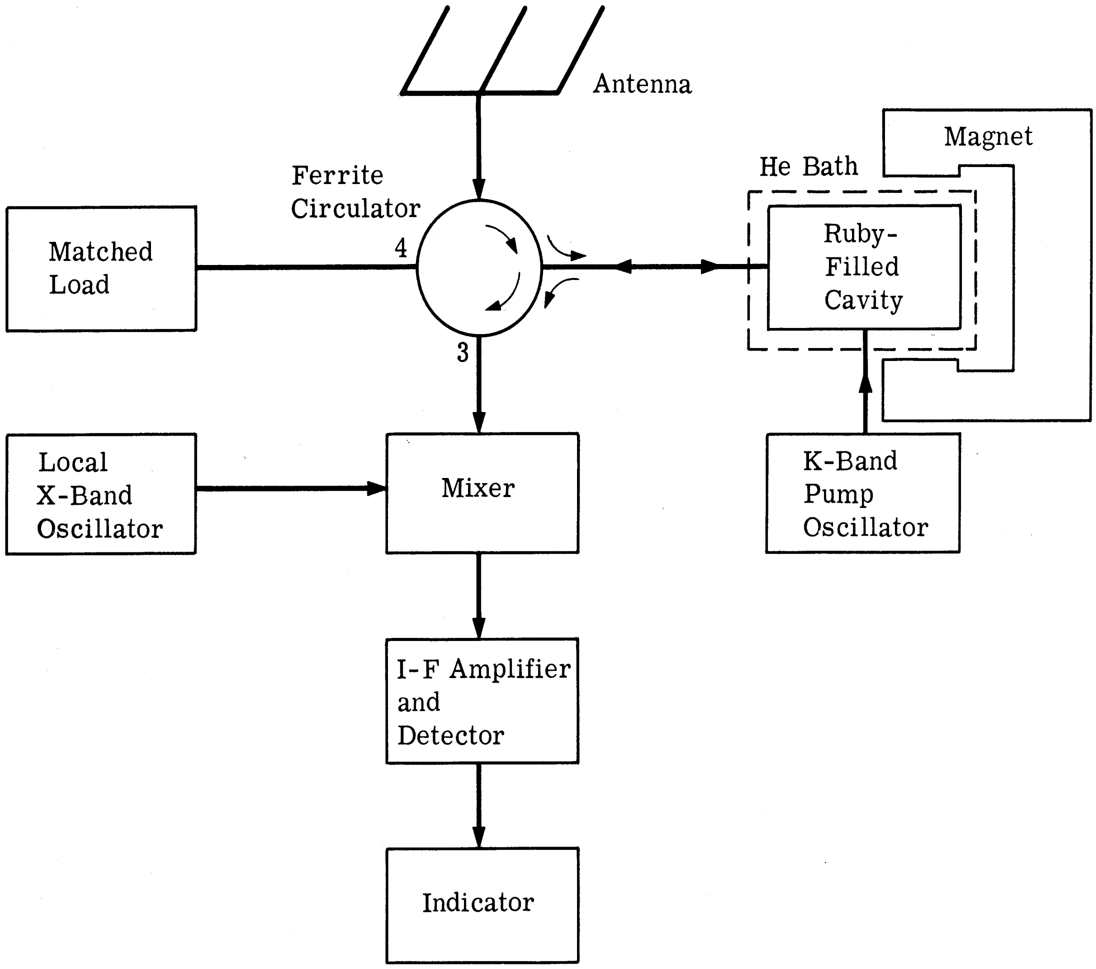

FIGURE 4. BASIC BLOCK DIAGRAM OF MASER SYSTEM

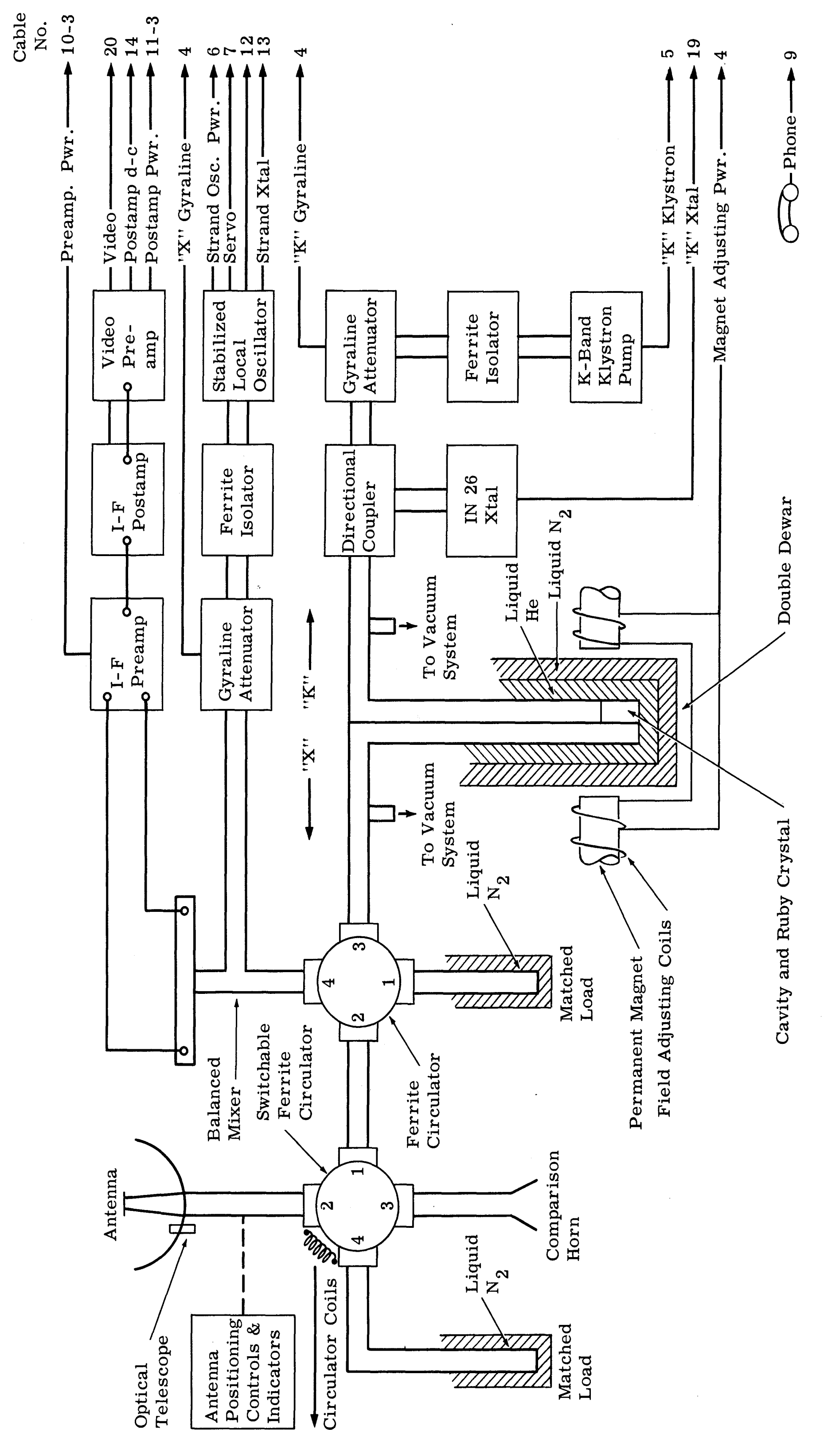

FIGURE 5. RADIO-ASTRONOMY MASER SYSTEM

3
PHYSICAL AND ELECTRICAL DESCRIPTION

Modification of the van for use with the maser required the removal or repositioning of much of the original equipment. All equipment except that required to operate the antenna was removed, and this antenna-control system was repositioned into more compact, convenient form. The antenna equipment, originally installed in the large control panel across the rear door, was moved to a 5-foot relay rack in the same location (Figure 6). Some of the remaining space is occupied by a small writing desk and the rest is used for working space. Several other items, such as the amplidynes, were repositioned into more favorable locations. The elevator circuitry and mechanical system was repaired to allow raising and lowering of the antenna mount. The manual voltage-adjuster was retained to correct for any local voltage variations. A Y-Δ, 220-110-volt, 3-phase transformer was installed to provide 110-volt a-c power as well as to distribute the load over the three phases. Two of the three phases are regulated and supply power for the more critical electronics, and the remaining phase provides lighting, auxiliary power, and power for less critical components. The use of this transformer permits more efficient (220-volt) power transfer to the van and also increases the mobility of the unit.

Two-way communication between the van facility and the laboratory base is provided by two modified AN/ PRC-10 radio sets. Communication is provided from inside the van to the antenna mount by sound power phones. This local communication is a convenience in positioning the antenna and operating the maser.

The maser power, control, and display center consists of one 6-foot and two 5-foot relay racks, in the space originally occupied by the radar system modulator (Figure 7).

Refrigerants are transferred to the maser dewar without movement of the two 25-liter storage dewars. The liquid-helium transfer employs a flexible transfer tube. The gas supply, required to transfer the liquid coolants as well as to pressurize various waveguide components, is obtained from storage tanks mounted outside the van. A gas control panel is mounted on the wall behind the storage dewars.

The original scan mechanism, reference generator, and receiver-transmitter system were removed from the antenna mount. The waveguide-dewar-magnet assembly required by the ruby maser was mounted in the vacated space. This assembly utilizes the original feed antenna in a simple rigid mount. The antenna feeds into the more complex maser-waveguide system. The entire assembly is supported by an angle-iron frame, approximately 2 feet on a side (Figure 8). This experimental design will be replaced in the near future by a more compact, packaged unit. The new design will house the waveguide-dewar-magnet assembly in a completely enclosed package, more adaptable to the 85-foot antenna. It will provide adequate shielding and weatherproofing and achieve complete compatability between the two antennas.

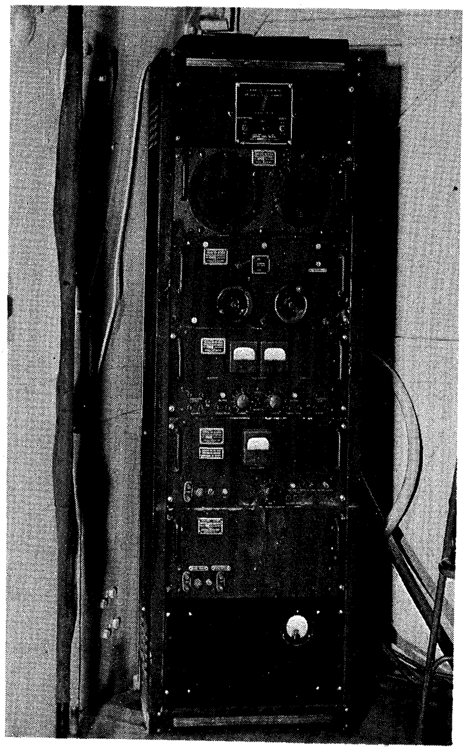

FIGURE 6. ANTENNA POSITIONING CONTROL UNIT

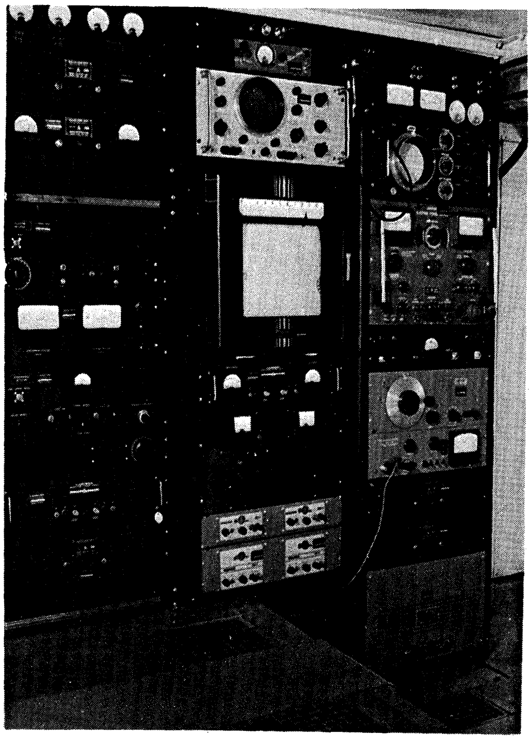

FIGURE 7. MASER POWER CONTROL AND DISPLAY CENTER

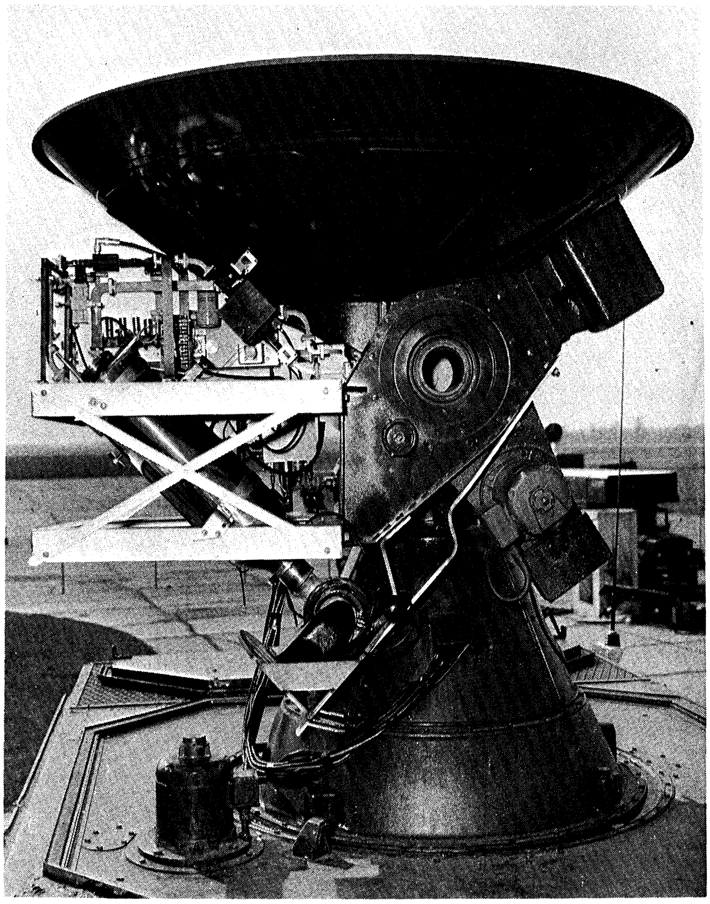

FIGURE 8. WAVEGUIDE-DEWAR-MAGNET ASSEMBLY

The output of the maser-control-power panel as well as the input to the display units, is a system of 20 individually shielded cables ducted through the floor and up to the antenna mount. Because of noise introduced by the original slip-ring feed, all cables have been attached directly to the rotating antenna mount. This requires a protective device to prevent excessive rotation from breaking the cables; an azimuth interlock system has been devised, which prevents rotation beyond one complete revolution.

Three terminal panels are provided in the maser cable system: one immediately following the racks, one in the van floor, and one on the antenna mount. The terminal panel in the van floor is accessible from the underside of the van. This panel permits operation of the maser on either the 6- or 85-foot antennas by connecting the appropriate set of cables (Figure 3). The other two panels are provided for convenience in servicing components.

All electrical equipment installed on the antenna itself is d-c operated. This is a precautionary measure to avoid any possibility of pickup into signal lines. All filaments and drive motors are powered by individual d-c supplies. No fans are permitted on the antenna mount; cooling is provided by forced air from a compressor in the van, and ordinary 1/2-inch OD air hoses. A vacuum pump is also available as a part of the van facility, to allow convenient pumping on dewars, transfer tube, and waveguide system as required.

4
COMPONENT DESCRIPTION AND CHARACTERISTICS

4.1. MICROWAVE SYSTEM

The microwave system consists of two major subdivisions: K-band (18-26 kmc) and X-band (8.2-12.4 kmc).

The K-band power is supplied by a specially selected, high-power klystron, which is a velocity-variation oscillator, designed for operation in the 22-25 kmc range. These high-power tubes have an output of 70 mw or more, whereas the average tube is limited to about 40 mw. Mechanical tuning is available, and remote control has been provided. The klystron is housed in its own case to allow forced-air cooling and weatherproofing.

An isolator and variable attenuator follow the klystron; the variable attenuator allows remote electronically controlled variable attenuation to 25 db. A directional coupler and crystal mount allow monitoring of the K-band signal. The remaining K-band system consists of standard bends and straight sections.

The X-band system includes signal input line, local oscillator supply, and cooled loads.

The input line permits comparison of the incoming signal with a reference signal by means of a switching four-port circulator. Application of a square-wave current to an electromagnet switches the device at a rate variable from 40 to 250 cps. The signal path has an insertion loss of 0.2 db at 8.6 kmc. A second, nonswitching, ferrite, four-port circulator provides the necessary isolation for a reflection-type maser. The reflection-type maser utilizes a portion of the input waveguide to carry the amplified output. The ferrite circulator, by means of a magnetic field, channels the two waves in the appropriate directions with an isolation of approximately 25 db (Figures 4 and 5). The input path, in this device, has an insertion loss of only 0.12 db, whereas the output path is 0.25 db at 8.6 kmc.

One unused port on each circulator is terminated in a matched waveguide load, cooled to liquid-nitrogen temperature. These waveguide systems consist of straight sections and bends, plus two standard matched terminations. The cooled, matched terminations minimize the random-noise signal originating at the unused ports, a precautionary measure for sensitive measurements.

The signal picked up by the 6-foot parabolic reflector is transmitted to the waveguide system by the original Signal Corps antenna assembly AS-23/AP pickup dipole. The parabolic reflector has a rated beamwidth of 1.4^{o}. An experimental plot of the antenna pattern appears in Figure 9. This pattern indicates an experimental beamwidth of 1.5^{o}.

Local oscillator power is supplied by a stabilized microwave generator operating in the 8.5-9.5-kmc range with a power output of 10 mw. The rf section is housed in its own case in the microwave system. It consists of a klystron, ferrite isolator, stabilization discriminator, and reference cavity. Tuning of both the reference and klystron cavities is available, and remote operation has been provided. This unit has an experimentally determined long-term frequency drift of 1 part in 10^{5}. A variable attenuator permits remote, electronically controlled variable attenuation to 35 db. The balanced crystal mixer is optimized over the range 8.5-8.9 kmc. This conventional superheterodyne mixer system feeds into a 30-mc receiver discussed later.

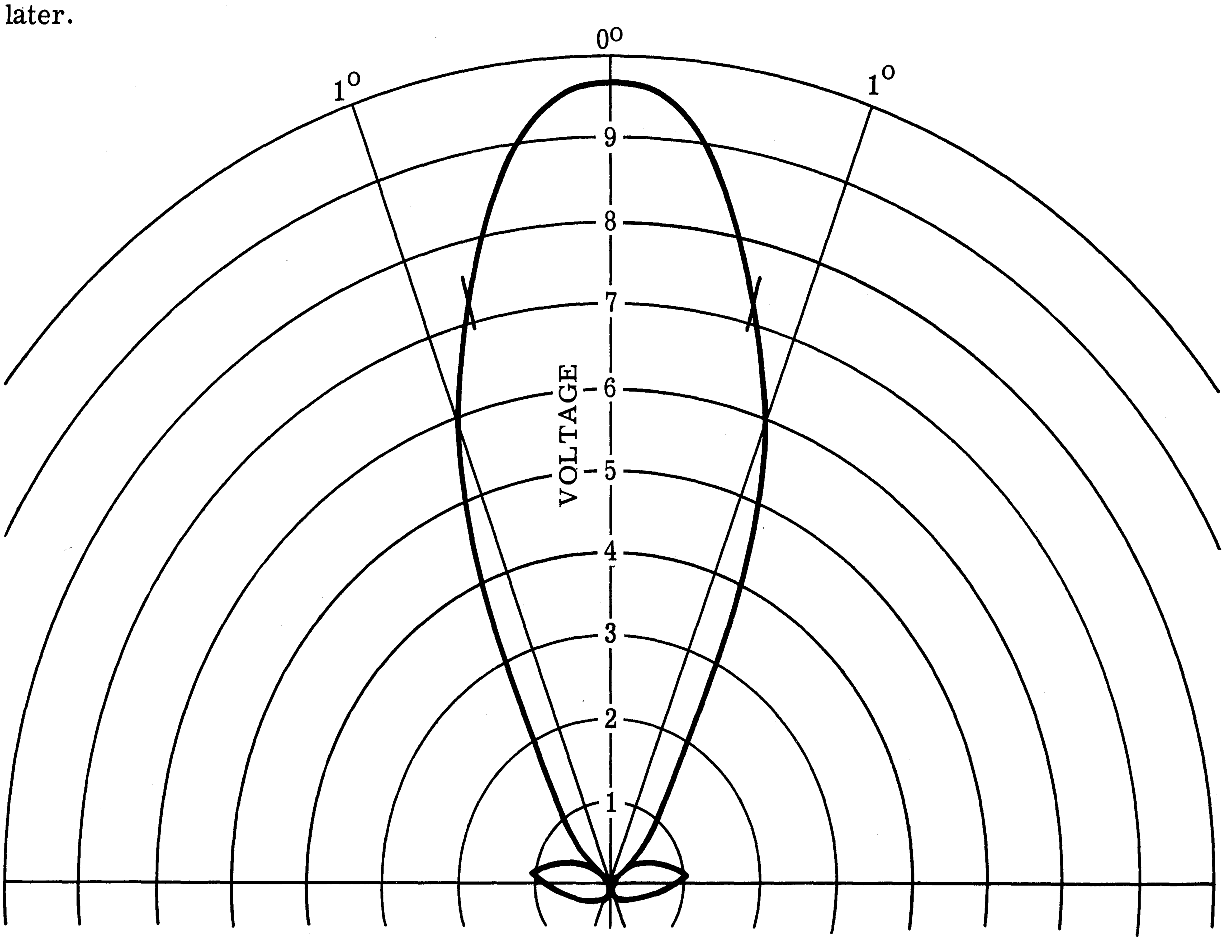

FIGURE 9. E-PLANE ANTENNA PATTERN. Beamwidth, 1.5^{o}.

An X-band noise source is available for noise measurement. Also a pickup horn is provided for cold sky comparison in radio-astronomy measurements.

To match all components, double-stub tuners are provided. These tuners are a specific design with a spacing of 0.787 inch (3/8 wavelength at 8.665 kmc). The design permits pressurizing or evacuating the guide by means of an O-ring sealed cap. Stepwise frequency variation to a higher X-band frequency is possible.

The cavity assembly (Figure 10) is designed specifically to operate at 8.665 kmc, with a maximum of gain stability and dependable performance. These features are realized with a gain bandwidth product of approximately 200. The cavity itself represents a radical design, being a solid, silver-plated ruby (Reference 3). This design has demonstrated the possibility of very high-gain-bandwidth products. At present, products up to 600 have been obtained.

Closely associated with the waveguide system is the magnet-dewar assembly. The magnet is a permanent Alnico magnet having a 1 1/2-inch gap, with a field of 3850 gauss. The field uniformity is, as specified by the manufacturer, within 0.1% inside a 1/2-inch cube at the

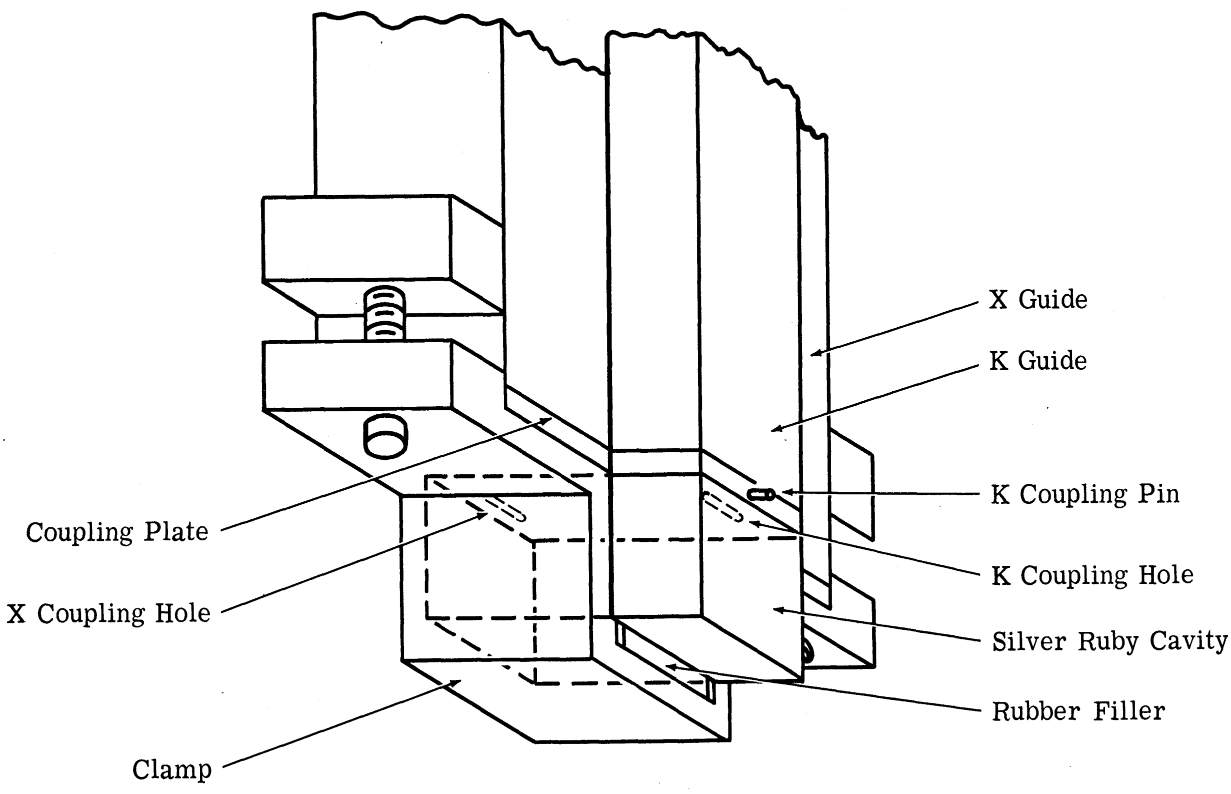

FIGURE 10. MASER CAVITY ASSEMBLY 5-186-B1

center of the gap. Coils are provided to vary the field through ±150 gauss at ±50 ma. The magnet mount allows a rotation of 35° and a translation of 3 inches along the axis of this rotation.

The dewar was designed to contain 3.4 and 8.1 liters of liquid helium and liquid nitrogen, respectively. These amounts have been seen to evaporate completely in about 36 hours, with a vacuum of 2×10^{-5} mm of mercury. Tests have shown that the loss rates of both liquid helium and liquid nitrogen are essentially independent of dewar angle from vertical to approximately 40° with the horizontal. Beyond this point, both rates appear to rise exponentially to a relative rate of 1.5 at 22° with the horizontal (Figure 11).

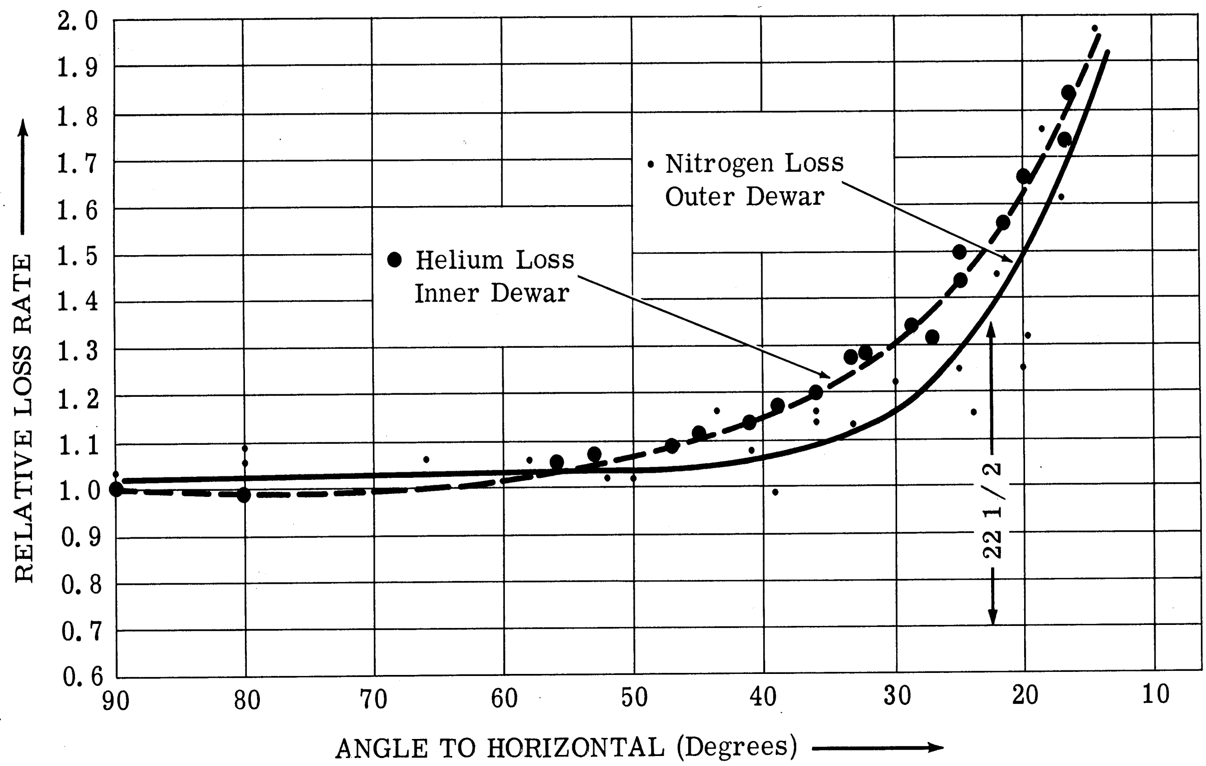

FIGURE 11. RELATIVE COOLANT LOSS RATE

4.2. ELECTRONICS

The switching circulator is driven by a square-wave generator. This device supplies a square-wave current to the electromagnet of the circulator over a controlled frequency range of 40 to 250 cps. A regulated supply furnishes the required 500 volts at 400 ma and 6.3 volts at 10 amp. Two other supplies provide ±300 volts across the multivibrator tube.

The magnet coil supply has an output of 0-300 volts at 0-150 ma with a 2-mv ripple. Requirements on this unit are to provide ±50 ma to vary the magnetic field from 3700 to 4000 gauss.

The local oscillator supply is a stabilized unit with a 550-volt output. The unit has been modified so that the klystron filament power is supplied by a d-c supply, discussed later.

The K-band klystron is powered by a universal klystron power supply providing the following outputs: beam voltage of 200 to 3600 volts at 0-100 ma, reflector voltage of 0-1000 volts below beam, and control grid voltage of 0-300 volts. The klystron filaments are also d-c operated.

K-band frequency stabilization is accomplished by frequency modulation at 100 kc across the cavity frequency. This signal is fed into a transistorized synchronous detector circuit. (See discussion of synchronous detector below.)

The crystal mixer output is fed into a miniature i-f preamplifier having a gain of 30 db, a center frequency at 30 mc, and a bandwidth of 8 mc. This output is fed into a second i-f amplifier having a gain of 60 db, a center frequency at 30 mc, and a bandwidth of 10 mc to the 1-db points.

The d-c power for all filaments on the antenna itself is provided by transistorized d-c supplies. A total of six such units are built into the facility. Three units, supplying 12 volts at 2 amp, power the i-f and 2K33 filaments. One unit, supplying 6 volts at 2 amp, and another supplying 28 volts at 0.5 amp, power the remote, electronically controlled variable attenuators. The remaining unit provides 12 volts at 1 amp and supplies filament power to the local oscillator klystron.

The synchronous detector system is a device permitting the detection of a signal in noise. It is, in essence, a detector followed by an RC filter. The operation may be described as one of integration over long periods (up to T = 200 seconds) whereby the noise contributes a decreasing output as T is increased. The synchronous detector multiplies by a reference signal both signal and noise of all frequencies present at the input. The reference signal is identical in phase and frequency to the signal to be detected. This multiplication process produces a d-c level proportional to the level of the signal to be detected and a-c signals proportional to the levels of all noise frequencies. A low-pass filter is used to reject all a-c signals of frequency greater than 1/T and produce a d-c output the level of which is proportional to the desired signal. Thus as T is increased the error is decreased, since more of the "noise-produced" a-c signals are rejected.

Two oscilloscopes having a maximum sensitivity of 0.1 mv/cm are provided. A sweep oscillator is available to provide an X-band test signal. This signal is used in setting up and testing the maser system. Continuously adjustable frequency over the entire X-band range (8.2-12.4 kmc) is provided. Frequency regulation is better than 4 mc. Power output is 10 mw or greater into a matched waveguide load. Also, swept-frequency rf is available in stepwise ranges from 4.4 mc to 4.4 kmc (full X-band range). The sweep rate is adjustable from 32 mcs to 320 kmcs.

Remote control of the various tuning devices is accomplished with slow-speed d-c motors. These motors are rated at 1 rpm at 30 volts input.

Regulated voltage is supplied to the more critical electronics by means of a 3000-volt-amp a-c regulator and a 1000-volt-amp magnetic regulator. The a-c regulator provides regulated output voltage of 110-120 volts with input voltages of 95-130 volts. Harmonic distortion is below 3%, from zero to full load. The magnetic regulator is harmonic filtered to 3% distortion and provides regulation ±0.5% over a 95-130-volt input range from zero to full load.

Appendix A

COMPONENT LIST

1. Air Compressor: Montgomery Ward Belt Drive.
2. Amplidynes: Original equipment amplidynes SCR-584B.
3. Antenna: Original equipment 6-foot-diameter, parabolic reflector.
4. Antenna Control Rack: Original equipment; Control Unit BC-1085-B; Control Panel PN-24-b; Indicator BC-1076-B; Tracking Units BC-1086B and BC-1090B; Rectifier Unit RA-141.
5. Audio Oscillator: Hewlett Packard Model 200AB.
6. Blower: Electric Ventilating Company, Model G-1.
7. Cables: See cable list, Appendix B.
8. Cavity: Model 5-186-B1 (see Figure 10 and Reference 3).
9. Circulator Electronics: Special design, Airtron Company.
10. Dewars: One 25-liter liquid-helium storage dewar and one 25-liter nitrogen storage dewar. Superior Air Products Company: 1-maser dewar, modified, Hoffman Laboratories.
11. Finder Scope: Edmund Scientific Company, 7-power objective lens, 6° angular field-of-view.
12. I-F Strips: LeL Model IF 20 B and IF 31 BP.
13. K-Band Equipment
    - (a) Detector: DeMornay Bonardi DBE 319.
    - (b) Directional Coupler: DeMornay Bonardi DBW 631.
    - (c) Frequency Meter: Waveline 989R.
    - (d) Gyraline: Cascade Research K-211.
    - (e) Isolator: Cascade Research K-131.
    - (f) Klystron: Raytheon, High-Power 2K33.
14. Magnet: Arnold Engineering Company, Alnico V.
15. Motors: Globe Industries, C-5A-1165.
16. Oscilloscopes: Hewlett Packard Model 130B; Dumont Model 403R.
17. Phones: Wheeler, Sound Power.

18. Power Supplies
    (a) Dressen Barnes, Model 3-150B.
    (b) Lambda Electronics Company, two Model 28, two Model 29, and one C-482M.
    (c) Nobatrons: three Q12-2, one Q12-1, one Q6-2, and one Q28-05, Sorenson Company.
    (d) Strand Model 10X Stabilized Power Supply, Microwave Development Company.
    (e) Universal Klystron Supply Model Z815B, FXR.

19. Radio Sets: AN/PRC-10, portable, Signal Corps.

20. Regulators: Sorenson; a-c Regulator Model 3000S and Magnetic Regulator Model 1000 MVRH.

21. Stabilizer: Specially constructed synchronous detector.

22. Synchronous Detector: See Section 4.2.

23. Vacuum System: Welch Mechanical forepump and Consolidated Electrodynamics diffusion pump type VMF-10.

24. X-Band Equipment:
    (a) Circulators: Special design, optimized by 8.6 kmc, one switching and one non-switching, Airtron Corporation.
    (b) Comparison Horn: DeMornay Bonardi B-520, 15-db gain at 9 kmc.
    (c) Crystal Mixer: DeMornay Bonardi G-655.
    (d) Frequency Meter: Hewlett Packard X532A.
    (e) Local Oscillator: Strand Model 10X RF unit, Microwave Development Company.
    (f) Tuners: Special design, see Section 4.1.

Appendix B

MASER CABLE LIST

Cable No.	Use	Description
1	Circulator	3-conductor – special
2	Circulator, spare	2-conductor – Belden 8412
3	Postamp power Preamp power	8-conductor – Belden 8418
4	Magnet coils K-band gyraline X-band gyraline	7-conductor – Belden 3427
5	K-band klystron power	6-conductor – Special high voltage, Alpha Wire Company
6	Strand Supply Power	7-conductor – Belden 8427
7	d-c motor supply	7-conductor – Belden 8427
8	Spare	7-conductor – Belden 8427
9	Phone lines	3-conductor – Belden 8735
10	Preamp filaments	2-conductor – Belden 8790
11	Postamp filaments	2-conductor – Belden 8790
12	Strand crystal	1-conductor – RG 58 AN BNC
13	Strand crystal	1-conductor – RG 58 AN BNC
14	Postamp d-c output	1-conductor – RG 58 AN BNC
15	Spare	1-conductor – RG 58 AN BNC
16	Spare	1-conductor – RG 58 AN BNC
17	Preamp crystal	1-conductor – RG 54 AN UHF
18	Preamp crystal	1-conductor – RG AN UHF
19	K-band crystal	1-conductor double shield – Belden 8233
20	Postamp video output	1-conductor double shield – Belden 8233

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RADIO-ASTRONOMY MASERS: TEST AND OPERATIONAL FACILITY by Jerald Cook and R. W. Terhune. Memorandum of Project MICHIGAN. May 60. 20 p. incl. illus., 3 refs.
(Memorandum no. 2900-100-R)
(Contract DA-36-039 SC-78801) Unclassified report

A low-noise radiometer using a maser preamplifier has been developed for radio-astronomy measurements. This radiometer uses a reflection-type cavity maser with the highest known gain-bandwidth product in practical use. Satisfactory gain stability and dependable performance are presently obtained with a gain-bandwidth product of 200.

This memorandum contains a discussion of the electrical and physical aspects of the maser facility together with its proposed uses and operation. Significant diagrams, circuits, and component characteristics are included.

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2. Radio astronomy — Equipment
3. Masers — Applications
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