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A. R. Dion

Survey of Satellite Communication Antennas

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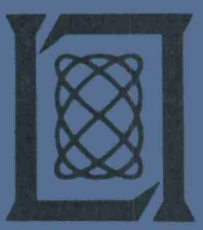

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

SURVEY OF SATELLITE COMMUNICATION ANTENNAS

A. R. DION

Group 61

TECHNICAL NOTE 1967-17

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LEXINGTON MASSACHUSETTS

ABSTRACT

The radiation characteristics and physical configurations of COMSATS communication antennas are compiled in this report. Included are antennas from the following spacecrafts: COURIER, RELAY I and II, TELSTAR I and II, the SYNCOM series, INTELSTAT I and II, the IDCSP, the ATS series and LES-1, 2 and 4. The description of each antenna, though very brief, is sufficient to impart to the cognizant reader a good knowledge of the concepts involved. References to more detailed documents are given when available.

Accepted for the Air Force
Franklin C. Hudson,
Chief, Lincoln Laboratory Office

Survey of Satellite Communication Antennas

COURIER

Frequency	Beamwidth	Polarization	Gain
1.7 and 1.85 GHz	Isotropic ± 3 db	Linear	0 ± 3 db

The transmit-receive antenna system consists of two similar units diametrically opposed on the equator. Each unit is a linearly polarized pair of slots cut on a protrusion mounted over the satellite body (Fig. 1). The protrusion allows for a larger H-plane beamwidth than would result with flush mounting. Each pair of slots is fed, through a short section of parallel plate line, from a centrally located transition to a coaxial line. Hemispherical coverage is obtained from one pair of slots. Incoherent feeding of the two units provides complete coverage.

Reference:

M. L. Ingalsbe, "The Courier Satellite Microwave Antenna," Philco Corp., Western Development Laboratory, WDL TR-1248, AD-419800.

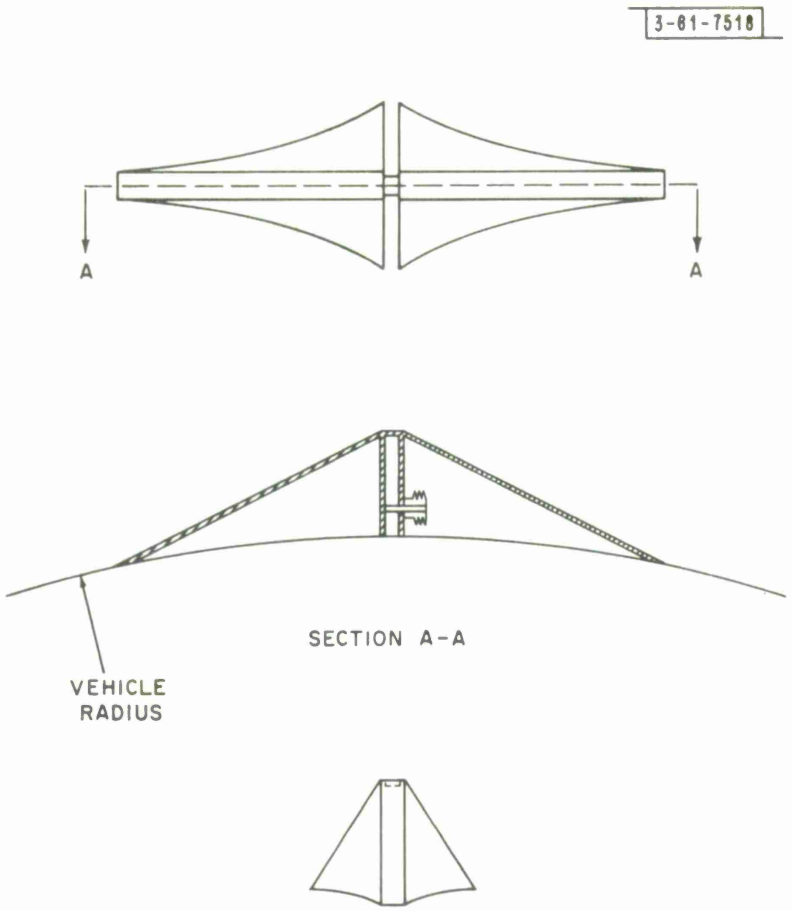

Fig. 1. COURIER communication antenna.

RELAY I and II

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization	Gain (db) (Ave. Equatorial)
Trans. 4.08 and 4.18	Omni	90°	Circular	1
Rec. 1.725	Omni	90°	Circular	1

The communication antenna system consists of a two-port transmitting antenna and of a receiving antenna, mounted on top of one another, along the spin axis of the vehicle is illustrated in Fig. 2. Each antenna is a circumferential array of 8 inclined slots cut in the outer conductor of a coaxial line. The transmitting antenna is fed by two circularly polarized TE_{11} waves, of opposite senses, one for each of the two transmitting frequencies. The coaxial TEM mode at each input port is transformed to a TE_{11} mode through a short section of rectangular waveguide coupled to the coaxial waveguide by a narrow longitudinal slot. A quarter-wave plate in the coaxial waveguide produces circular polarization.

The receiving antenna is fed by a TEM mode traveling in a coaxial waveguide located inside, and concentric with, the transmitting-antenna coaxial waveguide. A pair of capacitive probes are located adjacent to each slot to increase the coupling of the slot to the TEM mode. A short-circuited stub at the end of the transmission line assists in matching the slot to the line.

The slot arrays provide both axial and tangential field components. Circular polarization of the radiated field is obtained by using two parallel metal

discs to produce a 90° phase differential between the two components. To correct for deleterious effects resulting from reflections on the spacecraft surface, the bottom plate of the transmitting antenna parallel-plate region is a combination of a radial wire grid and a metal disc spaced $\lambda/4$ from the wire grid.

Reference:

Final Report on the RELAY I Program. NASA SP-76, pp. 95-100.

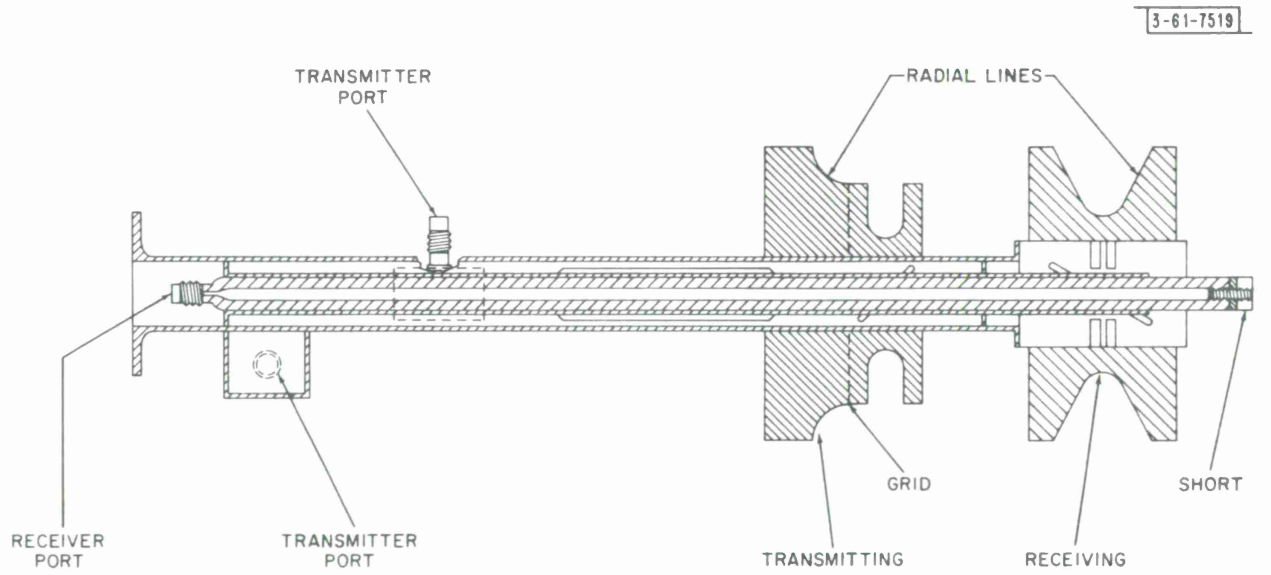

Fig. 2. RELAY communication antennas.

TELSTAR I and II

Frequency GHz	Beamwidth Equatorial	Polar	Polarization	Gain (db) (Ave. Equatorial)
Trans. 4.17	Omni ± 1 db	80°	Right circular	1.5
Rec. 6.39	Omni ± 1 db	80°	Left circular	2.

The spacecraft communication antennas consist of two equatorial arrays of waveguide radiators as shown in Fig. 3a. One array of 72 elements receives at 6.39 GHz, the other of 48 elements transmits at 4.17 GHz. Each waveguide radiator is a section of rectangular waveguide short-circuited at one end and excited with two orthogonal TE_{10} modes by means of a diagonal probe as suggested in Fig. 3b. The waveguide length is chosen to obtain a 90° phase differential between the two modes. Power dividers are used to split the energy, equally and in-phase, between all elements.

Reference:

J. T. Bangert, et al., "The Spacecraft Antennas," BSTJ, 42, No. 4 pp. 869-897 (July 1963).

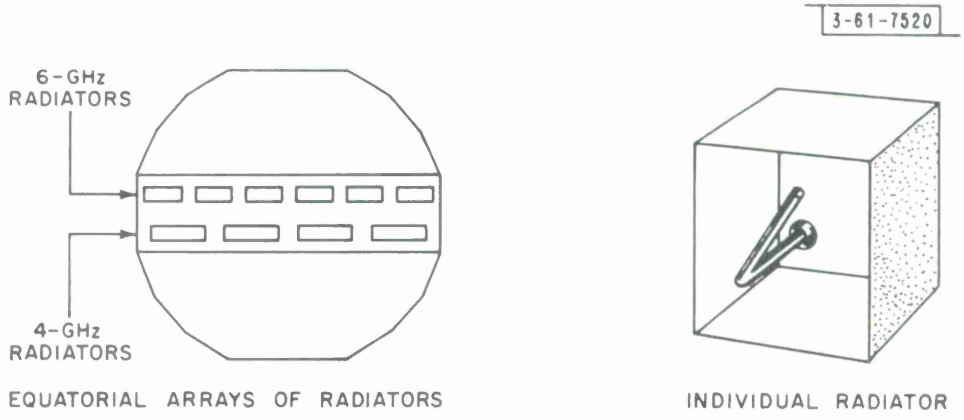

Fig. 3. TELSTAR communication antennas.

SYNCOM I, II and III

	Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization W/R to Spin Axis	Gain db
Trans.	1.82	Omni	23°	Linear, parallel	5.4
Rec.	7.36	Omni	dipole pattern	Linear, parallel	0.5

The receive and transmit antennas, mounted on top of one another along the spin axis, project from one end of the spacecraft (Fig. 4). The receiving antenna is a single skirt dipole fed from a coaxial line running inside and concentric to the transmitting antenna.

The transmitting antenna is a colinear, resonant array of three skirt dipoles. Element spacing within the coaxial feed line is one waveguide wavelength. A stub serves to match the transmitting antenna impedance to the characteristic impedance of the coaxial line.

Reference:

Hughes Aircraft Company, Aerospace Group, Culver City, California.

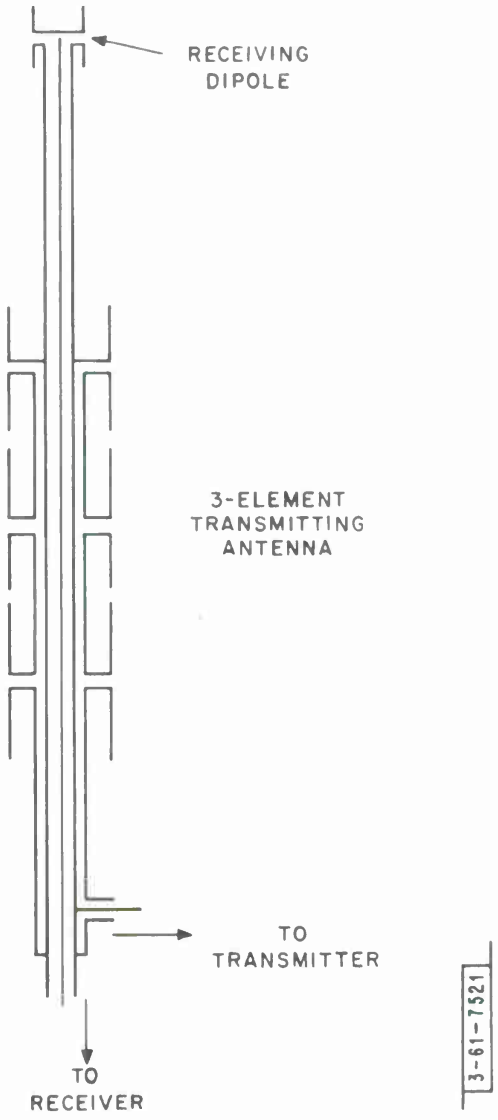

Fig. 4. SYNCOM communication antennas.

INTELSTAT I (EARLY BIRD)

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization W/R To Spin Axis	Gain (db) In Beam Pointing Direction
Trans. 4.1	Omni	10°	Linear, parallel	9.
Rec. 6.3	Omni	38°	Linear, perpendicular	4.

The receive and transmit antenna are mounted along the spin axis as shown in Fig. 5.

The transmit antenna is a 6-element colinear array of skirt dipoles, of design similar to that of the SYNCOM transmit antenna. Excitation of elements is slightly non-resonant to effect a beam tilt about 7° from the broadside direction.

The receive antenna is a colinear array of three cloverleaf elements that radiates a field polarized perpendicular to the spin axis. Element spacing within the coaxial line is $\lambda_g/2$ and adjacent elements are fed in reverse, thus providing in-phase excitation. The suppressor wire between elements serves to reduce longitudinal current on the outside of the coaxial line. The 2-1/2-inch ground plane serves to tilt the receiving beam about 5° from the broadside direction.

Reference:

Hughes Aircraft Company, Aerospace Group, Culver City, California.

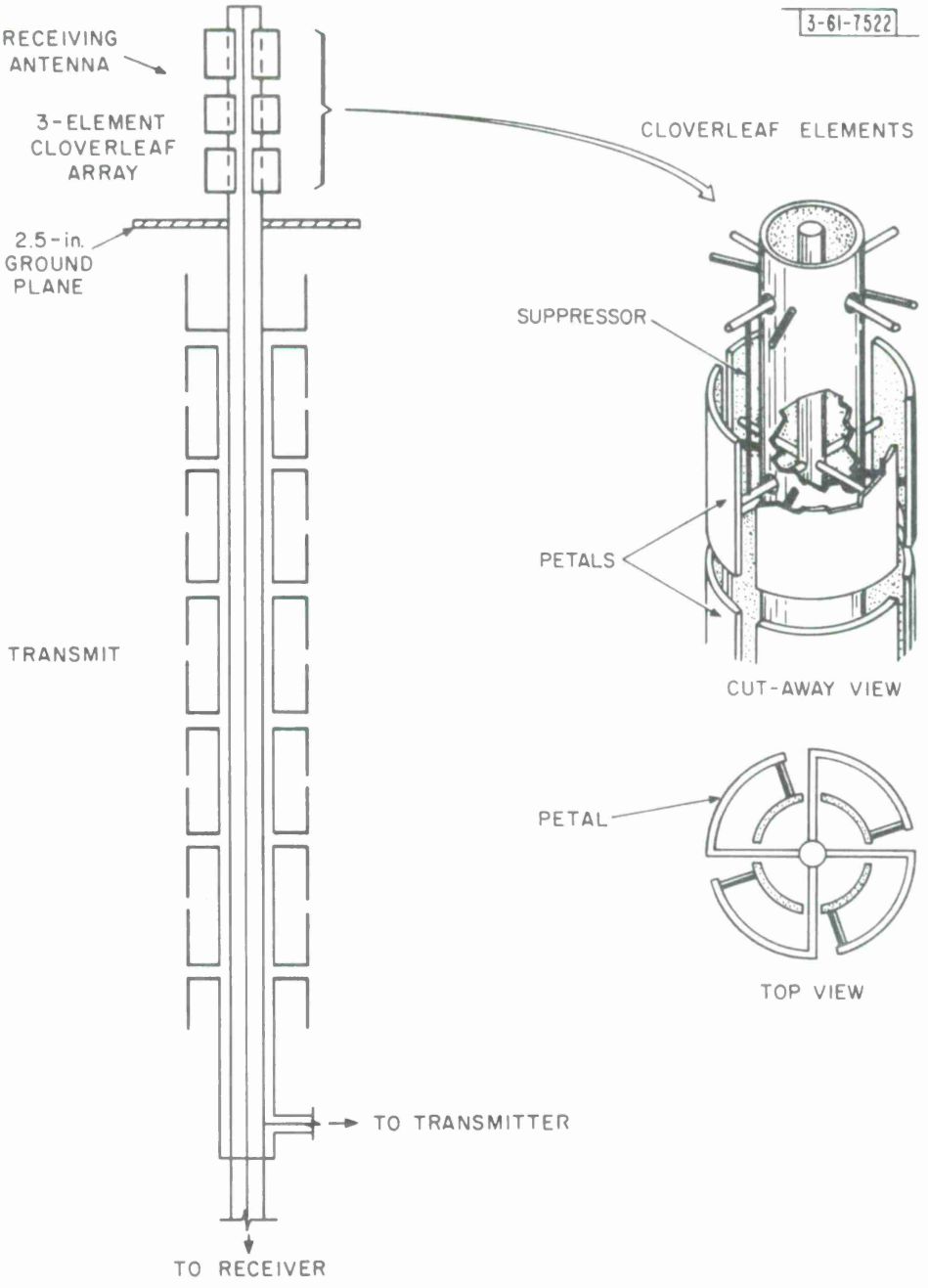

Fig. 5. EARLY BIRD communication antennas.

INTELSTAT II

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization W/R to Spin Axis	Gain db
Trans. 4.1	Omni	16°	Linear, parallel	>5.9 for $84° < \theta < 96°$
Rec. 6.3	Omni	32°	Linear, parallel	>4.3 for $84° < \theta < 96°$

The transmit antenna is a 4-element array of bicone radiators as shown in Fig. 6. The spacing in the feed line is resonant so that the bicones are excited in-phase and with equal amplitudes.

The receive antenna is a dual-mode biconical horn mounted on top of the transmitting antenna. This antenna is similar in concept to the RELAY transmit antenna except for the absence of a radiation circular polarizer.

Reference:

Hughes Aircraft Company, Aerospace Group, Culver City, California.

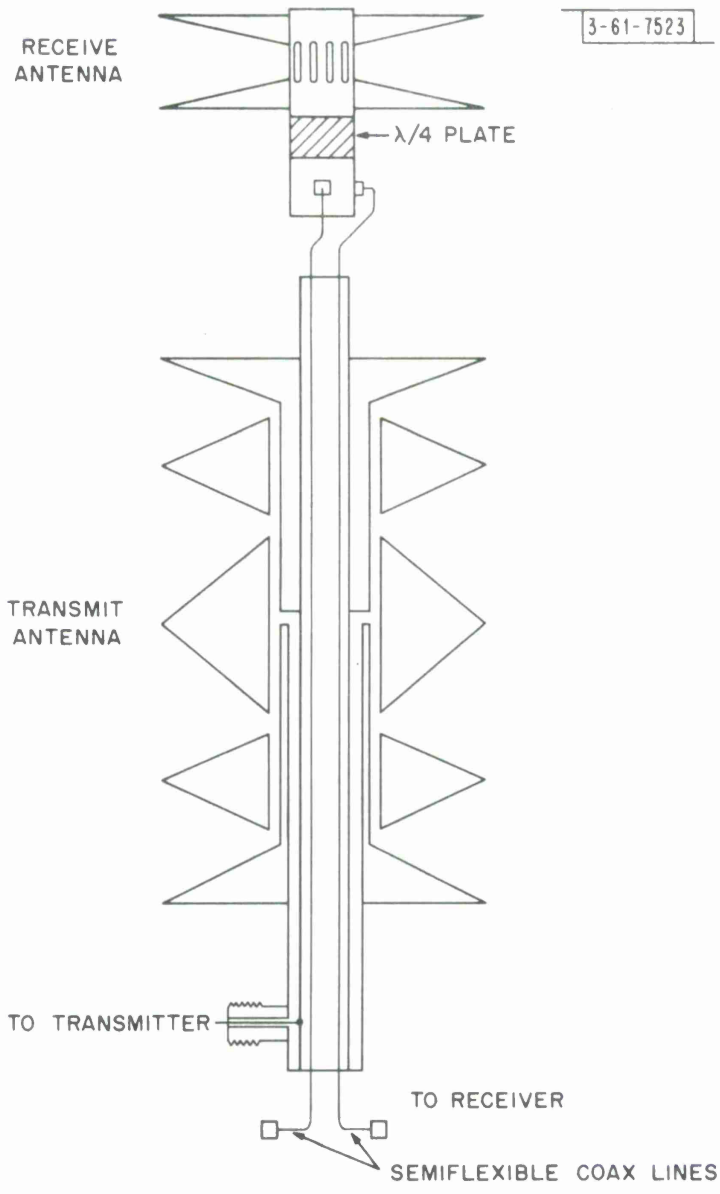

Fig. 6. INTELSTAT II communication antennas.

ATS-A

Frequency GHz	Beamwidth E-Plane	Beamwidth H-Plane	Polarization W/R to Spacecraft Axis	Gain db
Trans. 4.1	53°	44°	Linear, parallel	11.5
Rec. 6.5	53°	44°	Linear, perpendicular	11.5

The Applications Technology Satellite A is gravity-gradient stabilized. Its antenna system consists simply of two horns located 180° apart on the circumference of the spacecraft.

Reference:

Hughes Aircraft Company, Aerospace Group, Culver City, California

ATS-B

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization W/R to Spin Axis	Gain db
Trans. 4.1	22°	17°	Linear, parallel	13.3 (measured at input of power divider)
Rec. 6.5	Omni	19°	Linear, perpendicular	6.9

The communication antennas extend from the top of the spacecraft along its spin axis (Fig. 7). The transmitting antenna is a circular phased array of 16 linearly polarized elements parallel to the spin axis. The elements are equi-spaced on a circle of 1 - wavelength radius centered on the spin axis. Each element is a colinear array of four half-wave dipoles similar in design to those of the SYNCOM transmitting antenna. In operation the elements are phased such as to despin the beam.

The receiving antenna is a 6-element cloverleaf array similar in design to that of INTELSTAT I receiving antenna. It is fed from a coaxial line that runs along the axis of the phased array. Chokes, consisting of anti-resonant dipoles at the transmit frequency, are placed along the coaxial feed line to reduce deleterious effects arising from currents induced on this line.

References:

H.R. Erhardt, G. Gerson and D.C. Mead, "The Advanced Syncom Communication Antenna System - A Directive Array for a Spin-Stabilized Satellite," Record of the 1963 National Space Electronics Symposium.

J.R. McDermott, "Advanced Syncom High-Gains Antenna," Space/Aeronautics, pp. 86-88 (September 1963).

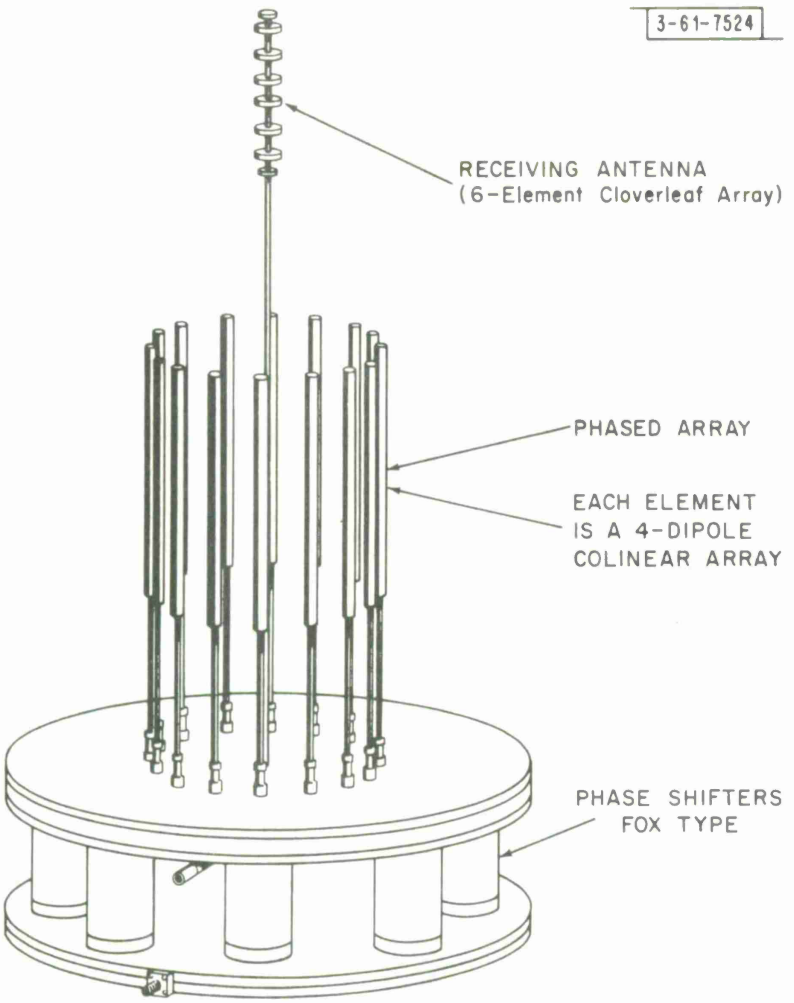

Fig. 7. ATS-B communication antennas.

ATS-C

Frequency GHz	Beamwidth Equatorial	Polar	Polarization W/R to Spin Axis	Gain db
Trans. 4.	20°	20°	Linear, parallel	17
Rec. 6.	20°	20°	Linear, parallel	17

The ATS-C has a mechanically despun antenna. A parabolic cylinder reflector rotates in opposite sense and synchronously with the spinning vehicle. The transmit and receive feeds (Fig. 8) are mounted one above another along the spin axis and rotates with the vehicle. Each feed is a colinear array of two skirt dipoles spaced 1-1/2 waveguide wavelength apart and reverse-fed to produce in-phase excitation. Each dipole array is about three free-space wavelengths long. A choke mounted between the transmit and receive array increases isolation. The parabolic cylinder is three wavelengths wide and is spaced $3\lambda/4$ from each feed to cause the direct and reflected ray to reinforce.

Reference:

Sylvania Electronic Systems, Eastern Operations, Waltham, Massachusetts.

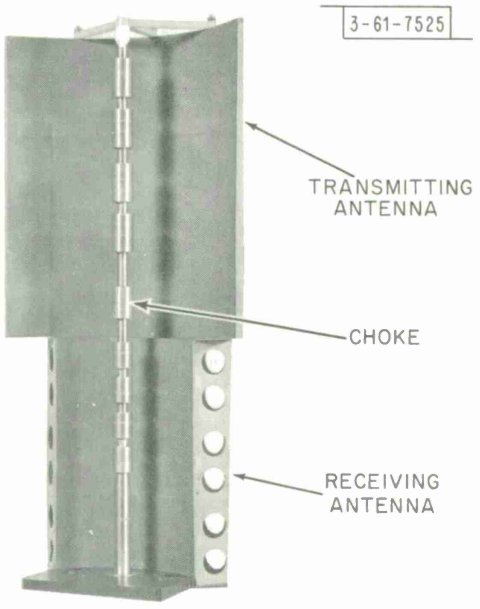

Fig. 8. ATS-C communication antennas.

ATS-D and E

This spacecraft is gravity-gradient stabilized at synchronous altitude. It incorporates two antenna systems: the first one is to be used before despin of the satellite and the second after gravity-gradient stabilization has been achieved.

SPIN MODE

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization W/R to Spacecraft Axis	Gain db
Trans. 4.1	Omni	Dipole pattern	Linear, parallel	0
Rec. 6.5	Omni	Dipole pattern	Linear, perpendicular	0

The transmit antenna is a single dipole mounted along the spin axis and above the receive antenna which is a circumferential array of four axial slots cut on a cylinder that is concentric to the feeding coaxial lines (Fig. 9). The proper excitation for the axial slots is obtained by first transforming the coaxial TEM mode to a similar mode in a radial waveguide concentric to the coaxial line. Next, four pairs of fins extending from the radial waveguide are progressively twisted to obtain a 90° rotation of the field which is then applied across the slots.

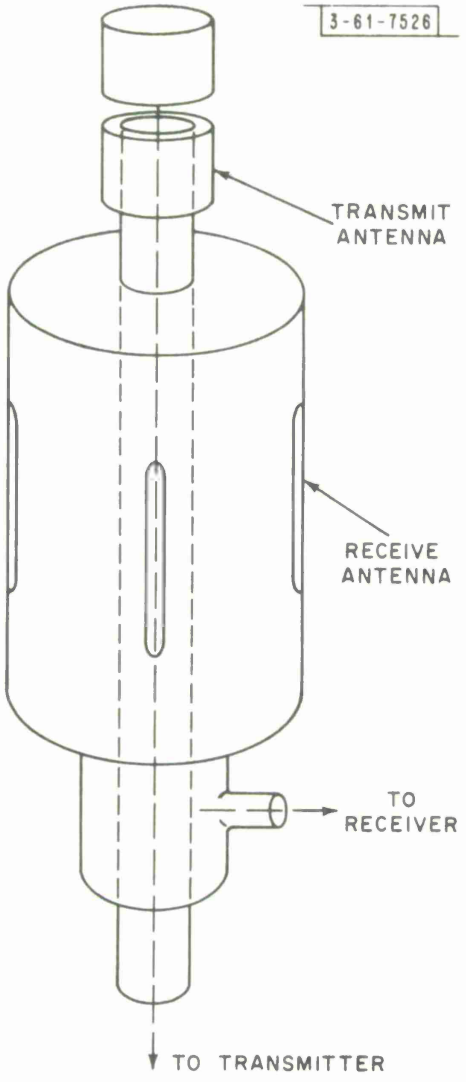

Fig. 9. ATS-D and E communication antennas. – Before despin

STABILIZED MODE

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization W/R to Spacecraft Axis	Gain db
Trans. 4.1	25°	22°	Linear, parallel	16.8
Rec. 6.5	25°	22°	Linear, perpendicular	16.8

In the stabilized mode both the transmit and receive antennas consist of a planar array of 16 slots cut in waveguides as illustrated in Fig. 10.

Reference:

Hughes Aircraft Company, Aerospace Group, Culver City, California

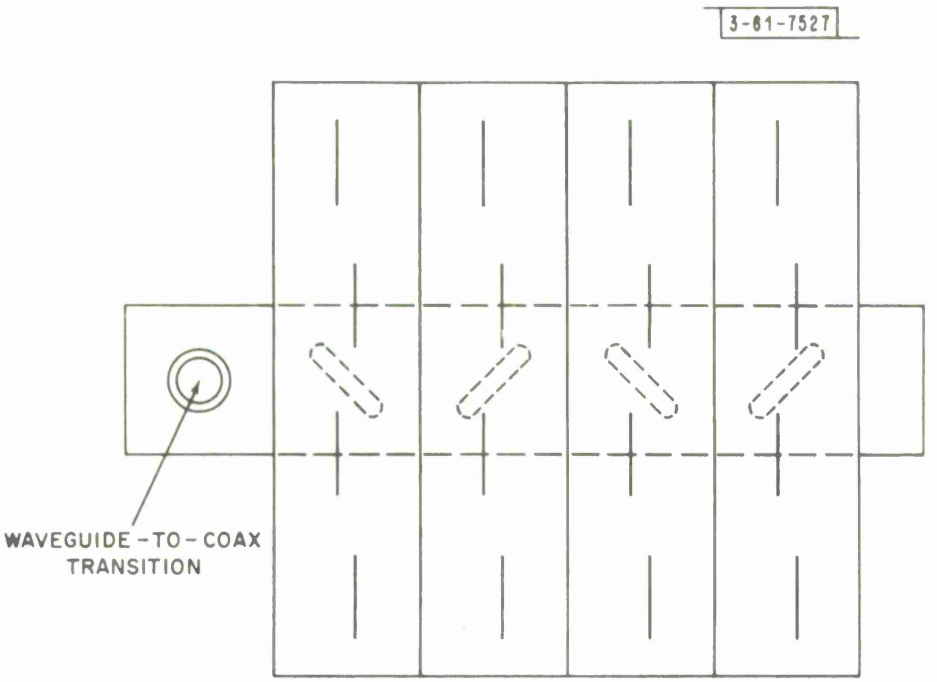

Fig. 10. ATS-D and E communication antennas. – After gravity-gradient stabilization has been achieved.

IDCSP - Initial Defense Communication Satellite Program

Frequency GHz	Beamwidth Equatorial	Beamwidth Polar	Polarization	Gain db
Trans. 7.275	Omni	27°	Left circular	4.9
Rec. 8.0	Omni	30°	Right circular	4.9

The communication antennas project from the top of the spinning satellite (Fig. 11). Both the receive and transmit antennas are circularly polarized antennas similar in concept to the receiving antenna of the Relay satellite. Circular polarization is derived in a slightly different way, however, utilizing the properties of a conical transmission section and of a cylindrical dielectric window to provide the desired polarization and radiation pattern.

Reference:

Philco Corporation, Western Development Laboratory, Palo Alto, California.

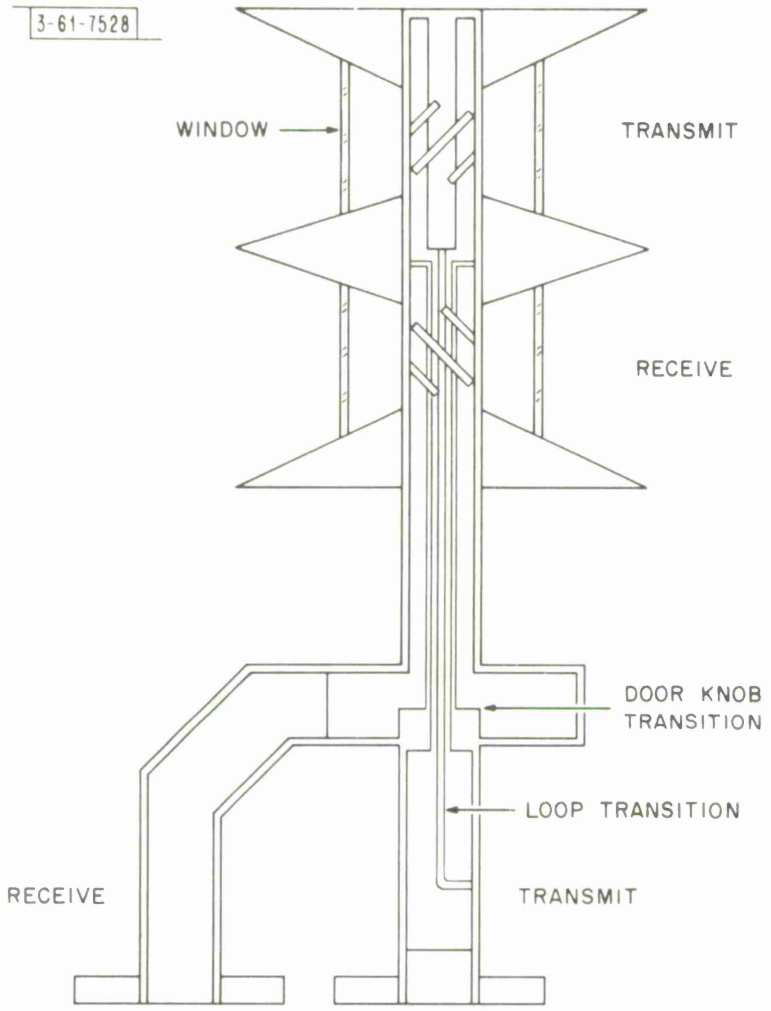

Fig. 11. IDCSP communication antennas.

LES-1 and 2

Frequency	Beamwidth	Polarization	Gain db
Trans. X-band	140° x 140°	Left circular	3.1
Rec. X-band	140° x 140°	Right circular	3.7

The Lincoln Experimental Satellite 1 and 2 communication antenna system makes use of eight horns, one in each octant of the satellite as suggested in Fig. 12. Each radiator is a lens-horn providing circular-polarization transmission and circular-polarization, of the opposite sense, reception. In operation, a switching system closes the path to the radiator closest to the earth direction, and open the paths to all the other radiators.

Reference:

R. N. Assaly, J. B. Rankin and L. J. Ricardi, "Switched-Beam Antenna System for LES-1 and LES-2," Technical Report 409, Lincoln Laboratory, M. I. T. (December 1965).

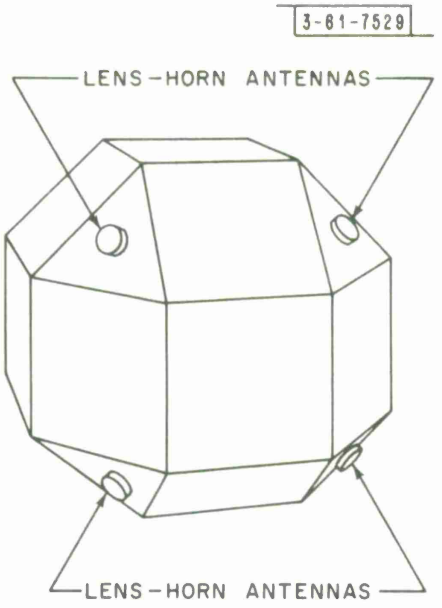

Fig. 12. LES-1 and 2 communication antennas.

LES-4

Frequency	Beamwidth Equatorial	Beamwidth Polar	Polarization	Gain db
Trans. X-band	58°	28°	Left circular	11
Rec. X-band	Omni	35°	Right circular	4.4

The receiving antenna is a biconical horn excited by 12 equi-spaced, inclined slots which are fed by a TM_{01} mode. Circular polarization of the received radiation is achieved by a proper selection of the dimensions of the horn. The receiving antenna is mounted along the spin axis and on top of the transmitting antenna. This latter utilizes eight circularly polarized horns equi-spaced about the spin axis and sequentially switched to despin the beam. Each horn has a rectangular aperture that provides the desired coverage, and is excited by a four-slot resonant array cut in the broad face of a waveguide. The combined effect of 45° vanes and dual-mode transmission lines yields circular polarization.

References:

J. B. Rankin, "X-Band Transmitting Antenna for LES-4," Technical Report 415, Lincoln Laboratory, M. I. T. (April 1966).

M. L. Rosenthal, "X-Band Receiving Antenna for LES-4," Technical Report 410, Lincoln Laboratory, M. I. T. (December 1965).

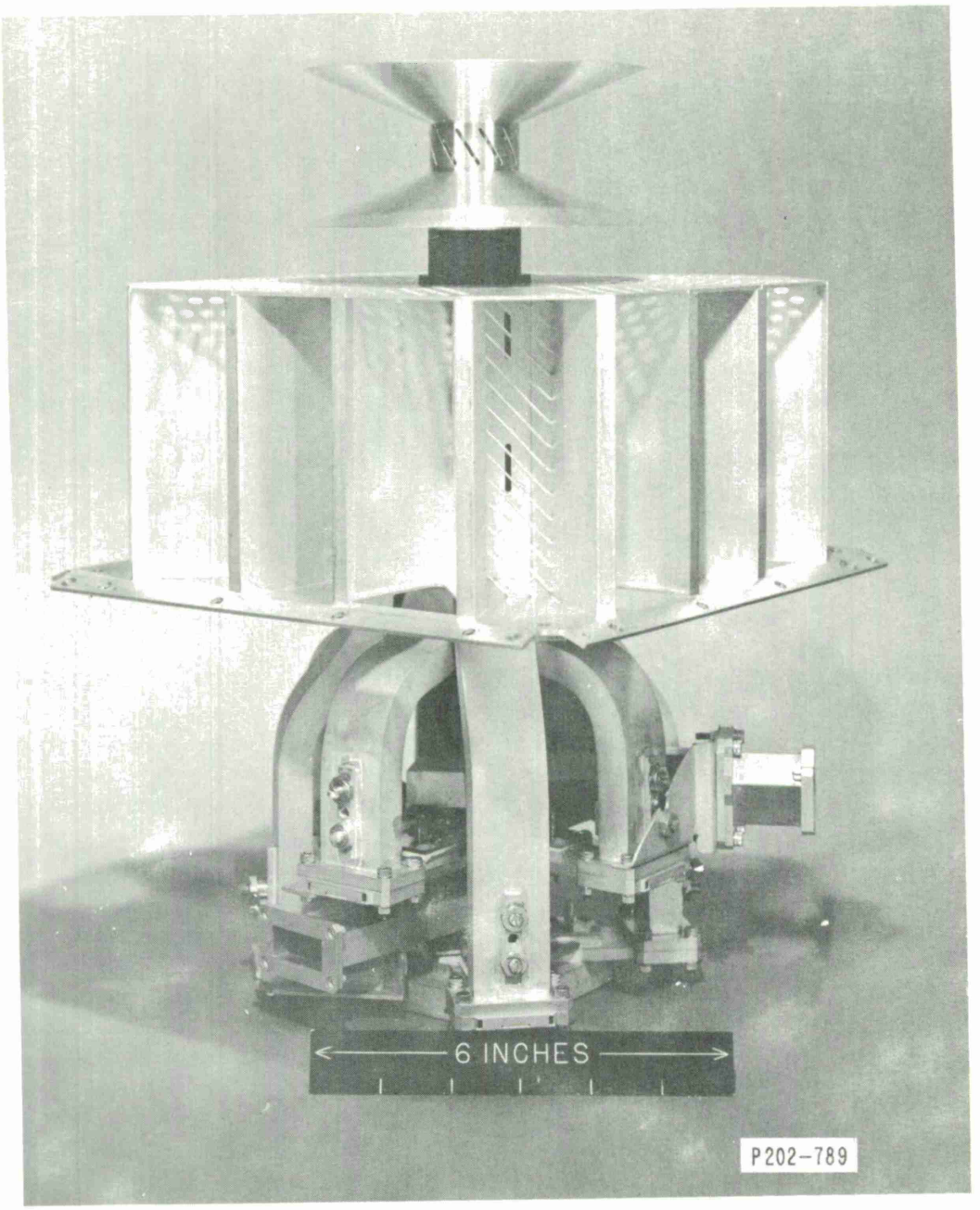

Fig. 13. LES-4 communication antennas.

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13. ABSTRACT

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