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ALTITUDE EVALUATION OF RADIO FREQUENCY ATTENUATION IN THE EXHAUST JET OF THE XLR91-AJ-5 ENGINE

By

C. M. Tuthill, Jr.

Rocket Test Facility
ARO, Inc.

TECHNICAL DOCUMENTARY REPORT NO. AEDC-TDR-62-160

August 1962

AFSC Program Area 107C

(Prepared under Contract No. AF 40(600)-1000 by ARO, Inc., contract operator of AEDC, Arnold Air Force Station, Tennessee)

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

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NOTICES

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a subsidiary of Sverdrup and Parcel, Inc.

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ARO Project No. 181228

[redacted]

FOREWORD

The author wishes to express his thanks to Dr. John A. M. Lyon, Professor at the University of Michigan and consultant to The Martin Company, Denver, for the development of the equations presented in the Appendix and used in the analysis of the data obtained in the present tests.

(This Abstract is classified CONFIDENTIAL.)

ABSTRACT

Attenuation of microwave signals by the exhaust gases of the Aerojet-General Corporation XLR91-AJ-5, liquid-propellant rocket engine was determined under simulated altitude conditions. Attenuation of K-band (24.15 kmc) and X-band (9.38 kmc) signals varied between 1.18 and 1.56 db for K, and 2.54 and 3.32 db for X. These attenuations yielded an average ion concentration of 5×10^9 per cc and an average collision frequency of 1.22×10^{11} per sec.

(Catalog cards with an unclassified abstract may be found in the back of this document.)

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

A	Attenuation, decibel
FS-1	Signal to fire igniter and actuate propellant valve open
K	Microwave frequency, 24.15 kmc
N	Electron density, meter^{-3}
N'	Electron density, centimeter^{-3}
S	Distance through ionized gas along the transmission path, meter
t	Time, sec
X	Microwave frequency, 9.38 kmc
α	Attenuation, meter^{-1}
ν	Collision frequency, sec^{-1}
ω	$2\pi f$

SUBSCRIPTS

avg	Average
k	K-band microwave frequency
Ref	Reflected
Rec	Received
Tr	Transmitted
x	X-band microwave frequency

1.0 INTRODUCTION

Observations made on a number of large ballistic missiles have shown that their exhaust gases can attenuate radio frequency communication signals severely. These signals are used for tracking, guidance, safety, and telemetery of flight data. Severe attenuation of these signals during the powered portion of the flight can cause loss of contact between the ground control station and the missile. Relocation of ground tracking stations to "look" at the transmitting/receiving antenna without looking through the engine exhaust, and thus eliminate exhaust-caused attenuations, is impractical. Increasing the power of the missile signal generating equipment to cope with these attenuations is also highly impractical because of weight restrictions imposed by this equipment.

To estimate the severity of the attenuation of signals to and from the missile it is necessary to know the electron density and the electron collision frequency in the exhaust. Therefore, tests were conducted in the Satellite Rocket Cell J-3, Rocket Test Facility (RTF), Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), to determine the electron density and the electron collision frequency in the exhaust of the SM-68B (Titan II) second-stage sustainer engine (XLR91-AJ-5). This investigation was conducted from January 23 to April 17, 1962, as requested by the Ballistic Systems Division, AFSC, for The Martin Company, Denver, Colorado.

Attenuation measurements were made at K-band (24.15 kmc) and X-band (9.38 kmc) microwave frequencies through the engine exhaust at pressure altitudes between 57,000 and 71,000 ft. These measurements were obtained as a secondary objective of a larger program involving testing of the Aerojet-General Corporation (AGC) XLR91-AJ-5 liquid-propellant rocket engine.

2.0 APPARATUS

2.1 TEST ARTICLE

The AGC XLR91-AJ-5 rocket engine (Fig. 1) is a liquid-propellant, wet jacket start, turbopump-fed rocket engine rated at 100,000-lb thrust at an altitude of 250,000 ft. The engine uses N_2O_4 and a mixture consisting of 50-percent hydrazine and 50-percent UDMH by weight as its propellants. A detailed description of the engine can be found in Ref. 1.

Manuscript released by author July 1962.

The Martin Company (TMC) supplied the microwave equipment used in these tests. The set-up consisted of power supplies, klystrons, detectors, associated waveguide, and transmitting and receiving antennas. A sketch of the antennas used is shown in Fig. 2.

2.2 INSTALLATION

The XLR91-AJ-5 was installed in the Satellite Rocket Cell J-3 with the nozzle exit extending into the cell diffuser inlet. The cell permits vertical firing of solid or liquid-propellant rocket engines at pressure altitudes in excess of 100, 000 ft. The cell uses a steam-driven ejector to augment the pressure ratio of the main RTF exhausters to simulate high pressure altitude start and tailoff conditions. Pressure altitude simulation during a firing is provided by utilization of the rocket exhaust as the primary ejector. A detailed description of the J-3 cell is in Ref. 2.

The microwave equipment was installed in and around the cell area as shown in Fig. 3. Figure 4 shows the relationship between the antenna and the engine-nozzle exit plane.

2.3 INSTRUMENTATION

The engine chamber pressure was sensed by a strain-gage-type, 1500-psia transducer with the output recorder on an oscillograph by a mid-frequency (600 cps) galvanometer. The test cell ambient static pressure was sensed by a strain-gage-type, ±5-psid transducer used in conjunction with a vacuum reference. The transducer output was recorded by a mid-frequency (600 cps) galvanometer. Engine propellant flowrates were obtained from turbine-type flowmeters; the outputs of which were recorded on oscillograph in cyclic form and on magnetic tape.

The output of the microwave crystal detectors was filtered (1000-cps line filters) and the modulating 1000-cps signal amplified to drive high frequency (3000 cps) galvanometers for recording purposes. However, the two received signals were fed through logarithmic converters prior to amplification to yield a d-c signal for recording purposes. A schematic of the microwave set-up is shown in Fig. 5.

3.0 PROCEDURE

The klystron power supplies were turned on and allowed to stabilize (prior to testing), the transmitting frequencies being determined with all components stabilized. The output of the various signals was amplified to give desired trace deflection on the recording oscillograph. The padder attenuator was set at 2 db for K-band and 14 db for X-band (for run Nos. 5, 6, and 8), and was not installed for the first four runs.

A calibration of each band was accomplished prior and subsequent to each engine firing. The calibrations were obtained by setting the precision attenuators to prescribe attenuations and recording trace deflection on the recording oscillograph. The recorder was turned on prior to FS-1 and run at a speed of 1. 6 in. /sec for the duration of the firing. All data presented in this report were manually reduced from the oscillograph records using the equations in the Appendix.

A check was made to see if the cell conical inlet had any adverse effects upon the signal attenuation. A reflective material inserted around the conical diffuser revealed no adverse effect on the signal levels at sea-level conditions.

4.0 RESULTS AND DISCUSSION

4.1 GENERAL

Excessive attenuation of radio frequency signals passing through missile exhausts was first recognized during firings of the V-2 developed in Germany. Later, during firings of the U. S. Army Redstone missile, signal attenuation was also noted. Tracking stations to the rear of the missile experienced as much as a 40-db gain in signal level when the engine was turned off, while those stations to either side of the missile noted no such initial signal attenuation. Present day missiles, such as the Titan II, are still susceptible to similar signal attenuations.

Despite the vast amount of theoretical knowledge on radio frequency technology, the exact attenuation of any signal to or from the missile, under flight conditions, is indeterminate. Sea-level measurements have been made but are hampered by the fact that the altitude nozzle is overexpanded at sea level, thus presenting a restricted flow field populated by strong shock families that do not exist at altitude. Additional engine-nozzle exit conditions that contribute to the ion concentration and collision frequency, such as exhaust static temperature, also differ from flight conditions.

It is present-day practice to include a flight recorder that plays back telemetery data subsequent to the powered portion of the missile's flight.

This solution is required because no foreknowledge is available on the expected attenuation of the telemetery signals. Should pre-fire information be available, a minor relocation of the missile's telemetry antennas to look through less of the engine's exhaust may be dictated, thus saving precious weight in the instrument package.

Thus, tests under simulated altitude conditions with full-scale hardware, such as reported herein, can be used to great advantage before-the-fact. Although the information obtained during these firings is not the end point in the information-acquisition cycle, it still is useful in the determination of a range of signal attenuation that can be expected due to the jet exhaust.

4.2 TEST RESULTS

Results of attenuation measurements can be summarized as follows:

Run No.	A_{xavg}	A_{kavg}
1	3.05	1.56
2	-	1.18
3	-	1.86
4	2.33	-
5	3.32	-
6	-	-
8	2.54	1.40
Overall average	2.81	1.50

Where no values of attenuation are noted, the measurement was not obtained or was considered unrealistic. As mentioned previously, these measurements were a secondary objective of the main test program, and consequently, conditions were not controlled to obtain complete reliability in these secondary measurements. A malfunction is main test components or test hardware, while not detrimental to main test results, in many cases yielded erroneous attenuation measurements. Water or hydraulic leaks in the test cell during a run were the main cause for the incorrect results.

Figure 6 presents the results of measurements obtained during runs 1 and 8. Data are presented for the time from FS-1+5 sec to FS-1+20 sec for the two runs. During this time period, the engine is operating at steady-state conditions at a steady simulated pressure altitude.

Prior to FS-1+5 sec, the cell pressure, engine-chamber pressure, and flow in front of the antennas were not fully established. Subsequent to

FS-1+20 sec, it is believed that moisture and/or foreign particles could collect in the entrance to the antennas causing unknown effects on transmission and reception.

Values of the electron density and collision frequency calculated for the two runs, using the method shown in the Appendix, are also presented in Fig. 6. Using the overall average of the attenuations observed and considered reliable yields an ion concentration of 5×10^9 per cc and a collision frequency of 1.22×10^{11} per sec.

5.0 CONCLUDING REMARKS

Radio frequency attenuation measurements were obtained at distances between 2.0 and 7.3 in. downstream of the exit of the XLR91-AJ-5 rocket engine. Data were obtained at test cell ambient pressures between 0.30 and 0.58 psia.

Average attenuations of 2.81 and 1.50 db were obtained for X-band and K-band microwave frequencies, respectively, yielding an ion concentration of 5×10^9 per cc and a collision frequency of 1.22×10^{11} per sec.

REFERENCES

1. Aerojet-General Corporation. "Training Textbook, WS107-2 Weapon System Propulsion Subsystem, Titan II." February 1961. (Confidential)

2. Test Facilities Handbook, (3rd Edition). "Rocket Test Facility, Vol. 2." Arnold Engineering Development Center, January 1961.

APPENDIX

The values of A, obtained experimentally, are readily given in proper units for further computations from actual test values from the formula:

$$a = \frac{0.1151\,A}{S}$$

The collision frequency can be expressed as:

$$\nu = \sqrt{\frac{a_k (\omega_k)^2 - a_x (\omega_x)^2}{a_x - a_k}} \ \mathrm{sec}^{-1}$$

and the electron density can be expressed as:

$$N = 0.187 \times 10^6 \left(\frac{a_x (\omega_x)^2 + a_x \nu^2}{\nu} \right) \mathrm{m}^{-3}$$

or

$$N' = 0.187 \left(\frac{a_x (\omega_x)^2 + a_x \nu^2}{\nu} \right) \mathrm{cm}^{-3}$$

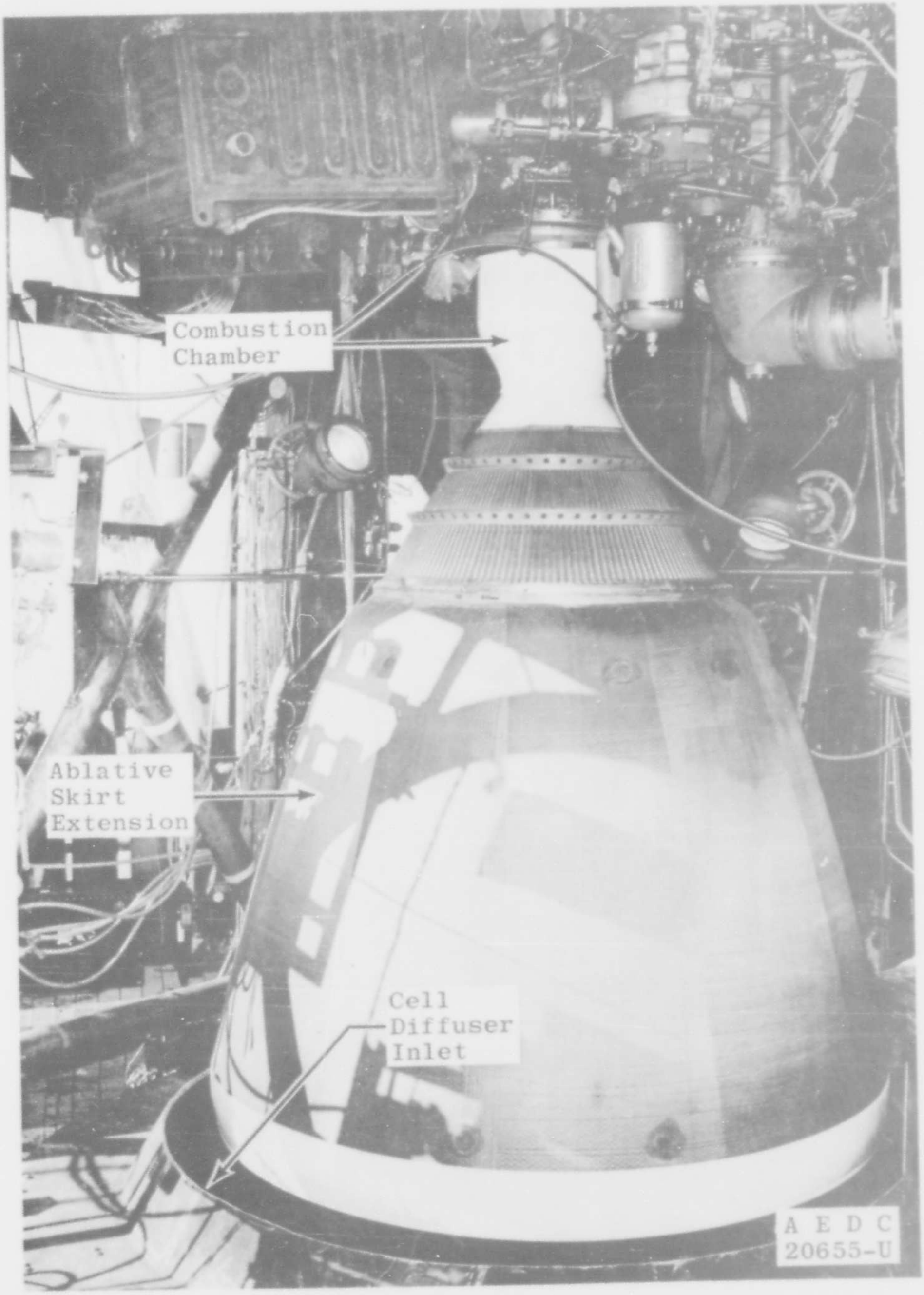
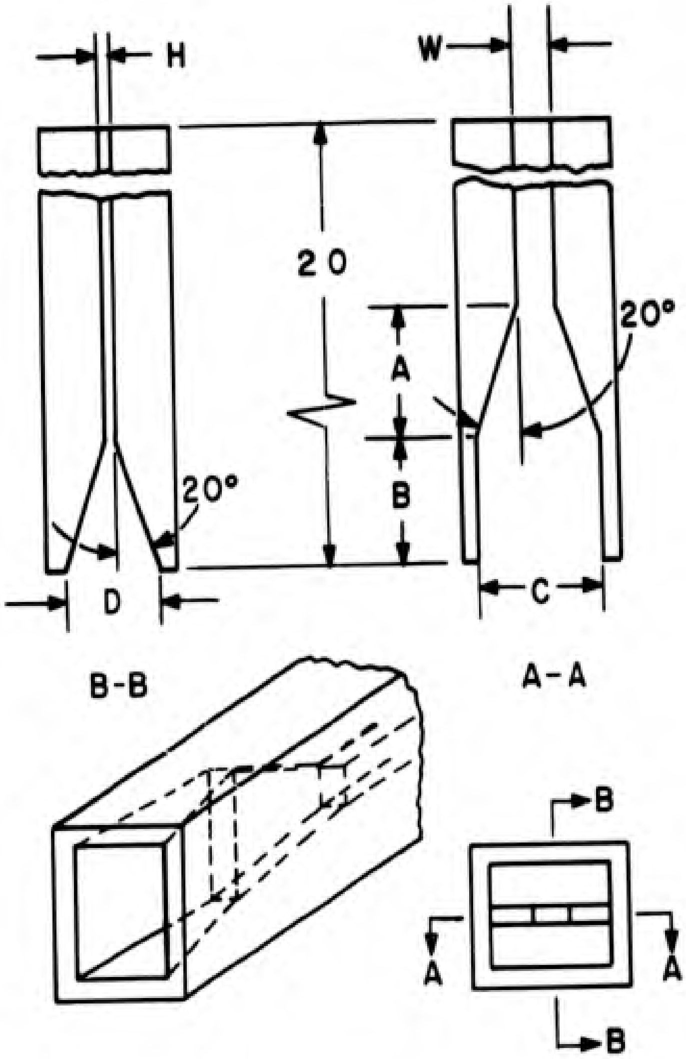


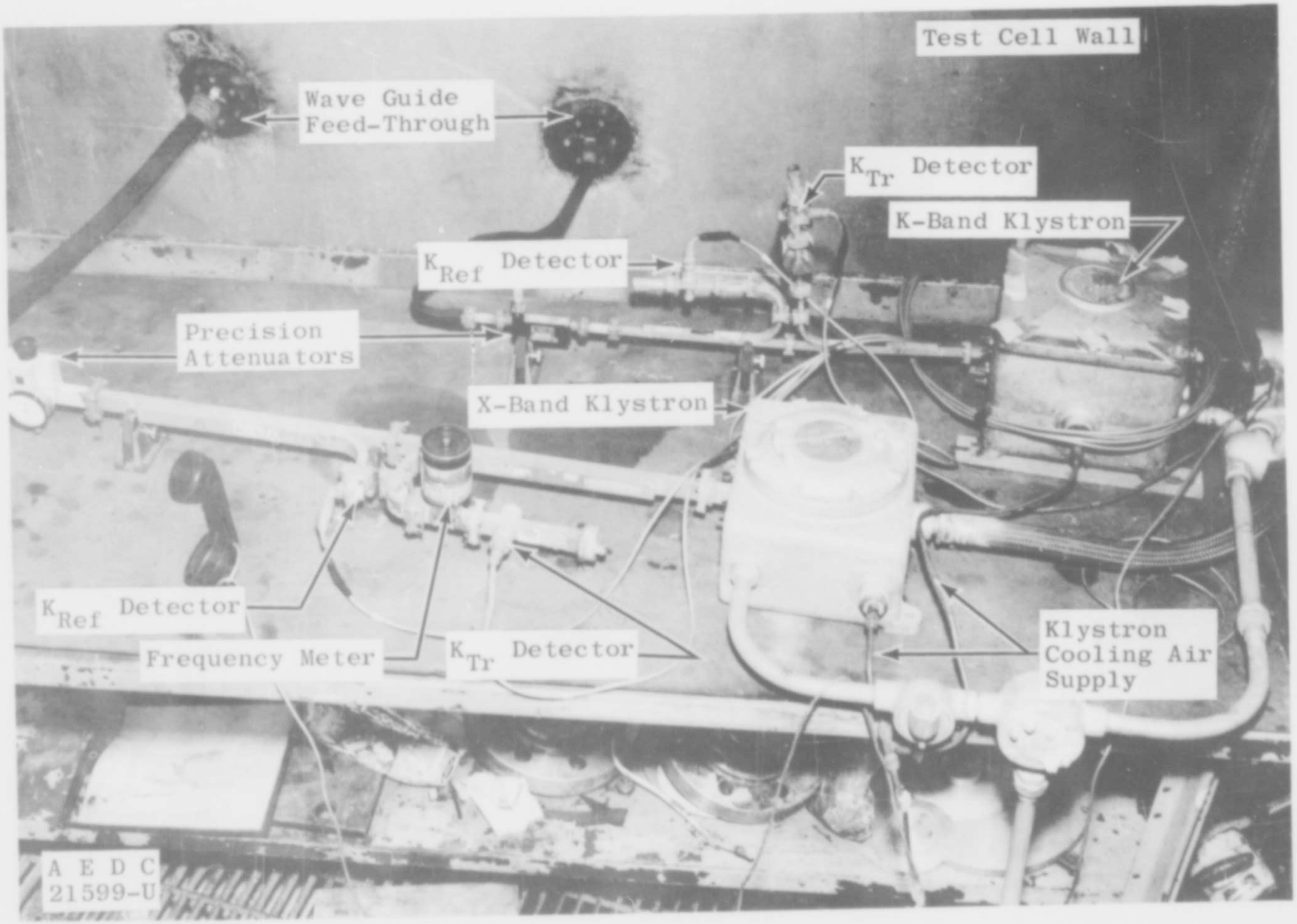
Fig. 1 XLR91-AJ-5 Rocket Engine



DIMENSIONS	A	B	C	D	W	H
X-BAND HORN	3.55	3.05	3.49	2.60	.90	.40
K-BAND HORN	1.30	1.15	1.34	1.00	.42	.17

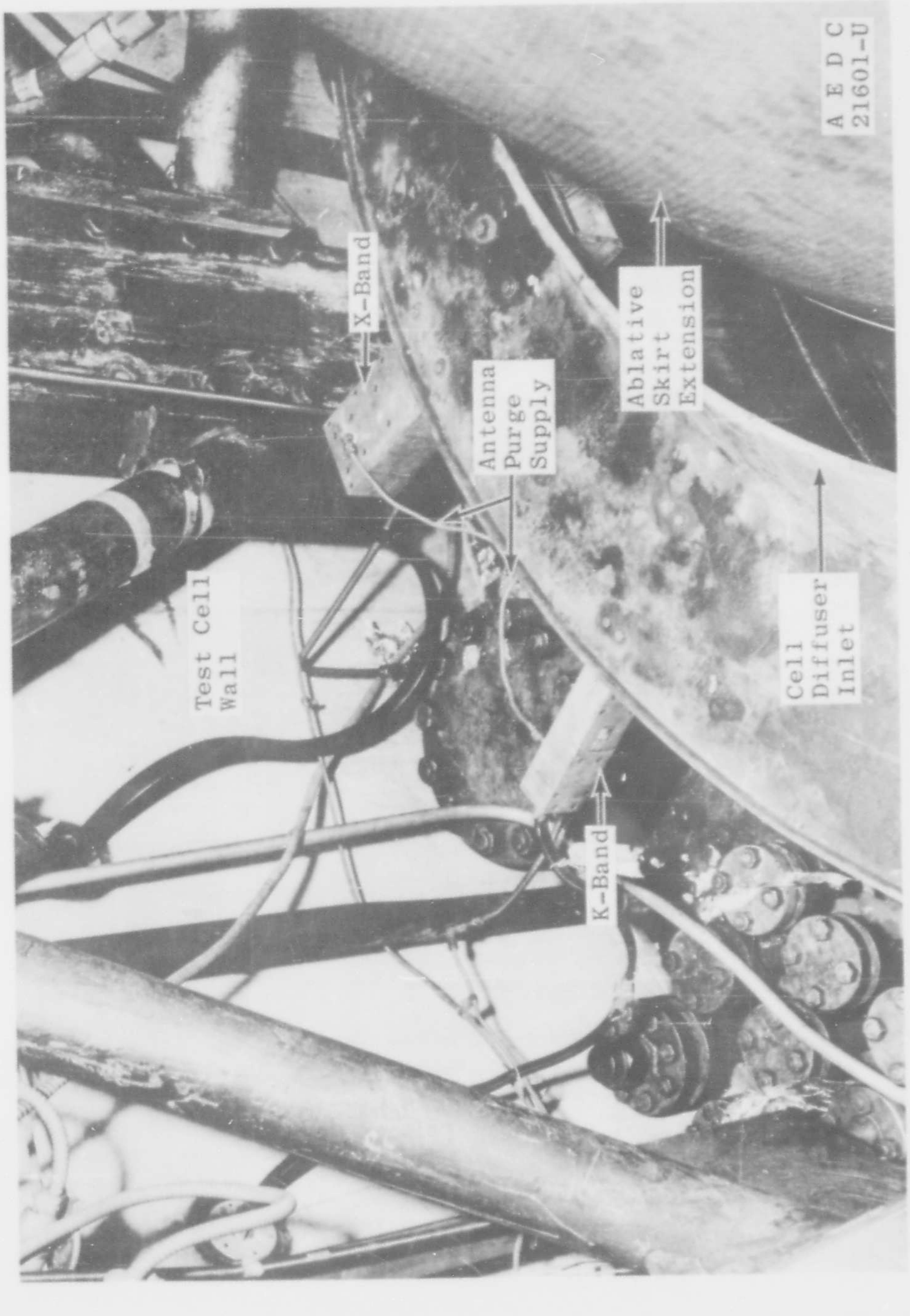
NOTE- ALL DIMENSIONS IN INCHES

Fig. 2 Receiving/Transmitting Antenna Details



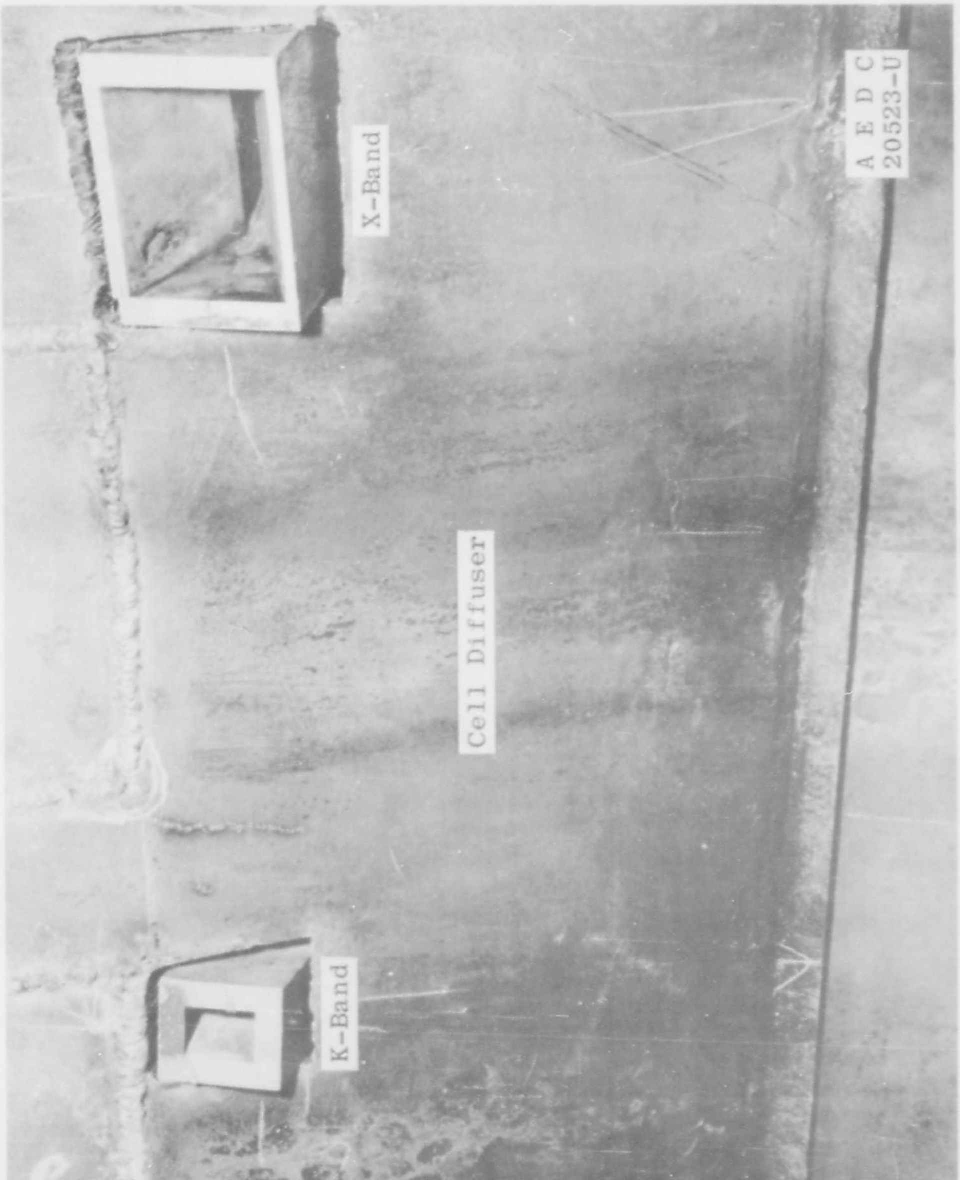
a. Transmitting Equipment

Fig. 3 Microwave Equipment Installation



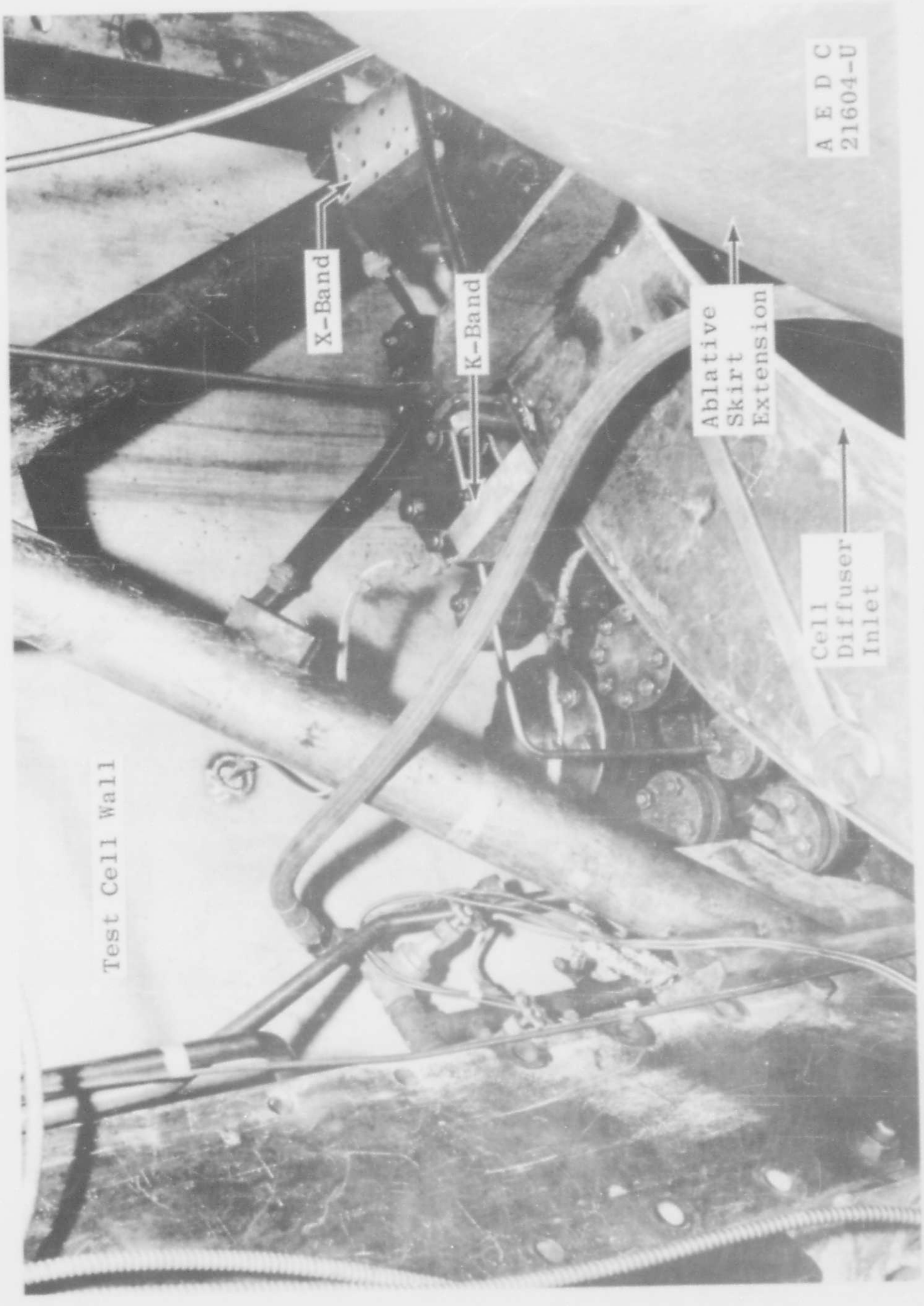
b. Transmitting Antennas

Fig. 3 Continued



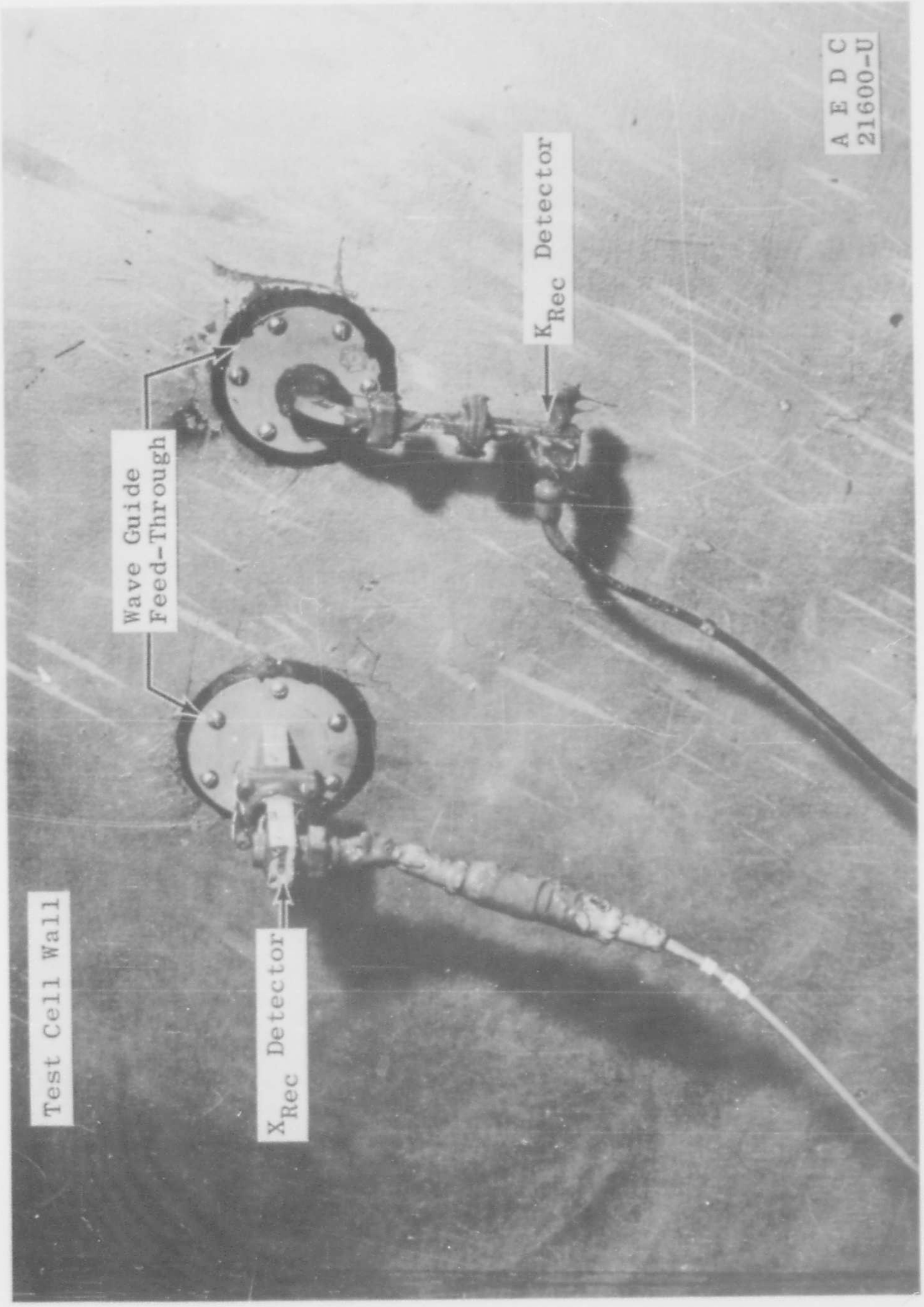
c. Antennas

Fig. 3 Continued



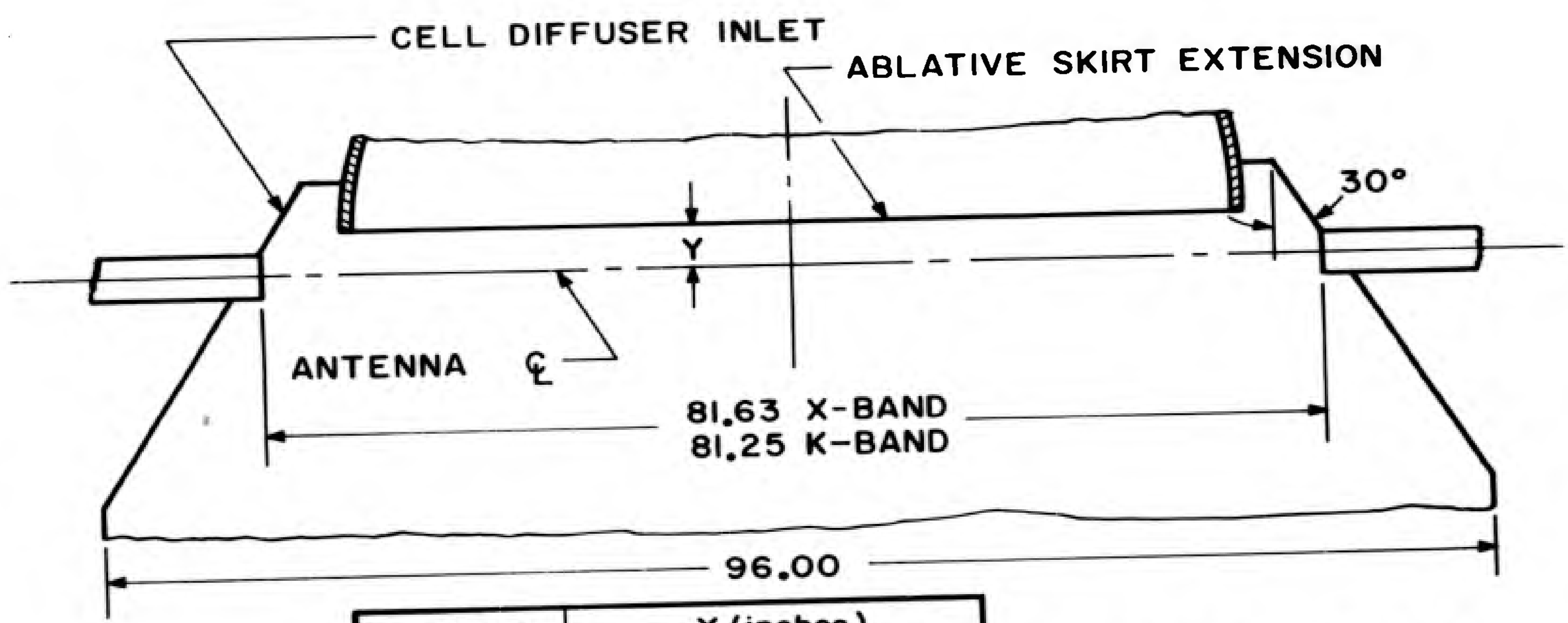
d. Receiving Antennas

Fig. 3 Continued



e. Receiving Detectors

Fig. 3 Concluded



RUN NO.	Y (inches)	
	X-BAND	K-BAND
1	4.7	4.2
2	4.7	4.2
3	2.5	2.0
4	2.5	2.0
5	3.5	3.0
6	7.3	6.8
8	7.3	6.8

NOTE: ALL DIMENSIONS IN INCHES

Fig. 4 Antenna Location Schematic

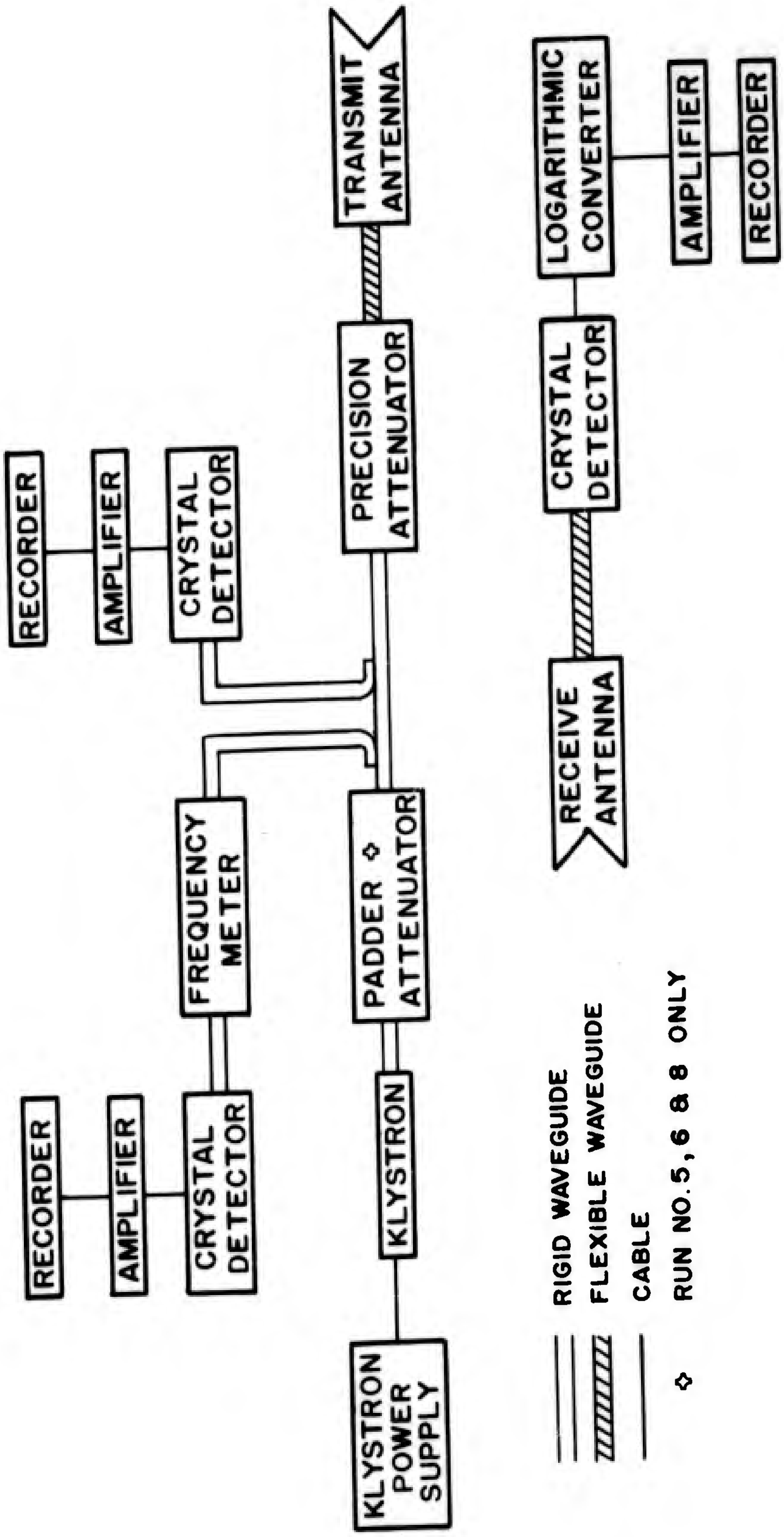
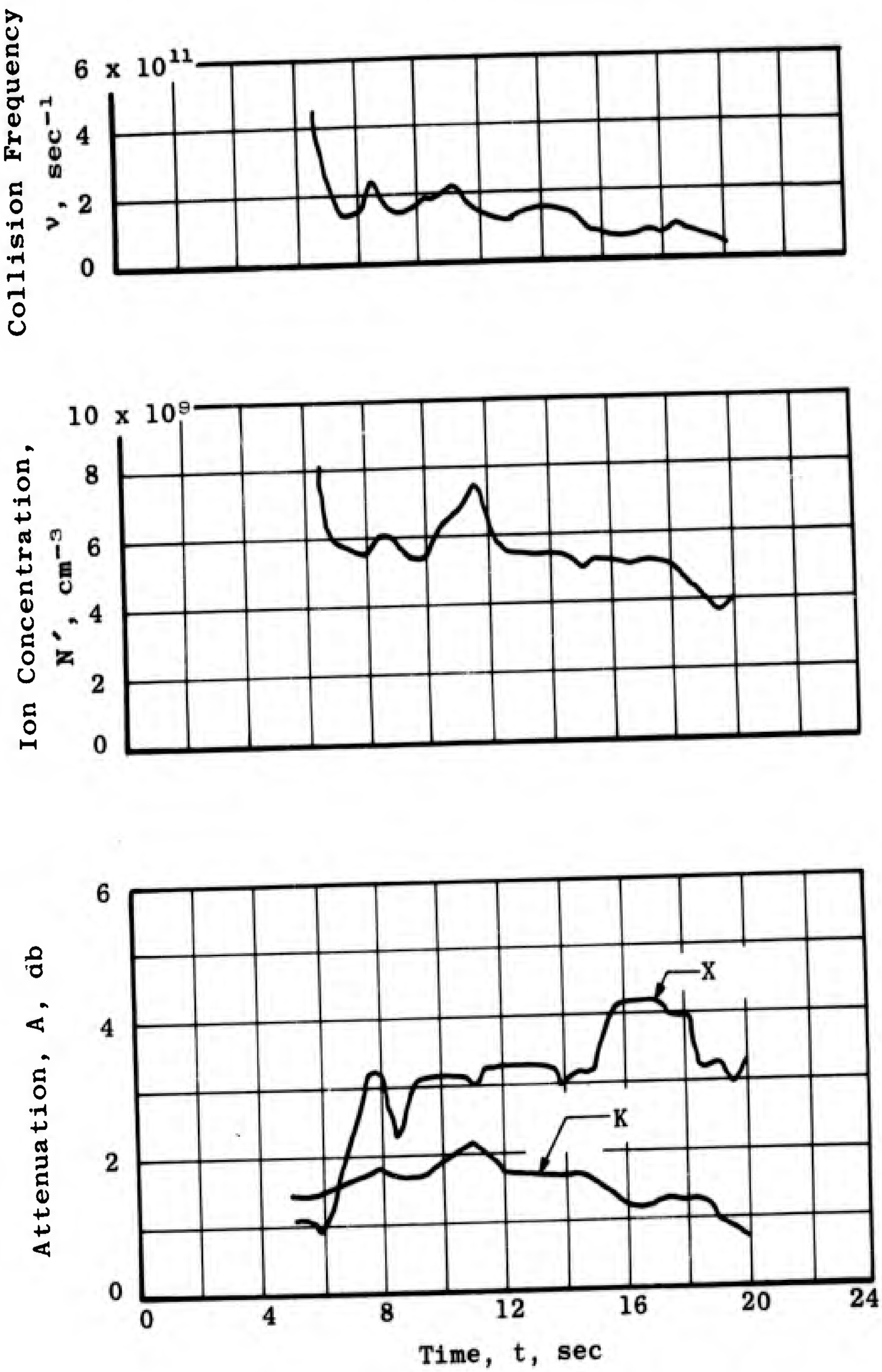
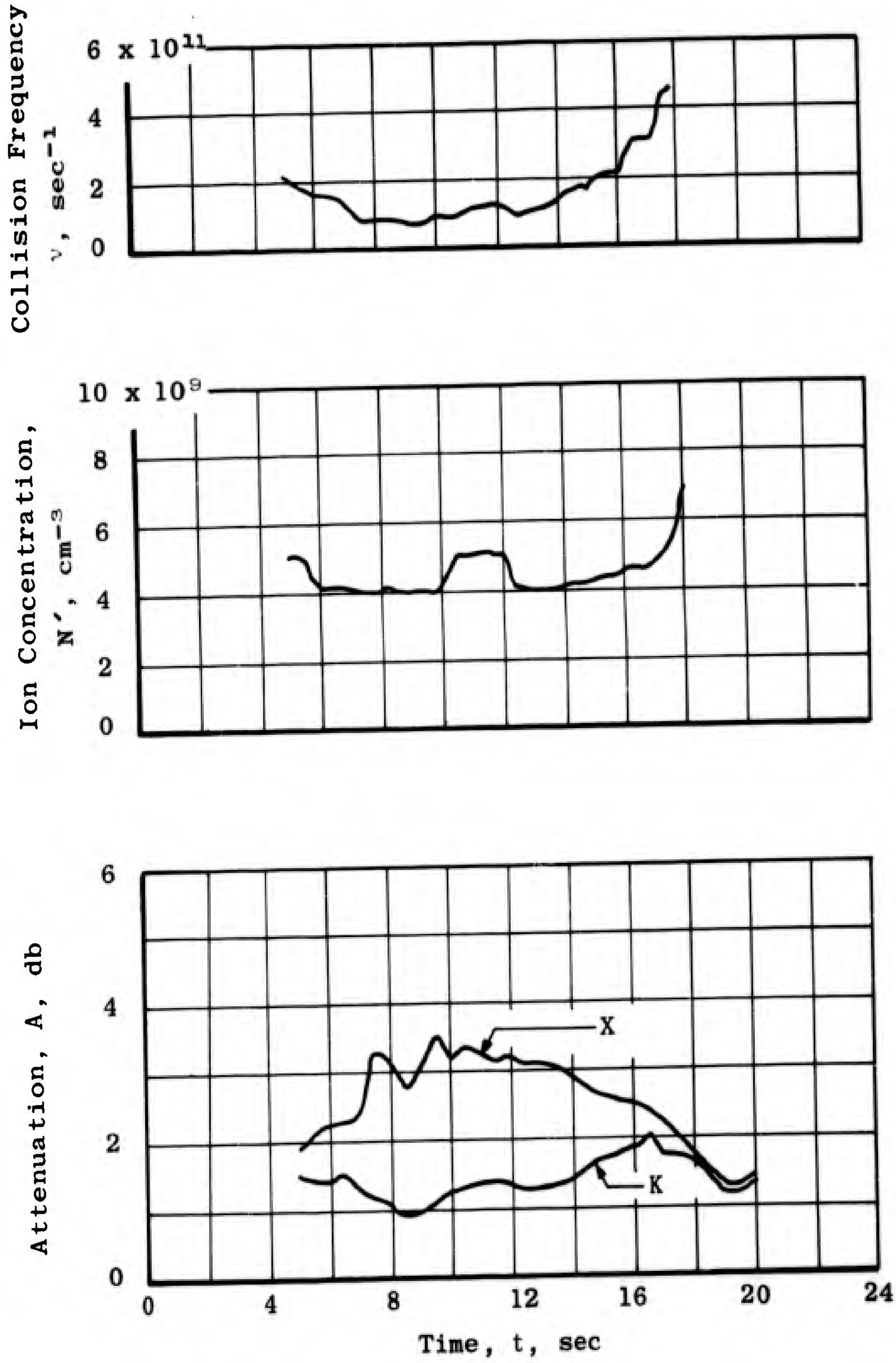


Fig. 5 Microwave System Schematic



a. Run No. 1

Fig. 6 Attenuation, Ion Concentration, and Collision Frequency



b. Run No. 8

Fig. 6 Concluded

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8. Antennas
9. Detectors

I. AFSC Program Area 107C
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. C. M. Tuthill, Jr.
V. In ASTIA Collection

UNCLASSIFIED

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