Telemetry antenna for Black Brant III rocket

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RADIO AND ELECTRICAL ENGINEERING DIVISION

TELEMETRY ANTENNA FOR BLACK BRANT III ROCKET

F. V. CAIRNS

OTTAWA

MAY 1962

ABSTRACT

Black Brant III rockets are being developed jointly by Bristol Aero-Industries Ltd., the Department of Defence Production, and the Defence Research Board. The National Research Council's contribution is the development of the r-f portion of the telemetry system. Development of the antenna is described in this report. The design of the antenna involves structural and aerodynamic as well as electrical factors, and therefore the responsibility was shared between the National Research Council and Bristol Aero-Industries Ltd.

Bristol's preliminary estimates of the performance of the Black Brant III rocket indicated that the velocity would be approximately 7500 ft/sec (Mach 7) at an altitude as low as 27,000 feet on some test firings. The estimated maximum skin temperature of the nose cone in the area where the antenna would be attached was 1400°F, and projections from the skin might be expected to reach temperatures in excess of 2000°F. Aerodynamic heating and drag therefore appeared to be very important factors in the antenna design.

The type of antenna chosen for development was an L-transmission line antenna, called a "quadraloop antenna" by workers at New Mexico State University. A description of the antenna indicating the steps taken because of the severe environment is given. Measurements of performance, including radiation patterns measured on a $\frac{1}{8}$-scale model indicate that this antenna is suitable for Black Brant III telemetry.

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TELEMETRY ANTENNA FOR BLACK BRANT III ROCKET

- F. V. Cairns -

INTRODUCTION

Black Brant III rockets are being developed jointly by Bristol Aero-Industries Ltd., the Department of Defence Production, and the Defence Research Board. The National Research Council's contribution is the development of the r-f portion of the telemetry system. In this report the antenna development is described. The design of the antenna involves structural and aerodynamic as well as electrical factors, and therefore the responsibility was shared between the National Research Council and Bristol Aero-Industries Ltd. Our responsibility was primarily that of assessing the problem from the point of view of telemetry operation and proposing and designing an antenna. Bristol Aero-Industries Ltd. was responsible for ensuring that the antenna was structurally and aerodynamically suitable for the Black Brant III rocket and for providing information on aerodynamic heating necessary for the design of the antenna.

ASSESSMENT OF THE PROBLEM

Bristol's preliminary estimates of the performance of the Black Brant III rocket indicated that the velocity would be approximately 7500 ft/sec (Mach 7) at an altitude as low as 27,000 feet on some test firings. The estimated maximum nose cone skin temperature in the area where the antenna would be attached was 1400°F and projections from the skin might be expected to reach temperatures in excess of 2000°F on these test firings. Aerodynamic heating and drag therefore appeared to be very important factors in the antenna design.

It was thought at first that a tripole turnstile antenna [1] consisting of three blade radiators mounted at 120° to each other and fed with voltages 120° different in phase might be used. This antenna system had been used successfully on Black Brant II rockets, and because of the short time available for antenna development it was attractive. Little further work would have been required to adapt it to the Black Brant III rocket.

An approximate aerodynamic analysis* indicated that portions of the blade might reach temperatures of up to 2400°F and be subjected

* Analysis done by Dr. R. F. Meyer, National Aeronautical Establishment, Ottawa, Ont.

to large drag and lift forces. Survival of the blades on test firings seemed doubtful and an alternative was sought.

The design was complicated by interaction between mechanical, aerodynamical, and electrical requirements. The necessary compromises between these conflicting design requirements were not set down explicitly at the beginning of the program, but were arrived at step by step during the development.

The main requirements were:

1) low drag (estimated maximum projection, 1 sq in),
2) operation across telemetry frequency band of 215-260 mc/s, preferably without adjustment,
3) VSWR less than 2/1,
4) power-handling capacity of 5 watts,
5) radiation pattern to be suitable for rocket-to-ground telemetry,
6) weight to be less than 2 lb,
7) impedance and radiating characteristics not to be affected by aerodynamic heating or mechanical forces of a firing,
8) impedance and radiation characteristics not to be affected by the rocket ablative coating (since the coating would be removed or charred in flight),
9) antenna to be compatible with, and preferably removable from nose cone fairing,
10) strength to be adequate to survive forces encountered on any Black Brant III firing.

The antenna chosen, after consideration of a number of types, was an L-transmission antenna. This antenna has been studied by Prasad and King [2] and has been developed into a rocket antenna by workers at New Mexico State University [3]. It appeared to be potentially capable of meeting the low drag and radiation pattern requirements, and it seemed likely that acceptable compromises on other requirements could be made.

This antenna has been called a "quadraloop", following the terminology of New Mexico State University, and consists of two shunt-fed radiators mounted on diametrically opposite points of the rocket skin and fed out of phase.

A suppressed quadraloop antenna imbedded in a high temperature dielectric was an attractive solution to our problem. However, it was not tried, because (a) design of the nose cone fairing and forward casting of the rocket was well under way when the antenna development was started and could not be delayed while the detailed configuration of the antenna was determined, (b) no suitable dielectric material was known, and it was doubtful that one could be found and incorporated in the design in the time available, and (c) it was not certain that the limited space in the nose cone could be used for a suppressed antenna. An external quadraloop was, therefore, chosen for development.

DESCRIPTION OF ANTENNA

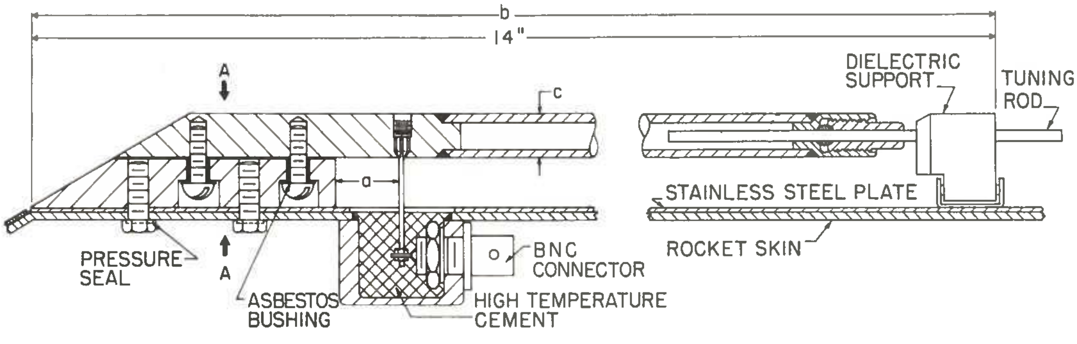


Fig. 1 Details of quadraloop antenna

The antenna mounted on a Black Brant III rocket nose cone is shown in Plate I. A mock-up was used for impedance measurements. It was electrically, but not otherwise similar to a portion of a rocket. The ablative coating was added so that its effect on impedance could be measured. The details of the antenna are sketched in Fig. 1. The antenna system consists of two quadraloop radiators fed through a matched power divider. A phase shift of 180° is accomplished by using cables differing by a half-wavelength to connect the power divider to the radiators.

CHARACTERISTICS OF ANTENNA

a) Impedance and Bandwidth

The first step in the design of the antenna was the determination of critical dimensions. Although general descriptions of the antennas were available, no detailed design information could be found.

The resistive component of the impedance is determined primarily by the distance between the feed point and the r-f ground (dimension (a) on Fig. 1), feedpoints farther from the r-f ground representing higher resistance. The position of the feed point is a function of frequency.

The length of the radiator determines the frequency at which the reactive component of impedance is a minimum. The appropriate dimensions for 215 to 260 mc/s were determined experimentally.

A major factor in determining the bandwidth of this type of antenna is the thickness or diameter of the radiator (dimension (c) on Fig. 1). It very soon became apparent that there was a major conflict between the requirement for low drag and for wide bandwidth. A compromise favoring low drag was adopted. It was thought that narrow bandwidth could be tolerated if a convenient tuning arrangement could be provided. These decisions determined the approximate shape of the antenna.

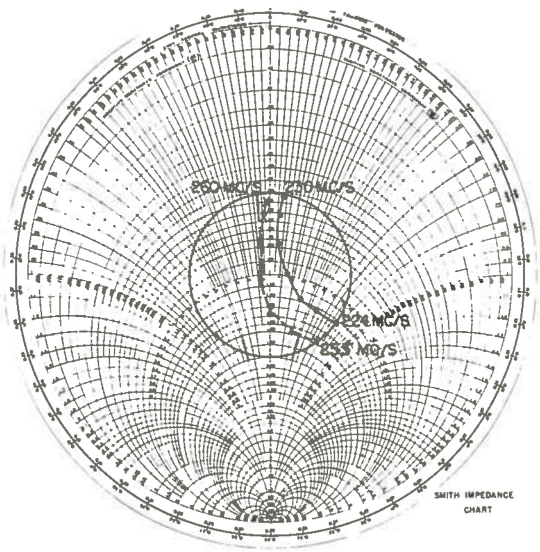


Fig. 2(a) Impedance of quadraloop antenna

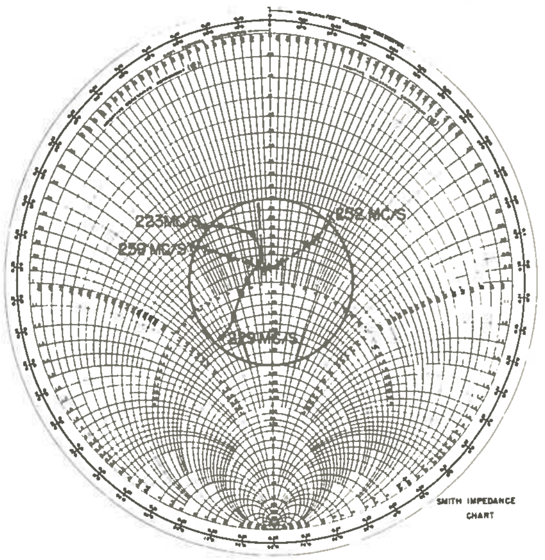


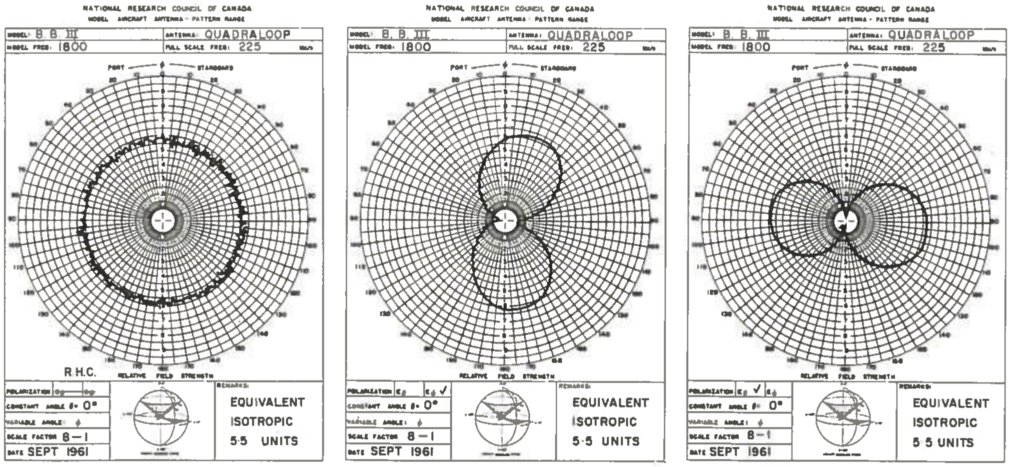
Fig. 2(b) Impedance of quadraloop antenna system at input to power splitter

The impedance of a radiator tuned to frequencies near the top and bottom of the telemetry band is shown in Fig. 2(a); also, the impedance of the antenna system at the input to the power divider is shown in Fig. 2(b).

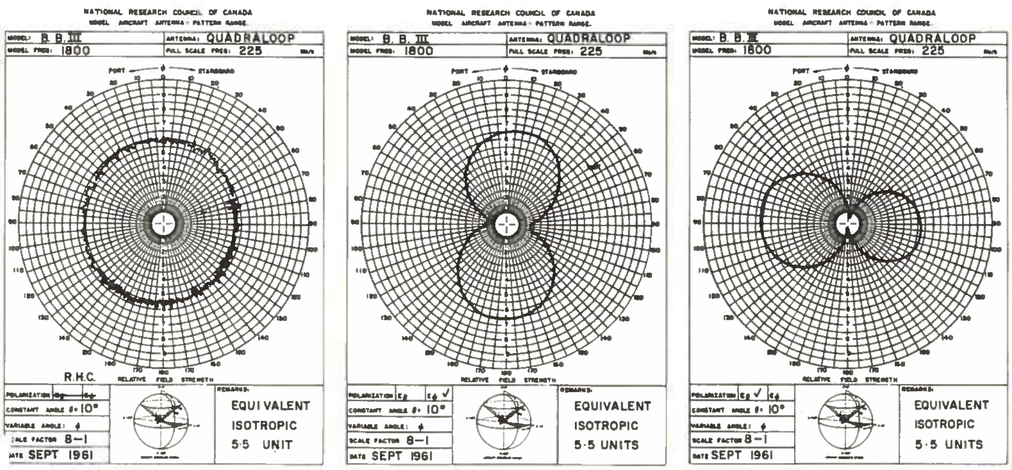
b) Radiation Patterns

The radiation patterns of a quadraloop antenna system on a Black Brant III rocket were checked by measuring radiation patterns of a $\frac{1}{8}$-scale model at 1800 mc/s. The optimum circumferential position of the antennas with respect to the fins was determined.

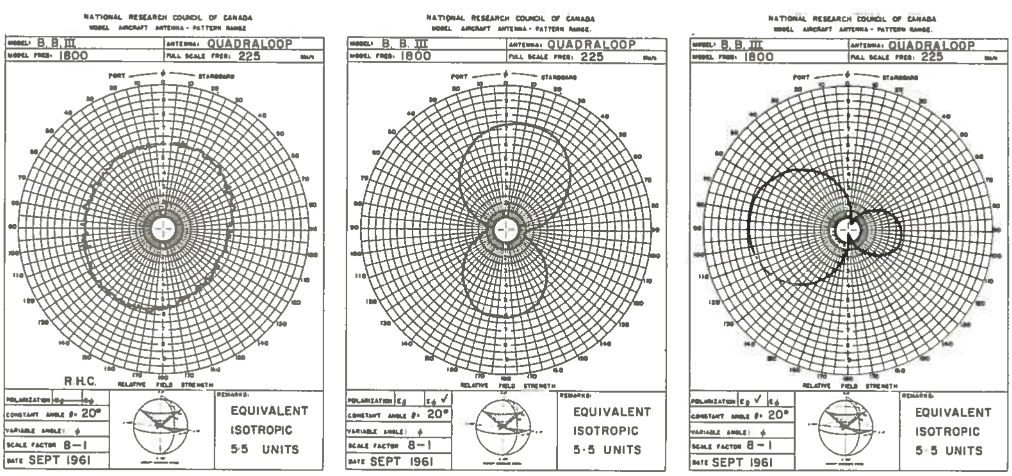
Measured radiation patterns are shown in Figs. 3 to 9. A tolerance, estimated to be ±2 db, must be placed on the level of the equivalent



θ =0°

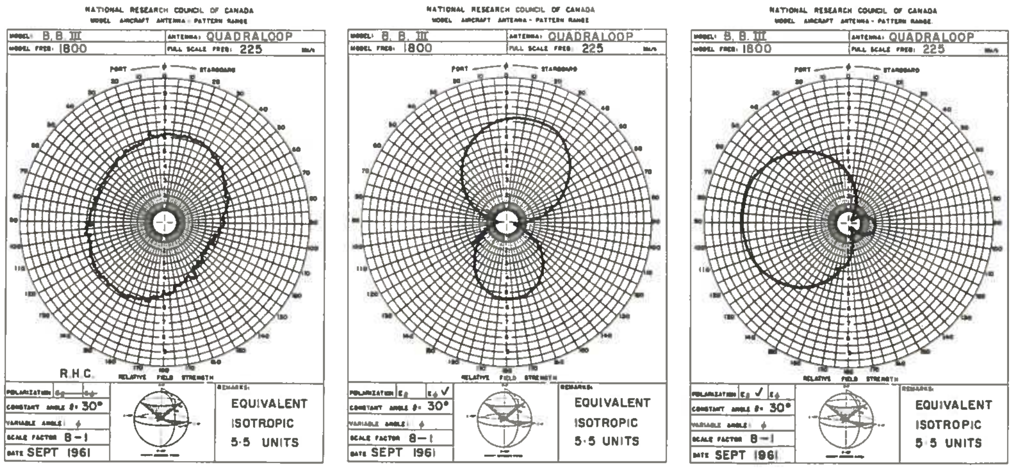


θ =10°

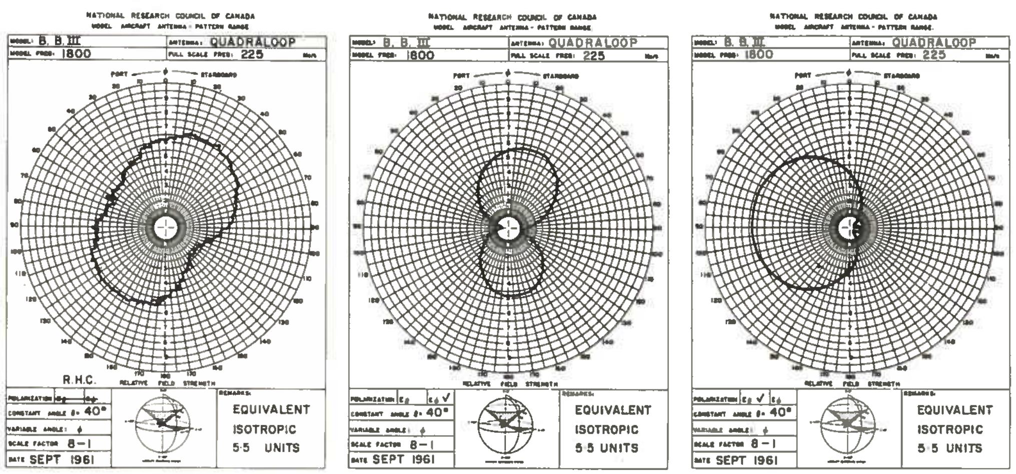


θ =20°

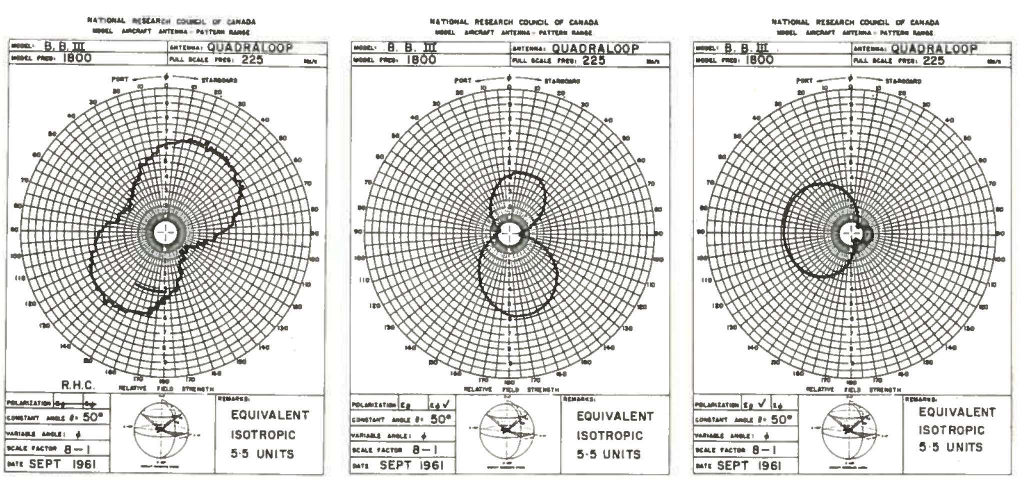
FIG. 3



θ = 30°

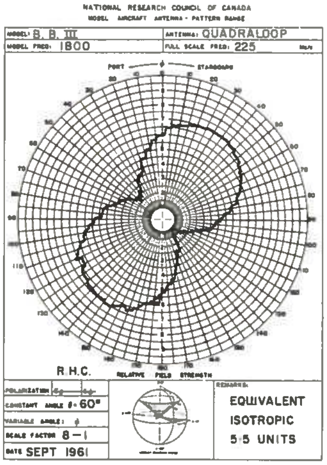


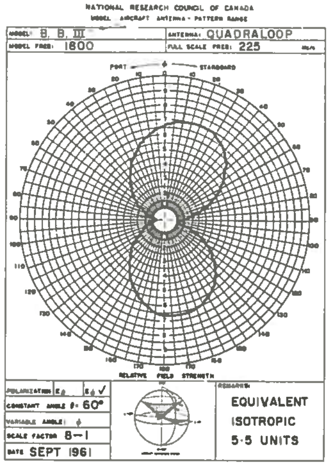
θ = 40°

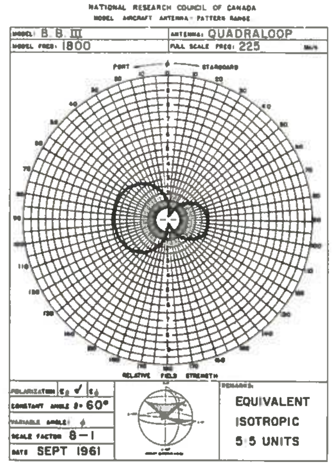


θ = 50°

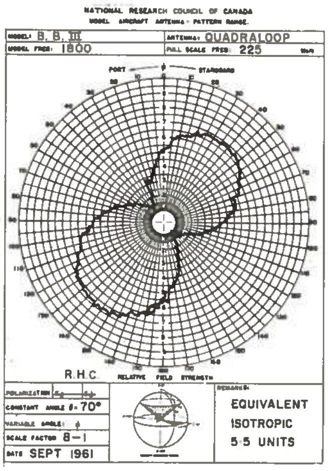
FIG. 4

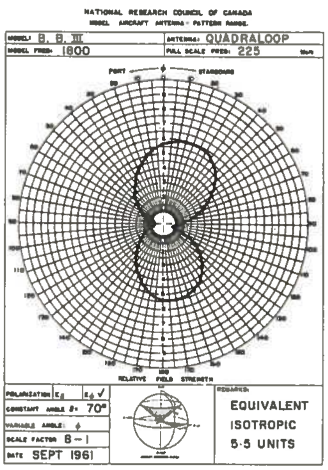


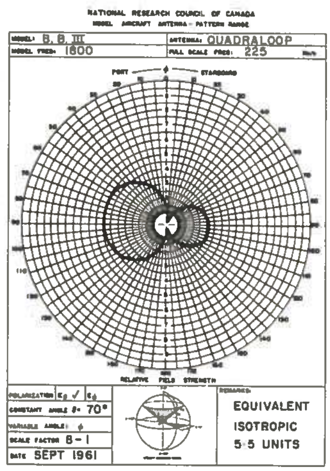




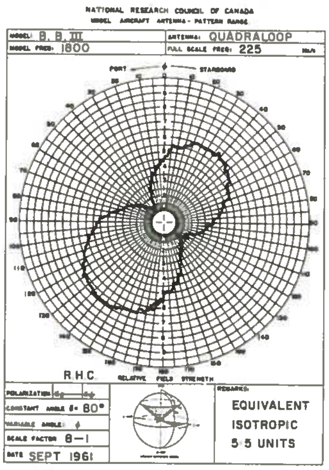
$\theta = 60°$

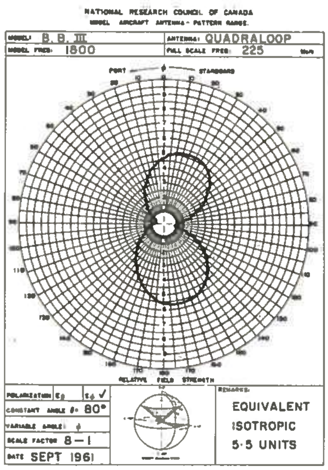


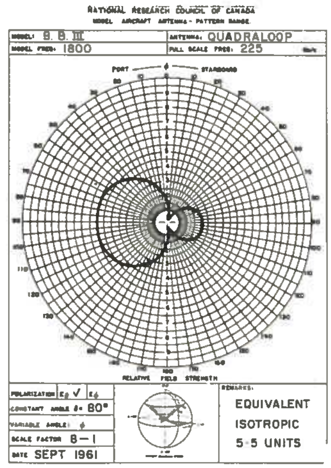




$\theta = 70°$

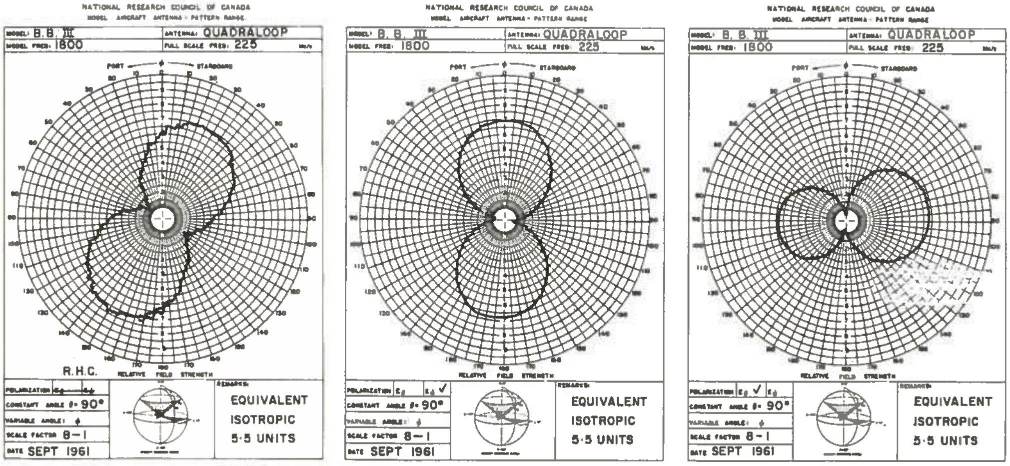




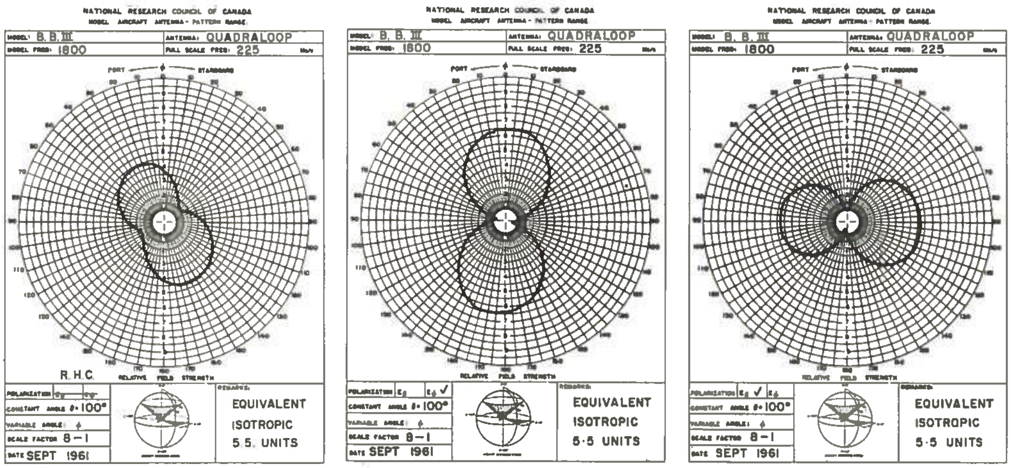


$\theta = 80°$

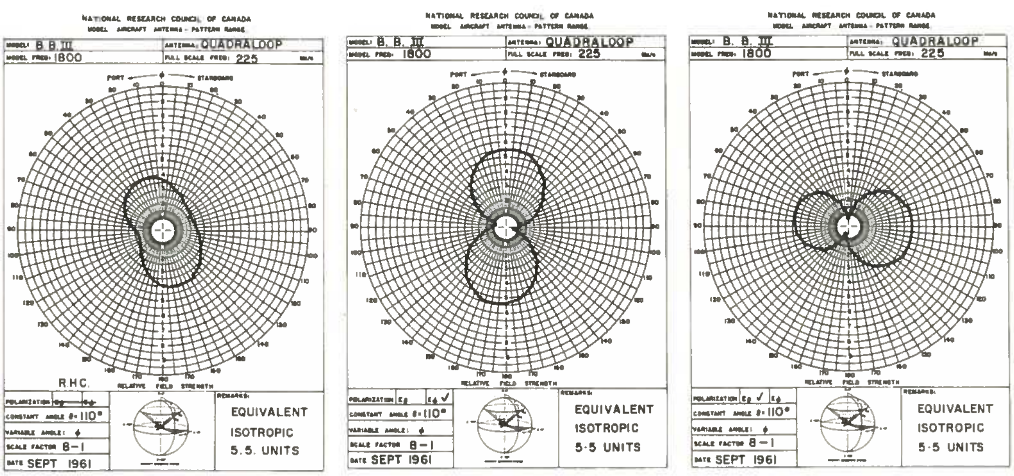
FIG. 5



θ = 90°

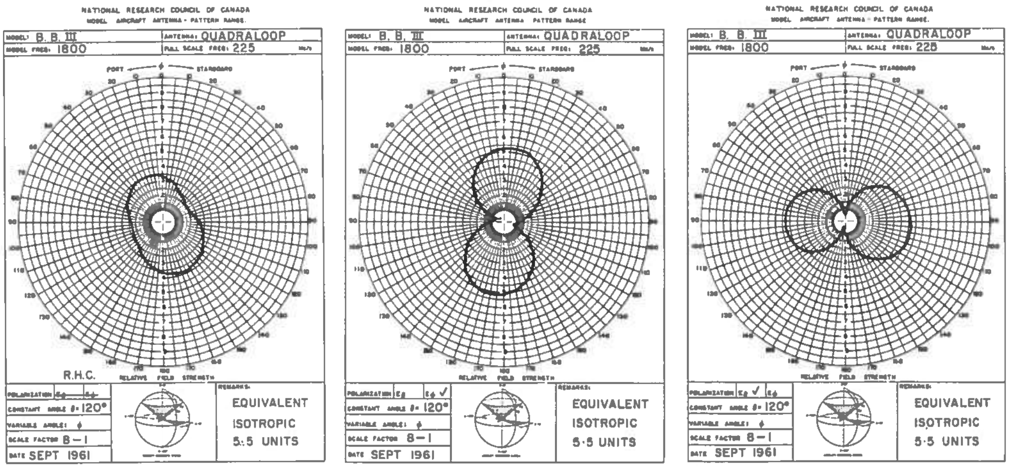


θ = 100°

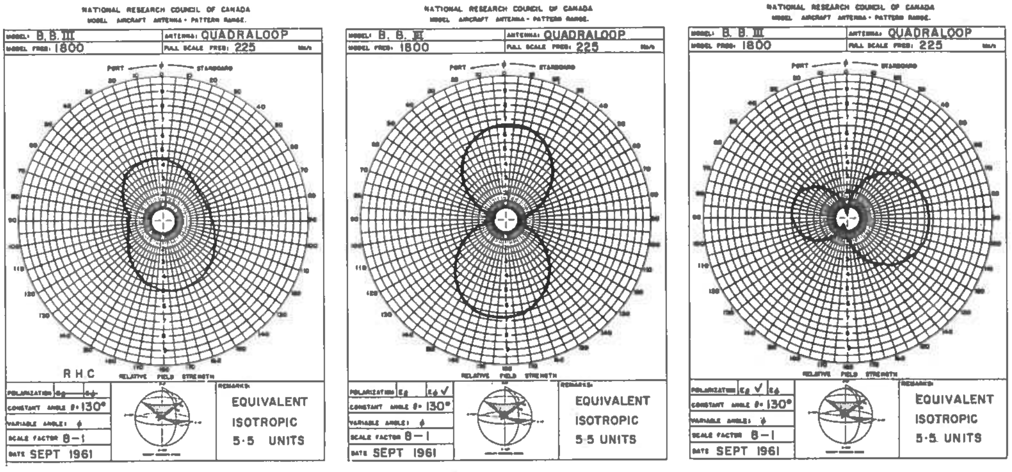


θ = 110°

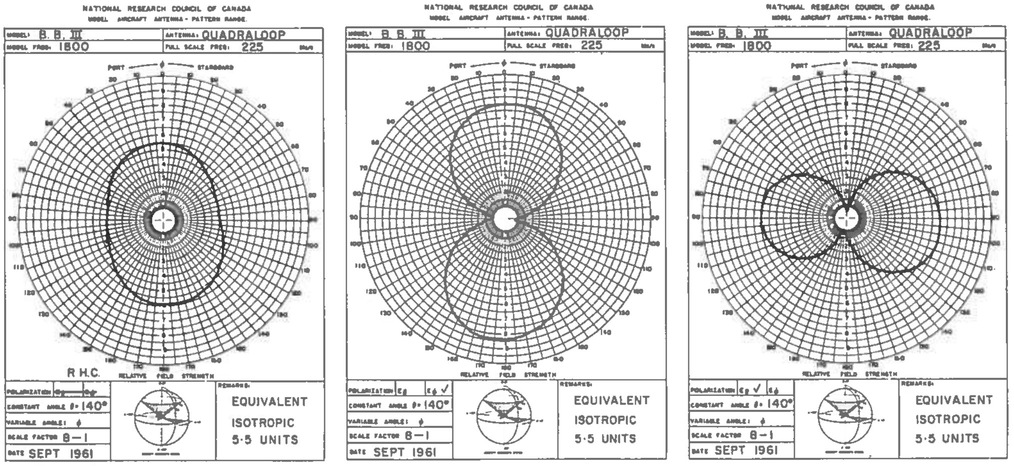
FIG. 6



θ = 120°

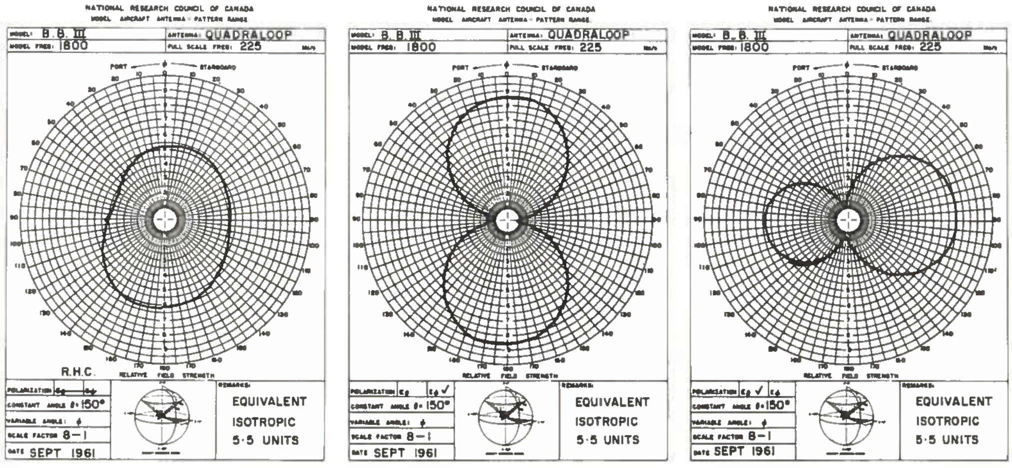


θ = 130°

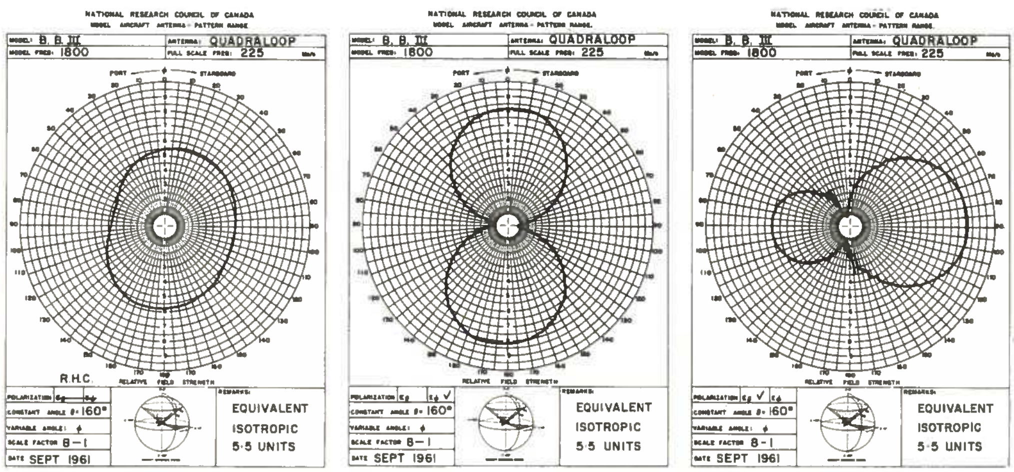


θ = 140°

FIG. 7

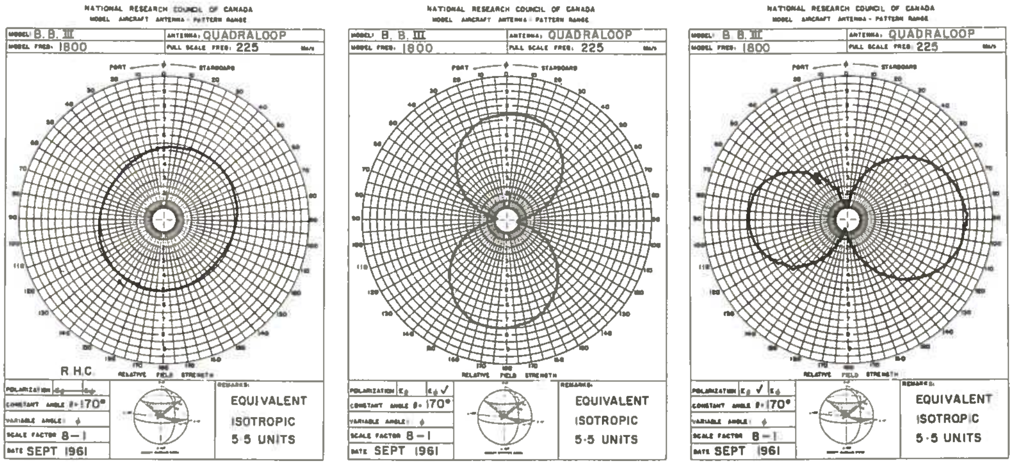


θ = 150°

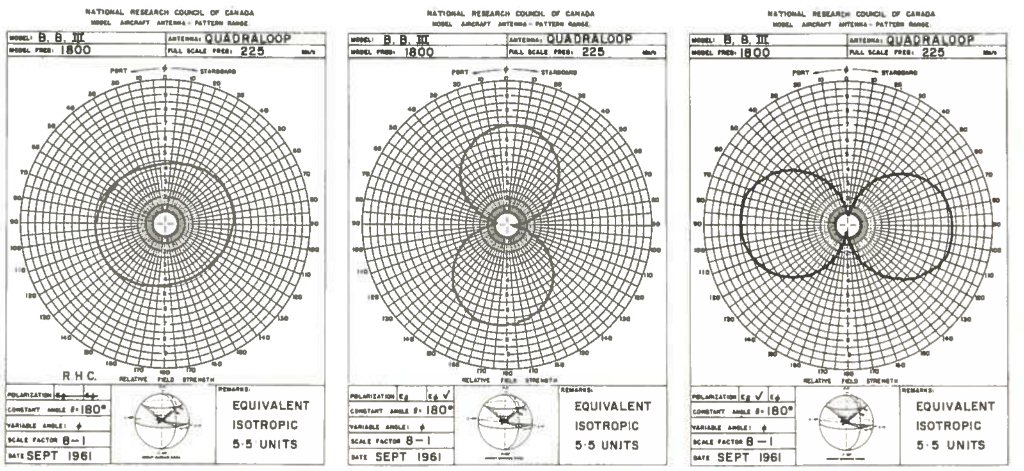


θ = 160°

FIG. 8



θ = 170°



θ = 180°

FIG. 9

isotropic radiator because of circumstances under which the measurements were made. Further measurements to reduce this uncertainty are not considered justified. There is also an uncertainty in the details of the radiation patterns owing to the difficulty of scaling details of the antenna and rocket accurately. These uncertainties are believed to be second order effects.

These radiation patterns show that the antenna system is suitable for rocket telemetry, since they indicate that the operation of the telemetry system will be reasonably independent of rocket attitude. Relatively small variations of amplitude are introduced due to rocket spin when the rocket follows its expected trajectory.

c) Power-handling Capacity

Voltage breakdown in the vicinity of an antenna occurs when the increase [4, 5, 6] in the number of electrons due to ionization by the r-f field exceeds the loss of electrons due to diffusion, recombination, and attachment. This takes place with the lowest impressed r-f field when the mean time between electron collisions in the medium is approximately equal to the period of the field. Hence, frequency and pressure, as well as field strength, determine the breakdown point.

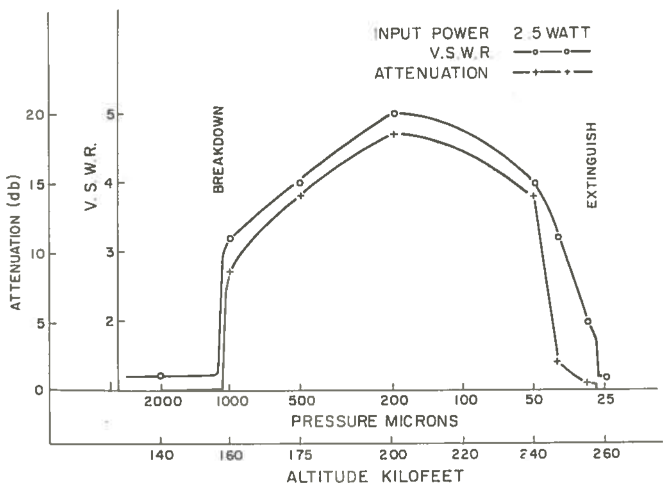


Fig. 10 Attenuation and VSWR of quadraloop antenna against pressure

The effects of voltage breakdown are of practical interest in rocket telemetry because most rockets pass through the region of the upper atmosphere in which voltage breakdown is most probable in the telemetry frequency band. Fig. 10 shows the results of bell jar measurements indicating the effect of voltage breakdown.

The altitude at which breakdown is most likely to occur depends on frequency, but the severity of the breakdown and the altitudes at which it starts and extinguishes depend on power level and the geometrical configuration of the antenna. It is difficult therefore to apply the information available in the literature [4, 5, 6] directly to the quadraloop antenna on the Black Brant III rocket. Rough estimates based on this information have been supported by measurements made in an evacuated bell jar.

The power-handling capacity was considered to be inadequate, and it was decided to increase it by applying a negative d-c bias voltage to the antenna. The power-handling capacity measured in an evacuated bell jar is shown in Fig. 11.

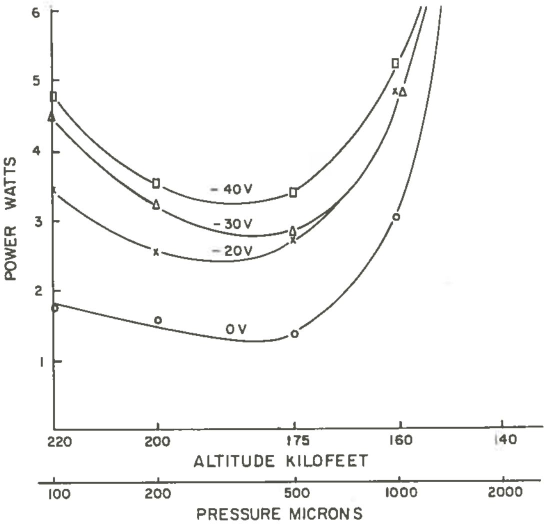


Fig. 11 Breakdown power against altitude and pressure for biased quadraloop

d) Temperature Effects

A major difficulty in the design of this antenna was meeting the requirement that its impedance and radiation characteristics should not change during a flight. Most conventional materials will not survive the elevated temperatures without change of characteristics.

The preferred materials for the radiator are good metallic conductors, such as brass or aluminum. Stainless steel, one of the poorest metallic conductors, was used to ensure sufficient strength at high temperatures. The antenna will increase in length by about one-eighth of an inch due to heating assuming an average temperature of about 1000°F. Compensation for this is not considered necessary.

The material for the d-c insulation required for bias is natural mica. No other material with the mechanical and electrical properties suitable for this environment has been found. A thin section is required to ensure large capacitance and low r-f impedance. The estimated average temperature in the vicinity of the mica insulation is 700°F, with portions reaching much higher temperatures. The mica has been tested through a cycle of heating and cooling; the results are shown in Fig. 12. The hysteresis effect is due to permanent mechanical distortion of the antenna after heating and not to a change in the mica.

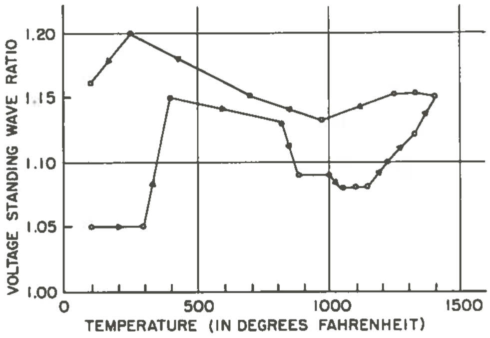


Fig. 12 VSWR of a quadraloop antenna during one cycle of heating and cooling

The effect of expected high temperature will be noted in the arrangement for clamping the adjustable tuning rod and for clamping the centre conductor of the feed to the radiator. Only sliding and threaded contacts have been used and spring contacts have been avoided.

e) Connection Through Rocket Skin

Transferring power from the inside of the rocket to the antenna presents special problems. The high temperature prevents use of ordinary connectors in contact with the rocket skin. The antenna was to be detachable without affecting the pressure seal of the nose cone fairing. The nose cone fairing itself is removed by sliding it along the axis, and therefore the internal projection of the connection must be small. A configuration satisfying these requirements is shown in Fig. 1. The cement in the cavity is necessary:

a) to assure a pressure seal around the BNC connector at high temperatures,
b) to insulate the connectors from the heat at the rocket skin,
c) to strengthen the connection.

It was difficult to find a cement with the properties needed for this application. Mechanical strength must be maintained as well as nearly constant dielectric constant and high resistance at temperatures up to at least 1200°F. We believe that Sauereisen Cement No. 31 will meet these requirements. Its mechanical strength appears to be adequate and the dielectric constant remains nearly unchanged up to 1200°F. The resistivity is reduced by a factor of 1000 at 1200°F, but is still high enough to prevent excessive dissipation of transmitter power.

Unfortunately Sauereisen Cement absorbs moisture when the relative humidity is high, and it must be sealed. Silicone D. C. 4 has been found suitable for sealing.

f) Ablative Coating

It was necessary that the effects of the ablative coating on the characteristics of the antenna should be small, since this coating will be partly removed in flight. Its effect on the radiation pattern was measured on a scale model and found to be detectable, but small. The effect of the ablative coating on the impedance of the antenna was too large to be tolerated. Its partial removal in flight would have detuned the antenna sufficiently to interfere with telemetry.

In the critical area under the radiator the ablative coating has been replaced by a stainless steel plate to overcome this effect.

g) Dielectric Support

A dielectric support for the unsupported end of the antenna was deemed necessary. The requirements for the material are the same as those for the cement described in the previous section, except that it must be machinable or mouldable. Few materials are suitable. Alumina is the most satisfactory found so far, but it has not been used because of the extreme difficulty of machining it. A refractory body supplied by Smith and Stone* is being used and is expected to be adequate.

Because data supplied by manufacturers were incomplete in the temperature range of greatest interest, some comparative measurements of the change of resistance and dielectric constant with temperature were made. The results are shown in Figs. 13 and 14.

LABORATORY TESTING

Laboratory testing has consisted of:

1) impedance measurement on a 3-foot mock-up section of the rocket,
2) radiation pattern measurements on a $\frac{1}{8}$-scale model shown in Plate II,

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* R69 Refractory Body - Smith and Stone Ltd., Georgetown, Ont.

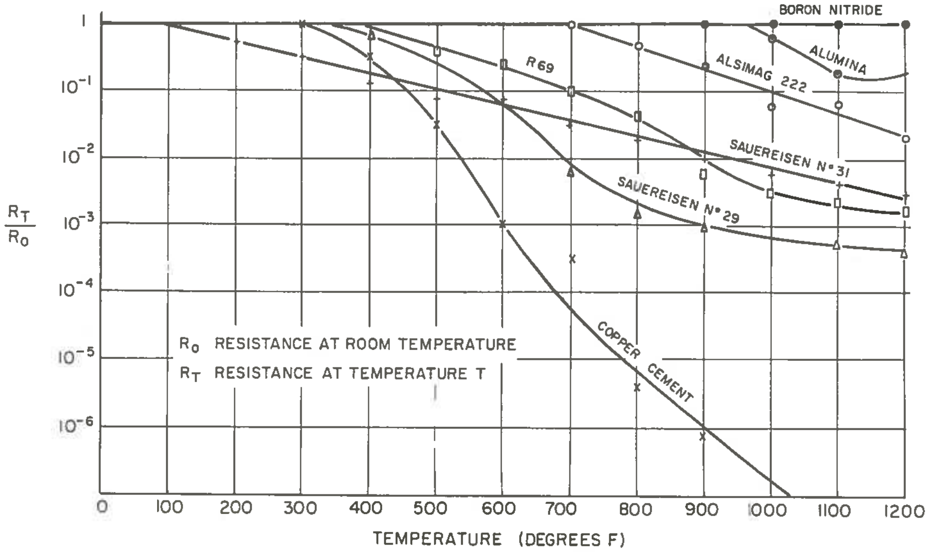

Fig. 13 Resistance versus temperature

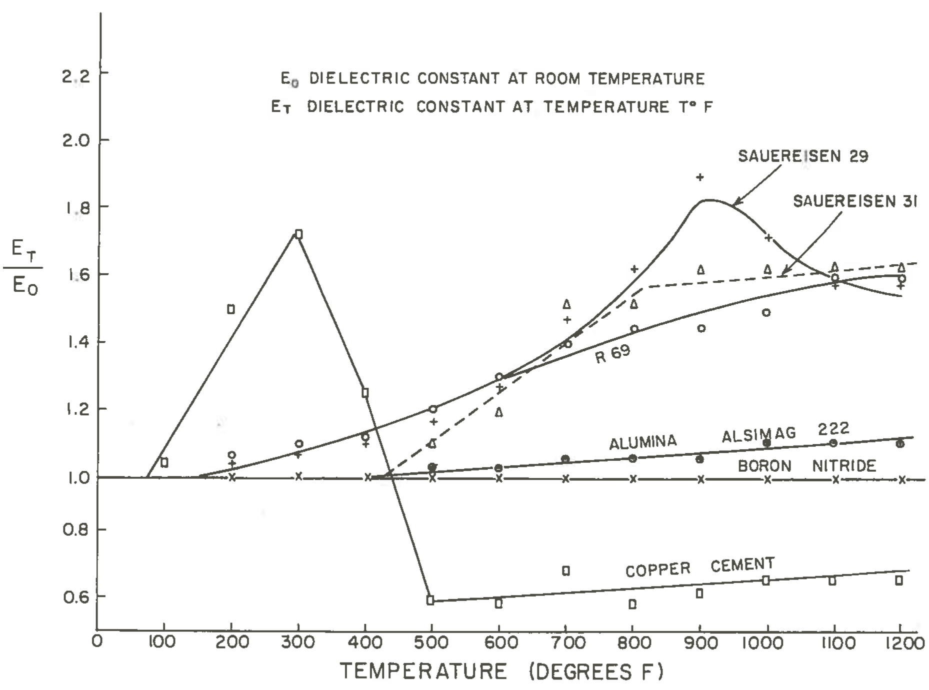

Fig. 14 Dielectric constant versus temperature

3) measurements of the change of impedance while heat is applied locally to portions of the antenna with torches,
4) voltage breakdown measurements in an evacuated bell jar,
5) limited vibration and shock tests.

Impedance and radiation pattern measurements on a full scale model would have given added confidence in the achievement of the predicted performance, but they could not be done.

Attempts to determine the performance of the antenna in its expected environment have been of necessity incomplete. However, all tests that could be done with our facilities have been performed, and every effort has been made to guard against failure in the anticipated environment.

CONCLUSION

A telemetry antenna designed for the severe environmental conditions encountered on a Black Brant III rocket has been described with a view to indicating the special problems and their solutions.

The antenna in its present form is regarded as an interim solution for the first test firings. Its power-handling capacity is marginal, and the d-c bias on the antenna would be unacceptable for some kinds of experimental firings. It is also a disadvantage to have the antenna attached to the nose cone fairings. A position on the forward casting of the rocket, which would allow the antenna to remain in place when the nose cone fairing is removed, would simplify adjustments during installation and check-out of the pay load.

ACKNOWLEDGMENT

The author would like to acknowledge the collaboration of Mr. John H. Craven in the construction of the model of the rocket and the measurement of radiation patterns.

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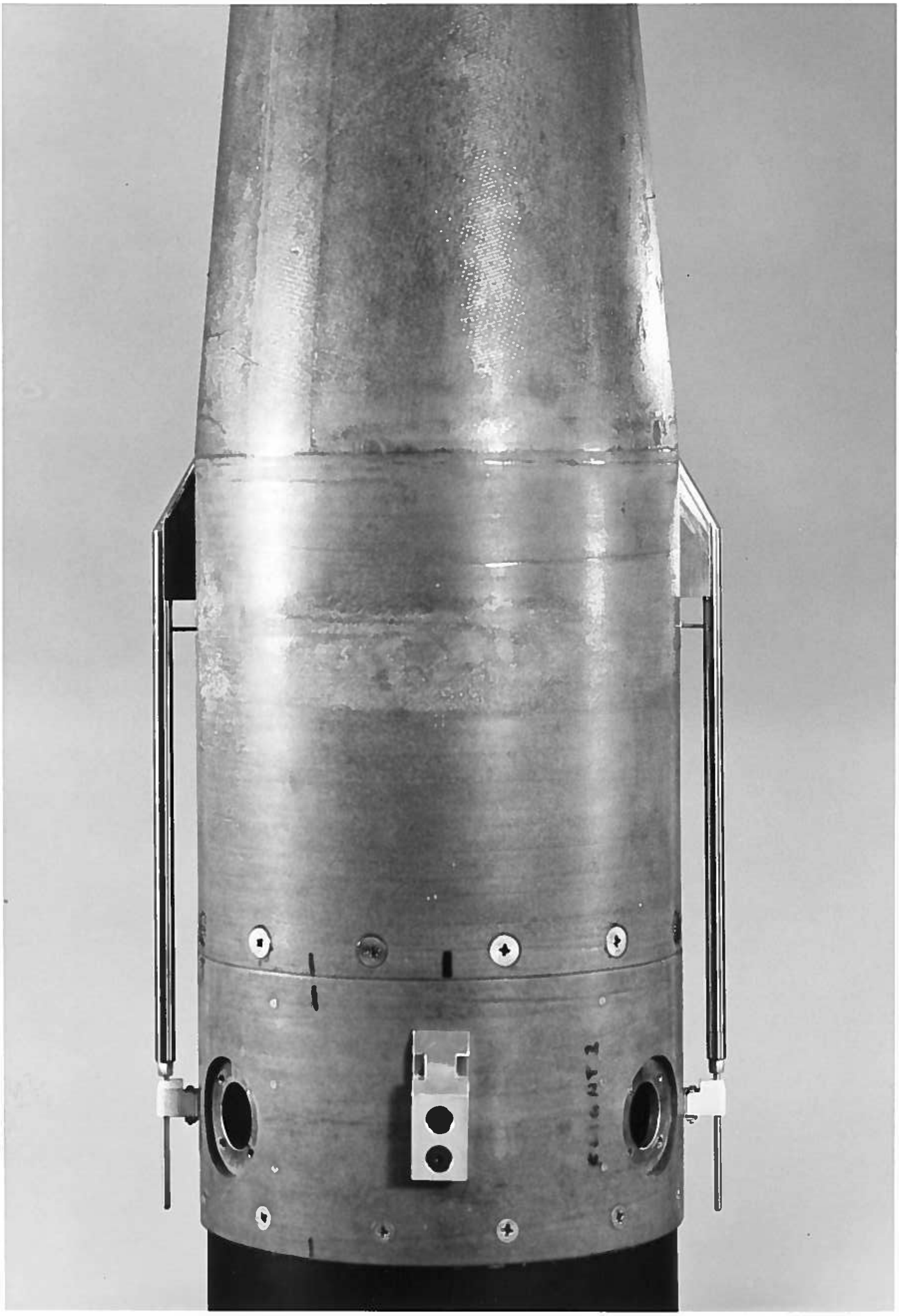

Plate I — Quadraloop antennas on nose cone of Black Brant III rocket

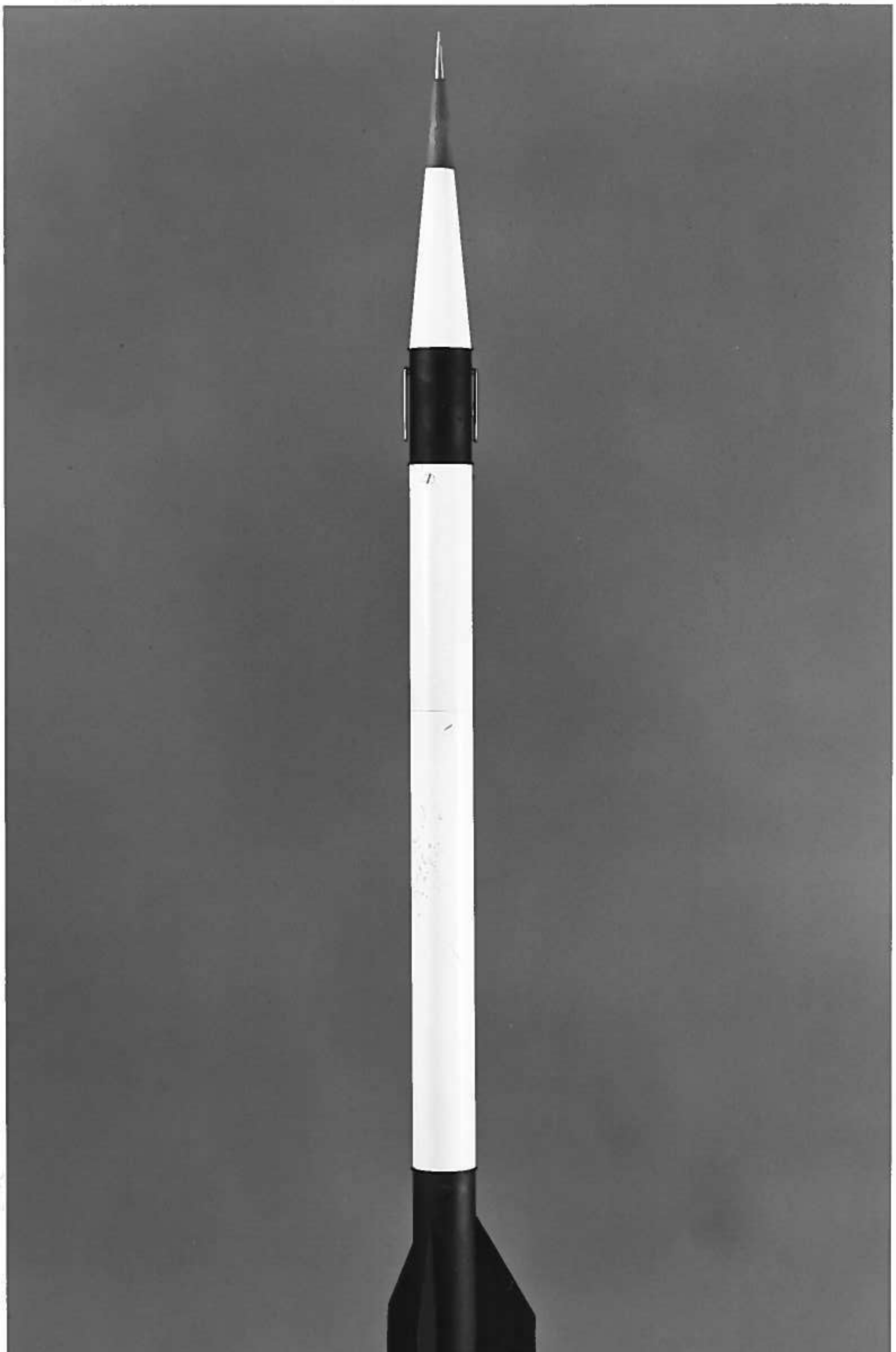

Plate II — One-eighth scale model of Black Brant III rocket with quadraloop antennas