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EIR 698

DEVELOPMENT OF A HELICAL ANTENNA FOR THE AN/DMQ-9 ROCKETSONDE

K. W. KIDD

THE BENDIX CORPORATION
FRIEZ INSTRUMENT DIVISION
BALTIMORE, MARYLAND 21204

CONTRACT NO. AF19(628)-5807

PROJECT NO. 6682

TASK NO. 668203

FINAL REPORT

JUNE 1966

PERIOD COVERED DECEMBER, 1965 THROUGH MAY, 1966

PREPARED FOR

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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ABSTRACT

The AN/DMQ-9 rocketsonde is an expendable meteorological instrument package designed for use with the Arcas rocket vehicle to obtain vertical profiles of temperature and winds in the upper atmosphere between 80,000 feet and 200,000 feet. The instrument is of the transponder type and is compatible with the AN/GMD-2 Rawin Set ground equipment.

The purpose of this effort was to develop a helical antenna for the rocketsonde transmitter to improve the reliability of the r.f. transmission link. Flight tests conducted at the Air Force Eastern Test Range, Cape Kennedy, Florida indicate the objective of the program was met.

LIST OF CONTRIBUTORS TO THE PROJECT

J. R. Cosby	Engineering Manager, Instruments Section
K. W. Kidd	Project Engineer
W. E. Rupp	Senior Engineer (Bendix Radio Division)

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INTRODUCTION

This report describes work performed for the Aerospace Instrumentation Laboratory, Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Massachusetts, during the period December 1965 through May 1966 under Contract No. AF19(628)-5807 for the development of a directional transmitting antenna for the AN/DMQ-9 rocketsonde. Previous design and development work on this instrument was accomplished under Contracts No. AF19(604)-8432, No. AF19(628)-1655 and No. AF19(628)-4045.

The AN/DMQ-9 rocketsonde is an expendable meteorological sounding device boosted to an altitude of approximately 200,000 feet. At apogee the instrument package is disengaged from the spent rocket motor by a gas generator separation device and descends to earth by parachute while utilizing radio telemetry to furnish meteorological data to the AN/GMD-2 Rawin Set ground equipment.

During descent, phase comparison of an 81.94 kc signal transmitted and received by the AN/GMD-2 equipment via the rocketsonde is used for computation of the slant range between the ground station and the sonde. Specifically, a 403 mc carrier, amplitude modulated by the 81.94 kc ranging signal is transmitted from the ground equipment to the AN/DMQ-9 where it is received, detected, and amplified by the receiver components of the sonde. The receiver output frequency modulates the 1680 mc carrier transmitted from the rocketsonde to the AN/GMD-2.

Temperature of the air through which the rocketsonde descends is sensed by a bead thermistor located at the forward end of the package and converted to a pulse repetition frequency by a blocking oscillator. A reference pulse repetition frequency is periodically generated to provide means for correcting for drift in the telemetry signal caused by environmental effects on the electronic components. The pulse signal also frequency modulates the 1680 mc carrier transmitted from the sonde to the AN/GMD-2.

The AN/DMQ-9 rocketsonde as finalized on the latest referenced contract employed a "bow-tie" dipole transmitting antenna somewhat centrally located within the instrument package. During the concluding flight tests of the contract, ten sondes were successfully flown when the Rawin Set receiver was supplemented with a parametric amplifier. To make the system more reliable in cases where a parametric amplifier might not be available, it was deemed worthwhile to try a different type of antenna, specifically a helical antenna operating in the beam mode.

INITIAL DESIGN CONSIDERATIONS

Examining the space available, it appeared practicable to develop a helical antenna that could be located in the nose of the instrument package. Following the basic design parameters discussed by Kraus[1], a two-turn helix having a circumference of approximately 0.9 wavelength and a spacing between turns of approximately 0.15 wavelength would fit in the available space. An antenna of these dimensions will operate in the beam or axial mode having maximum directivity off the nose of the instrument. Because of the few number of turns, however, the radiation pattern would be fairly broad. Data in the literature indicates that the half power beam width would be about 70° and would fall off to -15 db at a beam width of 120°. The antenna gain along the line of maximum radiation intensity is on the order of 7 db.

From the above data and other fixed system parameters, the system performance during descent of the sonde from its maximum altitude was predicted as follows:

1. Transmitter power - The output power of the 1680 mc cavity oscillator is at least 500 milliwatts at the conditions under which it operates in the rocketsonde. The subminiature coax cable between the transmitter and antenna introduces a loss of 50 milliwatts so that the power at the input to the antenna is:

$$P = 10 \log 450/1 = 26.5 \text{ dbm}$$

---

[1] J. D. Kraus, Antennas, McGraw-Hill Book Co. Inc., 1950, Chapter 7, "The Helical Antenna", pp 173-216.

2. Atmospheric attenuation over 40 mile line-of-sight path at 1680 mc:

$$X_{40} = 37 + 20 \log (1680) + 20 \log (40)$$
$$= 37 + 64.5 + 32$$
$$= -133.5 \text{ db}$$

3. Assume maximum gain of transmitting antenna is 7 db.

4. Gain of RAWIN Set antenna is +27 db.

Then, at apogee the maximum signal received at the RAWIN Set (sonde pointing at GMD) will be:

Transmitter power = + 26.5 dbm
Transmitter antenna gain at max. pt. = + 7.0 db
Path loss (40 miles) = -133.5 db
Receiver antenna gain = + 27.0 db
\- 73.0 dbm

This is equivalent to 50 microvolts across a 50 ohm impedance at the RAWIN receiver input or an "S" meter indication of approximately 23 microamps.

Now assuming that the elevation angle of the GMD-2 antenna is 75° at apogee and the sonde is swinging off vertical by 45°, the transmitting antenna gain will be down 15 db (60° from max.) from the maximum gain of 7 db for a net loss of 8 db.

Then, the signal at the receiver will be:

-73.0 dbm + (-15) db = -88.0 dbm

This is equivalent to 9 microvolts across 50 ohms or an "S" meter indication of approximately 7 microamps.

In summary, for the first few minutes after apogee, the r.f. signal level at the input to the RAWIN Set receiver would be such as to give an indication on the panel meter varying between 7 and 23 microamps.

Typical system performance at flight termination is calculated on the basis of the following data and assumptions:

1. Transmitter power remains constant throughout flight.
2. Termination altitude is 80,000 feet (15 miles), and slant range remains at 40 miles. (In many cases the slant range will decrease during flight.) Then the elevation angle of the RAWIN Set antenna will be 20° (approximately 25 minutes elapsed time).
3. Assume transmitting antenna gain is 18 db down from maximum (+7 db) at a beam width of 140°. Also, assume that the sonde is not oscillating appreciably on the parachute.

Then, under these conditions at flight termination, the signal received at the RAWIN Set will be:

Transmitter power = + 26.5 dbm
Transmitter antenna gain = - 11.0 db
Path loss (40 miles) = -133.5 db
Receiver antenna gain = + 27.0 db
- 91.0 db

This is equivalent to 6.5 microvolts across 50 ohms or an "S" meter indication of about 5.25 microamps.

If the elevation angle is 30° at a flight termination altitude of 80,000 feet then the slant range would be 30 miles. In this case the input to the RAWIN receiver would be:

Transmitter power = + 26.5 dbm
Transmitter antenna gain = - 8.0 db (no swing)
Path loss (30 miles) = -131.0 db
Receiver antenna gain = + 27.0 db
\- 85.5 dbm

or, 12 microvolts across 50 ohms giving an "S" meter indication of 8 microamps.

The need for tracking the rocketsonde on ascent still exists. In order to evaluate this consideration, the approximate pattern of the axial mode helix was calculated using equations given in Kraus' text. These calculations show that there will be a reasonable amount of backward radiation for a two-turn helix.

Thus, at a RAWIN Set elevation angle of 10° (shortly after T-0) the system performance is computed as follows:

1. Transmitter power delivered to antenna:

450 milliwatts or + 26.5 dbm

2. Atmospheric attenuation over 2.5 mile line-of-sight path:

$$X_{2.5} = 37 + 20 \log (1680) + 20 \log (2.5)$$
$$= -109.5 \text{ db}$$

3. Transmitting antenna gain at this look angle is calculated to be 18 db down from maximum gain of +7 db or a net gain of -11 db.

4. Gain of RAWIN Set antenna is 27 db.

Summing these terms, the net system gain is -67.0 dbm, equivalent to 100 microvolts across 50 ohms or an "S" meter indication of approximately 30 microamps.

Similarly, near apogee just before separation:

1. Transmitter power as before, +26.5 dbm.

2. Atmospheric attenuation over 40 mile path: -133.5 db.

3. Calculated transmitting antenna gain at a GMD look angle of 75°, 10.4 db down from maximum or a net gain of -3.4 db.

4. Gain of RAWIN Set antenna, 27 db.

Under these conditions the overall system gain is -83.4 dbm or 16 microvolts across 50 ohms resulting in an "S" meter reading of 12 microamps.

EXPERIMENTAL PROGRAM

In order to examine the properties of the basic helix, a laboratory model was mounted on a large square ground plane measuring about one wavelength on a side. The square shape was selected to avoid a summation of edge reflections at the center of the ground plane. The originally measured impedance of the helix on the square ground plane is shown in Figure 1A.

The measured VSWR was quite high (about 3.5:1) but the variation with frequency was slight, indicating that matching techniques might be used to bring the impedance group into the center of the chart.

Since the impedance is primarily reactive, an attempt was made to apply a reactive stub to the input transmission line. The attempt was unsuccessful due to the geometry of the feed. It was impossible to properly locate the stub with respect to the input connector.

A second approach to matching consisted of adjusting the length of the last turn on the helix. It was found that although the VSWR was not much improved, the center of the impedance plot could be shifted toward the real axis on the impedance diagram. Once this was achieved, a transformer was constructed by allowing the conductor to lie parallel to the ground plane for approximately one-quarter wavelength before beginning the helix. This concept is illustrated in Figure 2. The distance between the conductor and the ground plane was varied to control the transformer impedance.

Since the helix was mounted on a large ground plane, the input impedance was not optimized, but Figure 1B shows the effect of using the transformer section. The next step was to transfer the helix to a small two inch diameter circular ground plane. As expected, the impedance shifted considerably, but by adjusting the last turn of the antenna and the transformer section the impedance shown in Figure 1C was obtained. The VSWR at 1680 mc was 1.17.

Since the radiation characteristics of the antenna are as important as the impedance characteristics, the patterns of each helix were measured. Although the sense of polarization of the helix antenna is circular, the patterns were measured with a vertical dipole to simulate the polarization of the ground receiving antenna.

Figure 3A shows the average of the basic helix on the large square ground plane. The axial pattern is the expected cardioid shape, but the radial pattern shows some assymmetry. The assymmetry is not particularly disturbing since no attempt was made to make the helix ground plane symmetrical.

When the helix was transferred to the small two inch circular ground plane, the pattern shown in Figure 3B was observed. The axial pattern shows that there is more radiation to the rear than in the forward direction, while the radial pattern exhibits a high degree of assymmetry. This condition is undoubtedly caused by the limited ground plane which permits current to flow on its back side causing radiation to occur at the connection and whatever is attached to it.

Since the diameter of ground plane cannot be increased, it was decided to implement a quarter-wavelength skirt which hopefully would, in effect, extend the diameter of the ground plane. By extending the skirt a quarter-wavelength to the rear (away from the helix), and fastening it securely to the small ground plane a choke section is effected. Although the skirt can be expected to radiate, it should isolate the helix from the equipment located behind the small ground plane.

The patterns of the helix with a skirted ground plane are shown in Figure 3C. It is noted that the dominant radiation has been reestablished in a forward direction in the axial plane, and nearly omnidirectional coverage is observed in the radial plane. There is still a significant portion of the available signal being radiated to the rear in the axial plane, but since the transmitter must operate on ascent as well as descent, this is highly desirable.

The two deep nulls in the axial pattern occur at about 80° to 85° from the beam maximum. To determine if tracking can be maintained in this area, the cross polarized pattern was measured and is shown as the dashed curve in Figure 3C. It is seen that the nulls of the pattern are not coincident therefore tracking should be possible over the entire trajectory.

The effect of the quarter-wavelength skirt on input impedance can be seen in Figure 1D. Although there is a shift of the curve there is no degradation of input VSWR. The actual VSWR is less than 1.2 from 1560 mc to 1760 mc which exceeds the operational band of the transmitter.

The next step in the experimental program was to translate the information obtained from the investigations just described to a practical design configuration. Three additional design features had to be incorporated: (1) relocation of the input connector to the antenna off the axis of the helix to avoid interference with other sonde components beneath the ground plane, (2) inclusion of a length of one-eighth inch diameter copper tubing inside and along the axis of the helix through which a pair of leads to the temperature sensor could be passed, and (3) a support structure to hold the helix in a fixed position while encountering the environmental conditions of shock, acceleration and vibration imposed during flight.

The supporting structure consists of three vertical posts of dielectric material between the ground plane disc and the sensor support plate at the forward end of the instrument package. These posts are equally spaced around the circumference of the helix and have notches at the appropriate spacings to accept the helical conductor. As expected, shifting the feed point off-axis and inserting the copper tubing altered the antenna characteristics somewhat, but these effects were compensated for by altering the quarter-wave transformer section. The resulting antenna configuration is shown in Figure 4. Figure 5 shows the antenna mounted on the instrument package. The VSWR of five units constructed for flight testing varied from 1.21 to 1.35.

FLIGHT TESTS

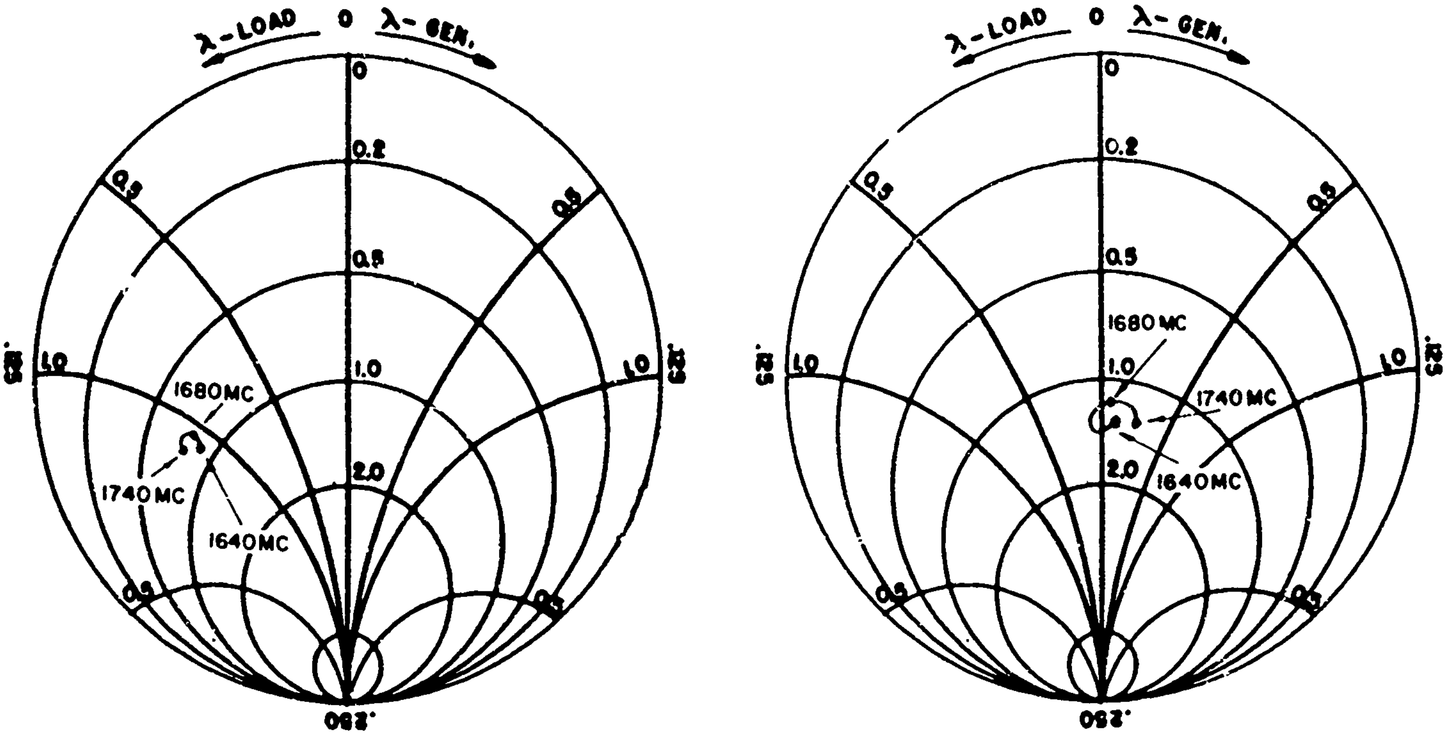
The five instrument packages were taken to the Air Force Eastern Test Range, Cape Kennedy, Florida for flight testing during the first week of May, 1966. Three of the flight tests were conducted using both an AN/GMD-4 Meteorological Data Processor with parametric amplifier and an AN/GMD-2 operating in the non-transponding mode and without benefit of a parametric amplifier. The other two instruments were tracked only with the AN/GMD-4 because of interference between the two ground stations.

Of the three units tracked with the AN/GMD-2, the radiosonde transmitted signal level as indicated by the RAWIN Set receiver panel meter was typically 30 microamps after a few seconds out of the launch tube and decreased steadily to approximately 6 to 8 microamps at apogee. This is in comparison to one flight under similar conditions during the previous contract where the signal level at apogee was 2 to 5 microamps. After deployment, the signal level typically fluctuated between 15 to 25 microamps during the next ten minutes with many rapid signal drop-outs indicative of severe parachute oscillations. (During a similar period of the flight on the previous contract the signal level fluctuated between 2 and 15 microamps.) For the remainder of the sonde descent to 80,000 feet the degree of signal fluctuation subsided. Signal levels indicated by the AN/GMD-4 were of course higher because of the additional system gain introduced by the parametric amplifier.

The use of the AN/GMD-4 Meteorological Data Processor provided an opportunity to observe the performance of this equipment in sounding rocket applications. It was noted that the apparently severe parachute oscillations and resulting signal level fluctuations during the early part of the flight are quite detrimental to optimum performance of this system.

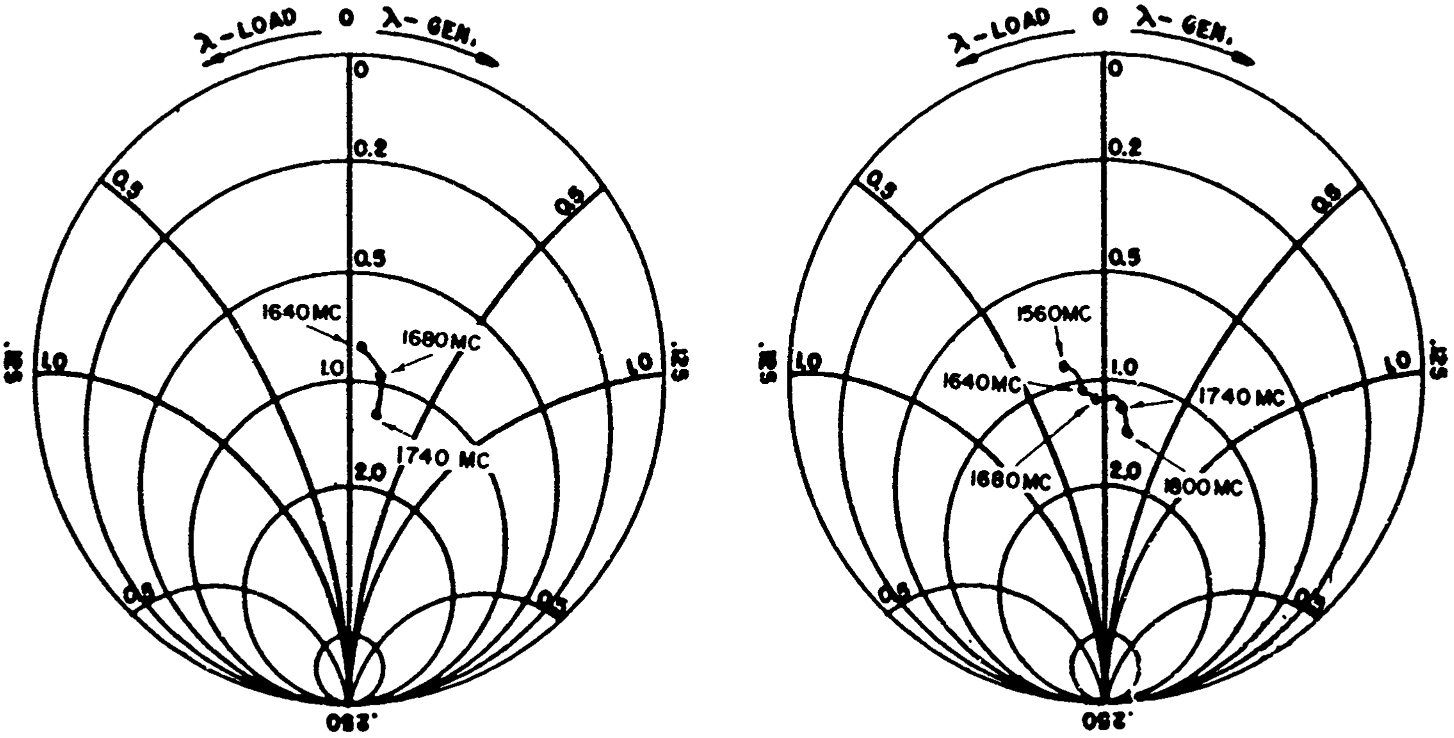
CONCLUSIONS

It is concluded that the substitution of a helical antenna in the forward end of the AN/DMQ-9 rocketsonde for the "bow-tie" dipole centrally located in the payload structure does improve the quality of the radio telemetry link to the extent predicted.



A. Helix on square ground plane

B. Matching with transformer on square ground plane



C. Matching with transformer on 2" circular ground plane

D. Helix on 2" ground plane with λ/4 skirt

FIGURE 1

IMPEDANCE CHARACTERISTICS OF HELICAL ANTENNAS

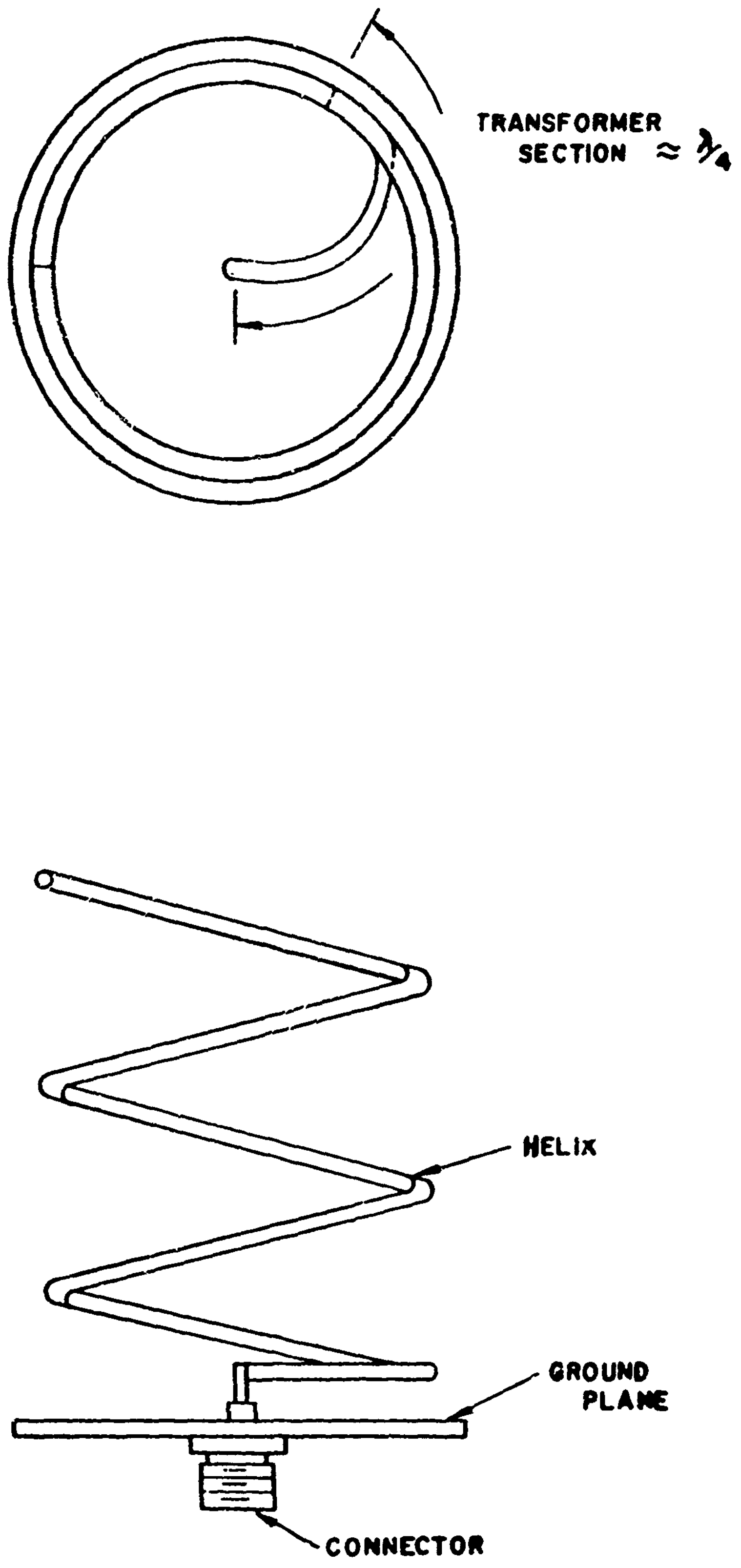


FIGURE 2

BASIC HELIX ANTENNA WITH TRANSFORMER

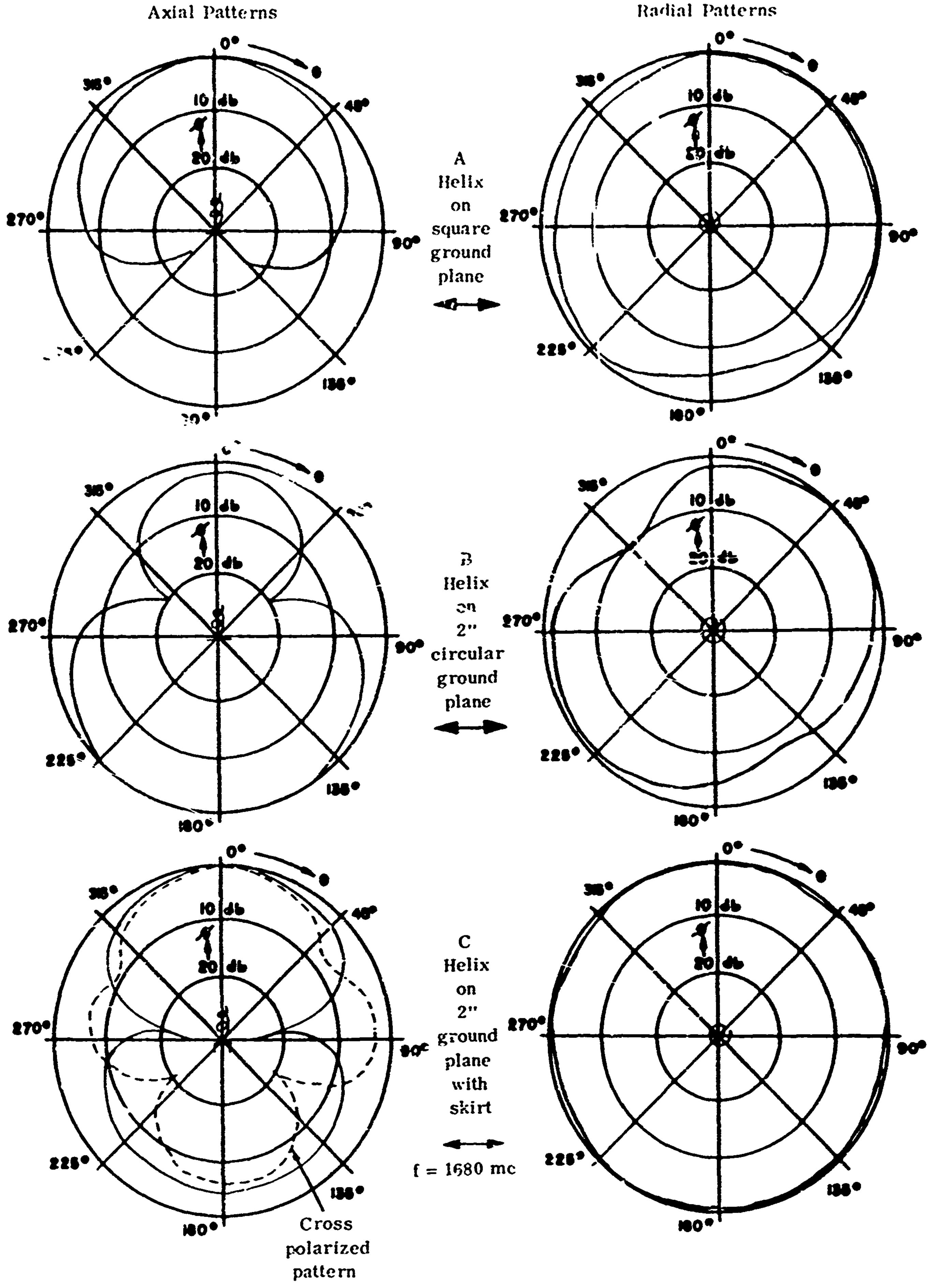


FIGURE 3

RADIATION PATTERNS OF HELICAL ANTENNAS

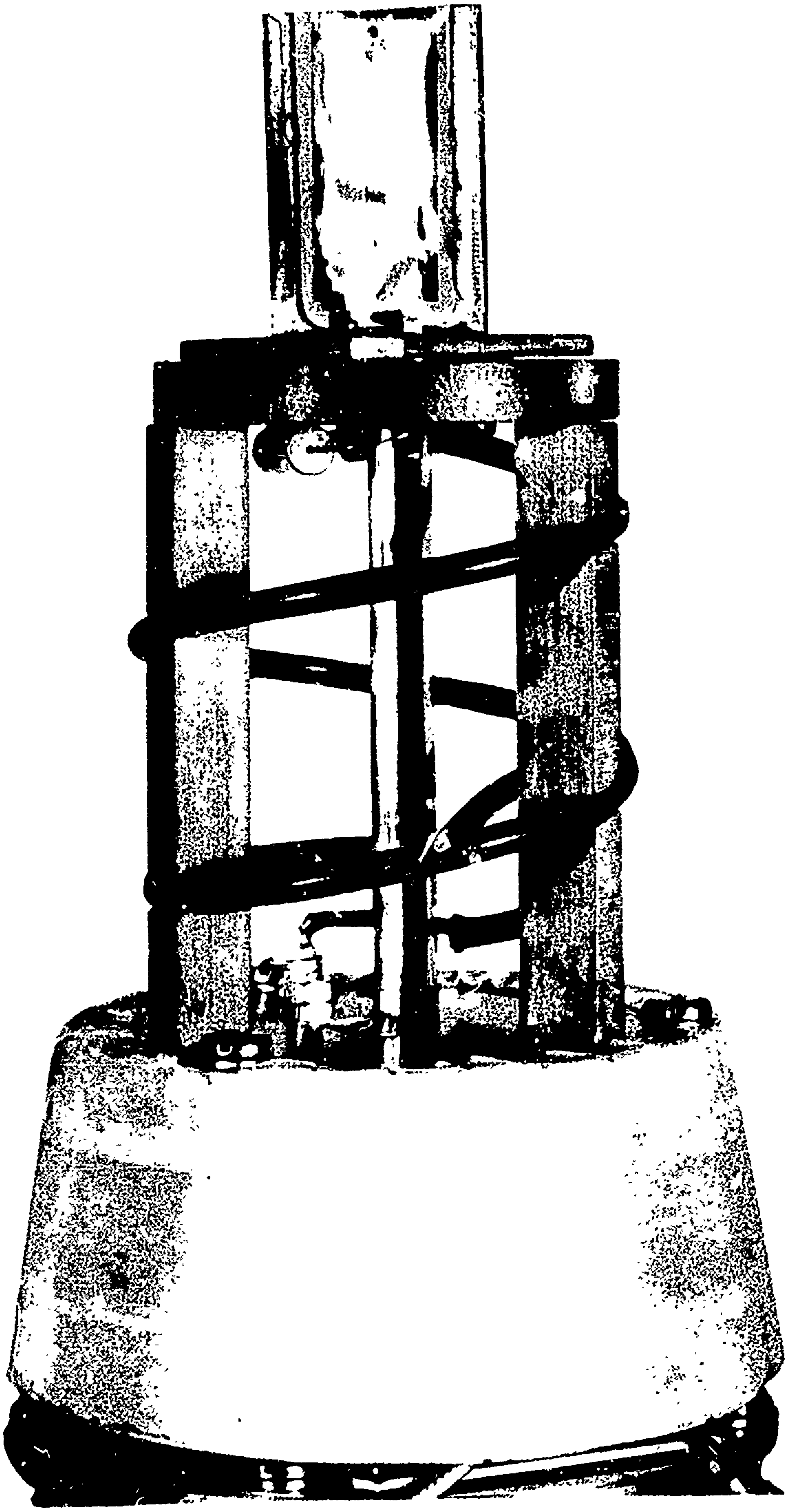


FIGURE 4

FINAL CONFIGURATION OF HELICAL ANTENNA

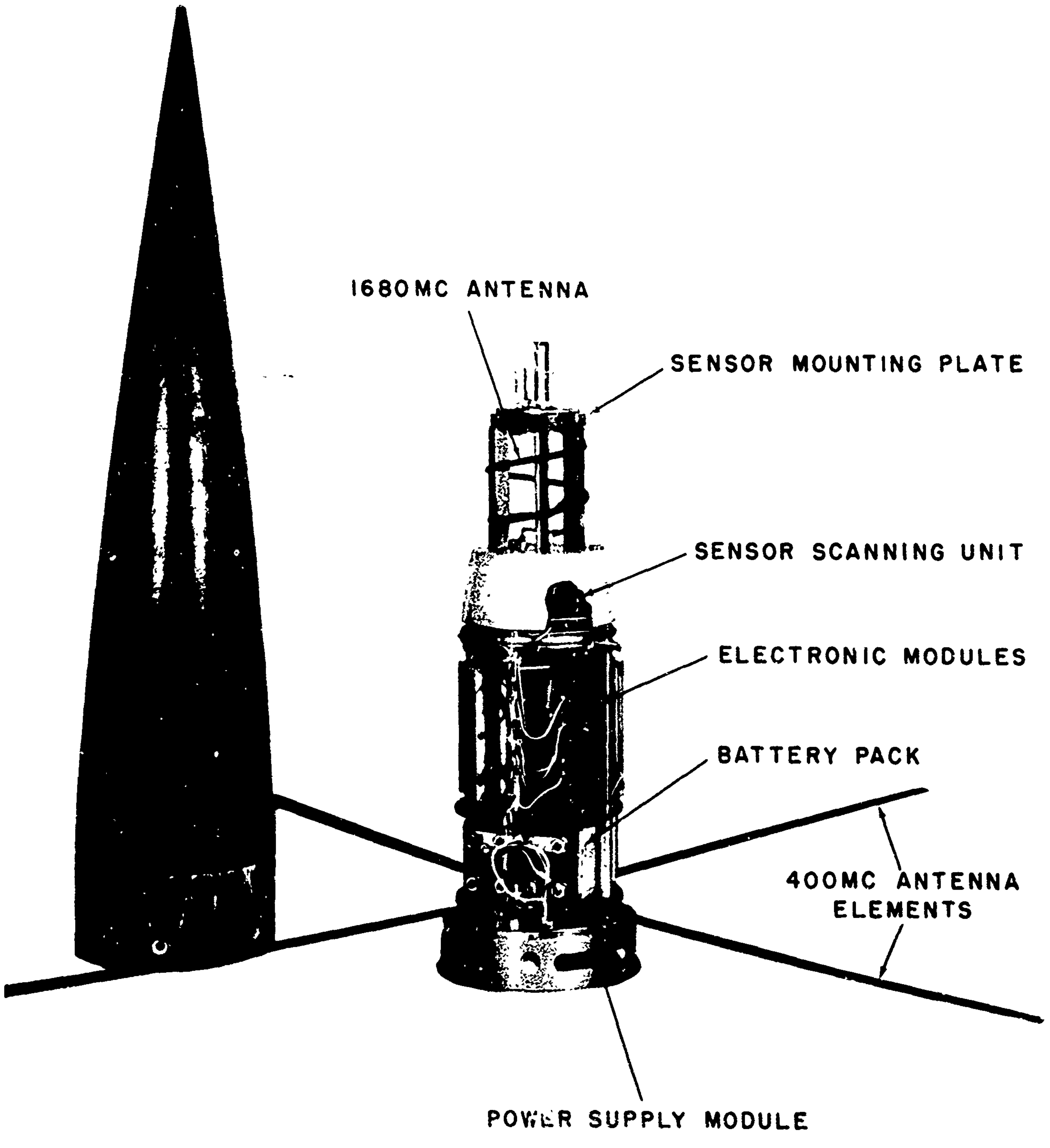


FIGURE 5

AN/DMQ-9 ROCKETSONDE WITH HELICAL ANTENNA

BIBLIOGRAPHY

Stoudenmire, J. H., McCoy, R. T., and Greene, D. R., "Development Of A Rocketsonde Instrument Package For High Altitude Meteorological Sounding", AFCRL-62-875, December, 1962.

Kidd, K. W., "Continuation Of The Development Of The AN/DMQ-9 Rocketsonde", AFCRL-63-841, October, 1963.

Kidd, K. W., "Further Development Of The AN/DMQ-9 Rocketsonde", AFCRL-65-458, June, 1965.

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Addendum To Operation and Maintenance Manual

AN/DMQ-9 Rocket Instrument Package

(May 1965)

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
L. G. HANSCOM FIELD
BEDFORD, MASSACHUSETTS

CONTRACT NO. AF19(628)-5807

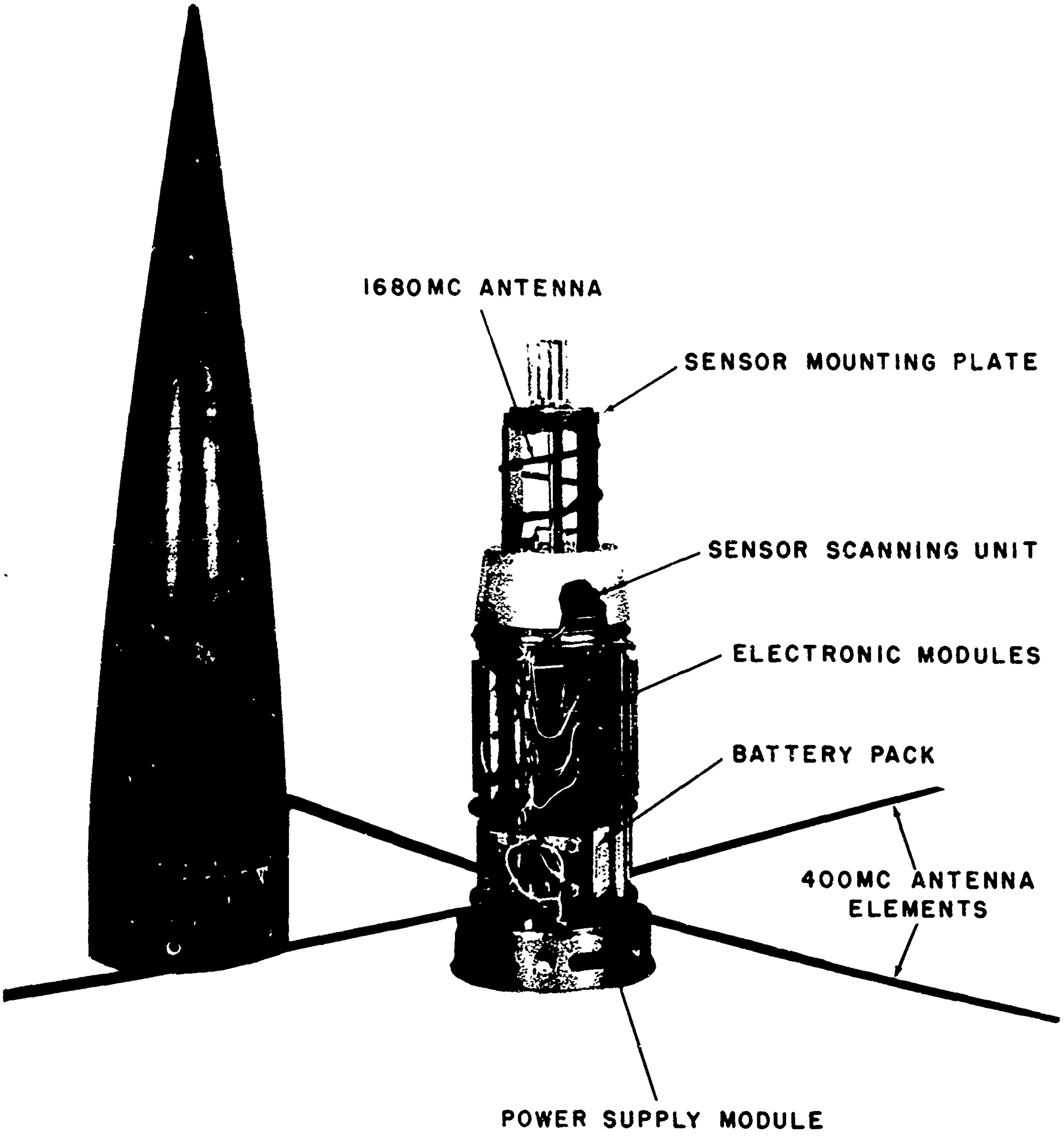
June 1966

THE BENDIX CORPORATION
FRIEZ INSTRUMENT DIVISION
BALTIMORE, MARYLAND 21204

This addendum has been prepared to cover a helical transmitting antenna which has been developed for the AN/DMQ-9 rocket instrument package under provisions of Air Force Contract AF19(628)-5807. The Bendix Friez part number for the AN/DMQ-9 with helical antenna is 2410160.

The new antenna consists of a two-turn helix with skirted ground plane located at the forward end of the instrument package between the sensor scanning unit and the sensor mounting plate as shown in the attached figure. Except for the fact that the helical antenna occupies space previously available for other purposes, as mentioned on page 2 of the manual, all information given in the manual pertains to this version of the AN/DMQ-9 rocket instrument package.

It is pointed out that the radiating and ground-plane elements of the transmitting antenna are at B+ potential.



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The purpose of this effort was to develop a helical antenna for the rocketsonde transmitter to improve the reliability of the r.f. transmission link. Flight tests conducted at the Air Force Eastern Test Range, Cape Kennedy, Florida indicate the objective of the program was met.

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