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UHF Polarization Characteristics of LES-8/9

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FOR THE COMMANDER

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ABSTRACT

Lincoln Experimental Satellites 8 and 9 (LES-8/9) were launched together in 1976. On-orbit tests made shortly after launch indicated that their UHF communications systems were working properly. In particular, the RHCP characteristics of their UHF antenna systems on orbit were found to be close to those measured before launch. Several years after launch, however, a user of LES-8/9 UHF functions found discrepancies at some frequencies between the test data and what was expected to be observed, based on RHCP antenna characteristics. Subsequent measurements made at Lincoln Laboratory indicated that the UHF antenna system of LES-8 has changed in its polarization characteristics. It is nearly linearly polarized at some frequencies. A possible cause for this failure has been deduced. So far as is known, LES-9 remains unaffected in this regard.

This work was first reported at the Eleventh Meeting of The Technical Cooperation Program (TTCP), Subgroup-S (Communication Technology and Information Systems), Technical Panel STP-6 (Space Communications), held at the Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, 24–28 October 1983.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. UHF POLARIZATION CHARACTERISTICS OF LES-8/9

1.1 INTRODUCTION

Lincoln Experimental Satellites 8 and 9 (LES-8/9) were launched from Cape Canaveral, Florida, by a single Titan-IIIC booster on 15 March 1976 UTC. These satellites [1, 2] are three-axis-stabilized in nearly circular, geosynchronous, inclined Earth orbits. They can support intersatellite communication links at EHF (36 to 38 GHz). They provide uplink and downlink communications at EHF and at UHF (225 to 400 MHz). Significant on-board signal-processing and system-reconfiguration capabilities in LES-8/9 provide the means for demonstrating a wide variety of communications functions.

During their 14 years on orbit, LES-8/9 have proved to be highly reliable spacecraft. It has been possible to work around the few failures that have taken place by switching to backup and alternative modes, accepting graceful degradation in some cases. There are subsystems, however, for which no backup exists. The single gimbaled momentum wheel (the spinning-top stabilization element in the satellite's attitude-control system) is an example and the UHF antenna system is another.

Lincoln Laboratory learned in 1982 that one user of LES-8/9 [the Air Force Wright Aeronautical Laboratories (AFWAL), Wright-Patterson AFB, Ohio—now the Wright Research and Development Center (WRDC)] was having difficulty reconciling theory with experiment during tests that involved LES-8's UHF communications system. The engineers at AFWAL were not newcomers to satellite communication. Their results had to be given credence. Lincoln Laboratory therefore undertook to remeasure the axial ratios of the UHF antennas of LES-8/9 on orbit.

1.2 DESCRIPTION OF THE TESTS

Tests made in 1982 by AFWAL indicated that the downlink polarization of LES-8 at UHF was far from circular [3]. These tests were made using antennas of relatively low directivity, so the results were stated with qualifications. LES-8's elevation angle varied between 12 and 55 deg daily. These results are given in Table 1, together with those from measurements made on a UHF downlink from a FLTSAT satellite at 42-deg elevation angle.

TABLE 1

Axial Ratios of UHF Satellite Antennas Near 250 MHz*

	LES-8	FLTSAT
Using rotating LP antenna		
Without anti-ground-reflection fence	4 to 5 dB	10 to 12 dB
With anti-ground-reflection fence	18 to 21 dB	1.9 to 2.2 dB
Using rotatable RHCP/LHCP antenna		
With anti-ground-reflection fence	19.3 dB	3.3 dB

*Results of AFWAL tests made in 1982.

AFWAL personnel indicated informally that their observation of LES-9's UHF downlink signal showed it to be much closer to RHCP than LES-8's.

Lincoln Laboratory undertook to make similar measurements using UHF antennas atop Building B at Lexington, Massachusetts (Figure 1). The first attempts were made from the Lincoln Experimental Satellite Operations Center (LESOC) using its low-directivity UHF antennas (each a linear array of four crossed dipoles over a ground plane, Figure 2). These tests yielded inconclusive results, even when observations were made with LES-8 or LES-9 at a high elevation angle (40 to 50 deg). A second set of tests was carried out by Lincoln Laboratory, Group 61 (now Group 64), in which LESOC's 30-ft-diam. antenna (Figure 3) was fed by a rotating UHF dipole over a ground plane placed just inboard of the focus (Figure 4). Only one of the two orthogonal dipole elements in this test antenna was active. The cross-polarized linear component was 27 dB down from the intended radiation. The approximately one-half-wavelength defocusing caused by the axial placement of the test antenna results in only 1.5-dB degradation in on-axis gain. The gain of this antenna in its normal configuration at about 250 MHz is approximately 23 dBi, the half-power beamwidth being about 9 deg.

Figures 5 and 6 show the results of these UHF downlink tests for narrow-band (HELP-mode) transmissions from LES-8 (249.2 MHz) and LES-9 (249.6 MHz), respectively. The photos show spectrum-analyzer displays for instrument operation in the fixed-frequency mode (0-Hz frequency span). In each case, one photo was taken with the rotatable dipole oriented for minimum signal. Another photo was taken with the rotatable dipole oriented for maximum signal. A third photo was taken with the dipole rotating, to show a number of sweeps corresponding to different orientations. The maximum and minimum signal levels in these photos correspond to orientations of the test dipole along the major and minor axes, respectively, of the polarization ellipse of the satellite's UHF antenna. The minimum signal-plus-noise-to-noise power ratio was sufficiently high ($\approx$12 dB) during these tests so that the axial ratios could be estimated with confidence from the differences between the power levels. LES-8 was found to have an axial ratio of 8 to 10 dB; the LES-9 ratio was 4 to 6 dB.

Figures 7 and 8 show the results of UHF uplink tests for LES-8 and LES-9, respectively. CW signals at 302.8 MHz (LES-8) and 303.5 MHz (LES-9) were transmitted at constant power level from the 30-ft-diam. antenna through the test dipole. The orientation of the dipole was varied to find the maximum and minimum levels of power received at the satellite. This quantity was telemetered to LESOC and plotted, scaled to correspond to equivalent Earth-terminal RHCP EIRP. The minimum signal-plus-noise-to-noise power ratio was sufficiently high in each case (7 to 8 dB) so that the axial ratios could be estimated with confidence from the differences between the power levels. LES-8 and LES-9 were found to have axial ratios of 5.0 dB and 4.6 dB, respectively. Prelaunch data taken in an anechoic chamber showed axial ratio of 2 to 3 dB for LES-8 and 2 dB for LES-9.

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Figure 1. Antenna farm atop Lincoln Laboratory Building B, Lexington, Massachusetts.

156264-2

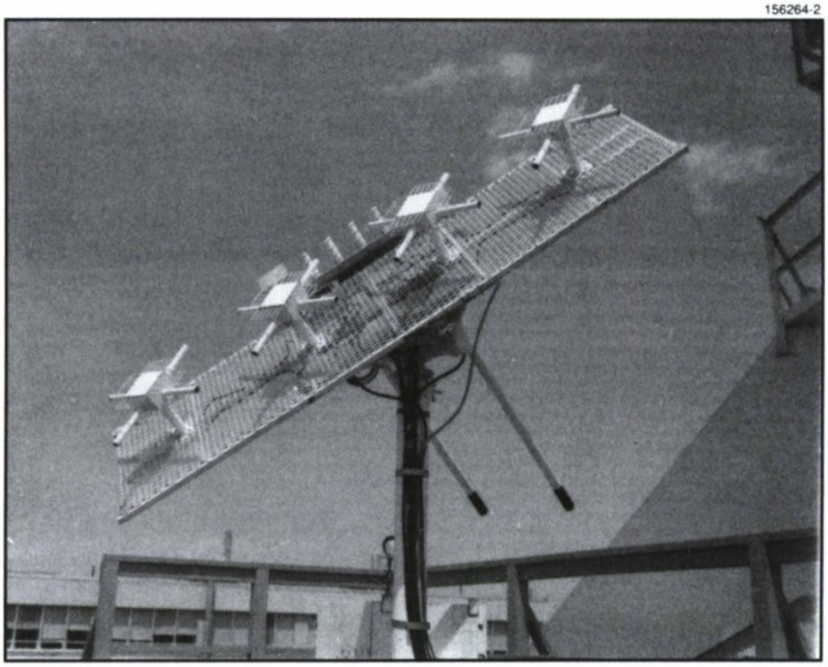

Figure 2. Array of UHF crossed-dipole antennas.

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Figure 3. 30-ft-diam. antenna.

156264-4

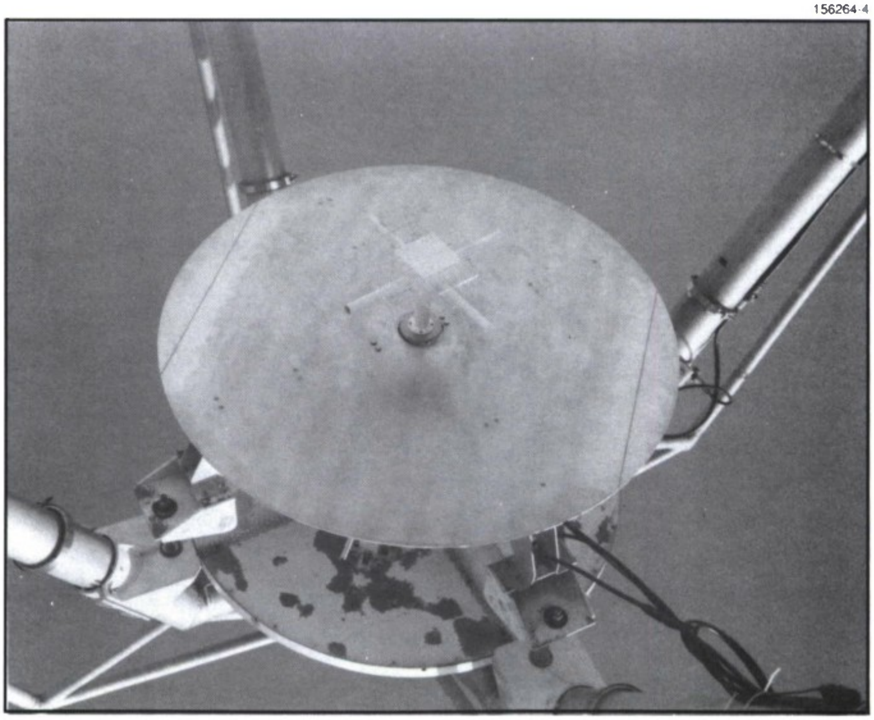

Figure 4. Rotatable test dipole installed on antenna.

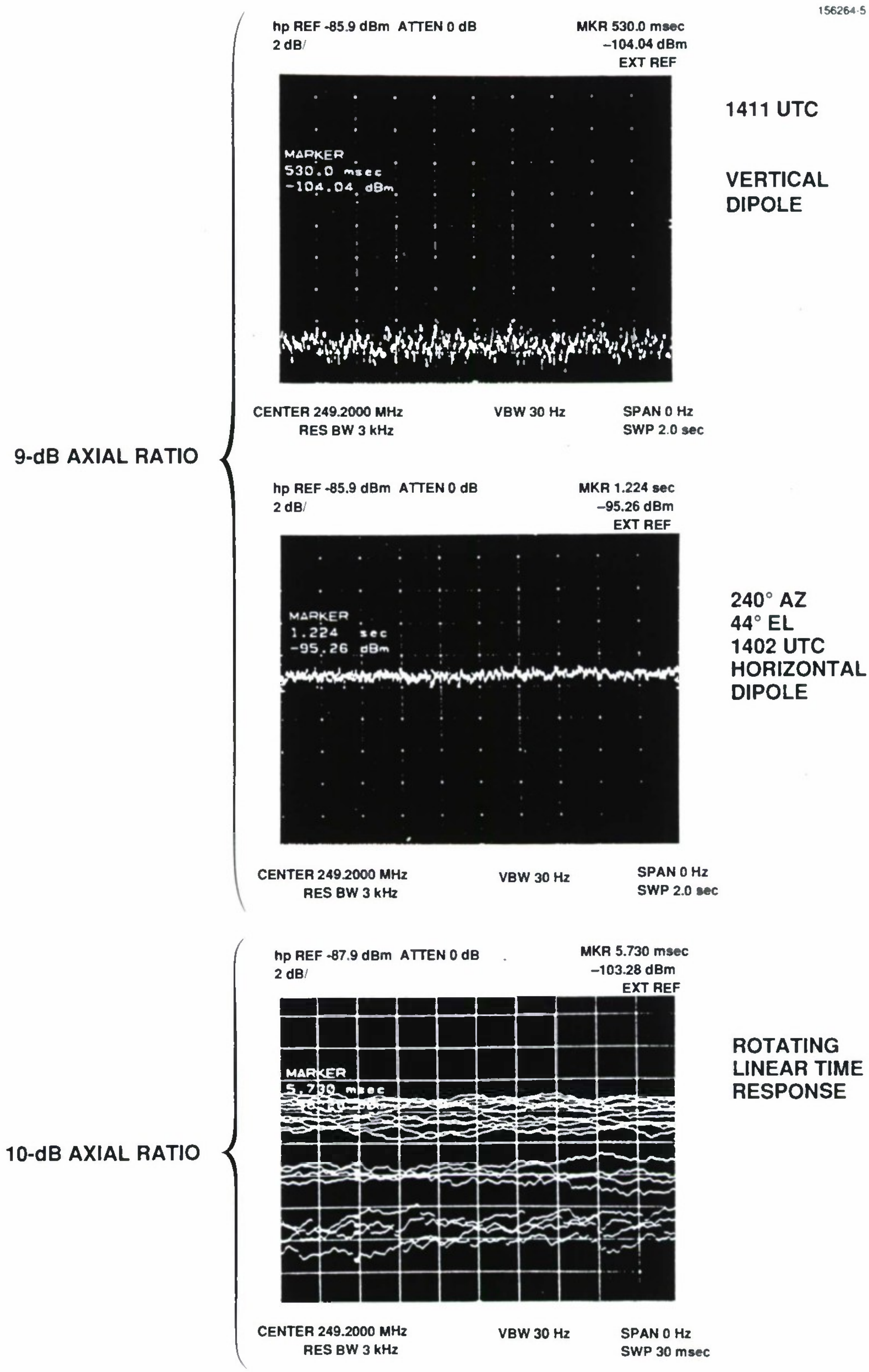

Figure 5. LES-8 UHF downlink test, 1 October 1983.

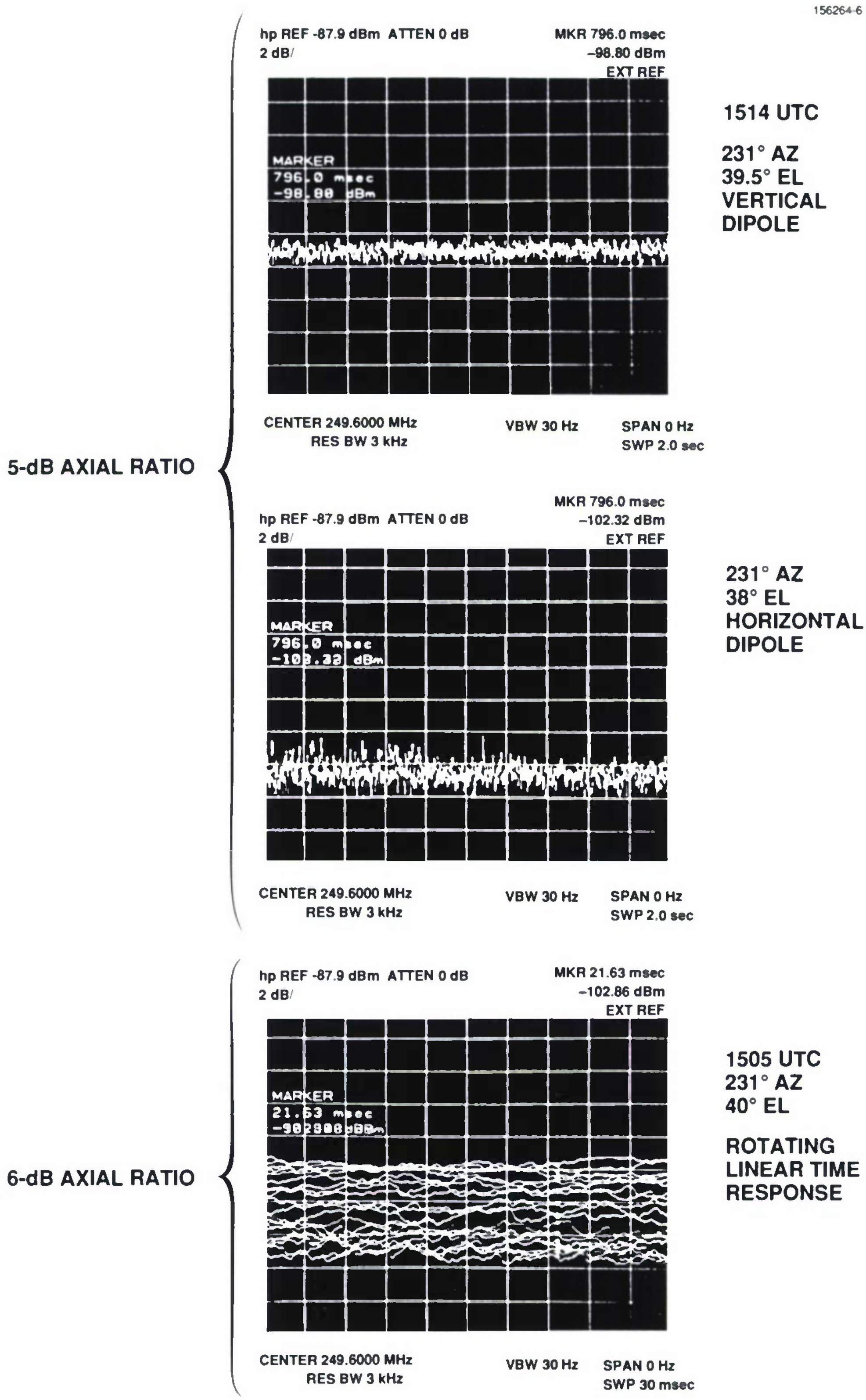

Figure 6. LES-9 UHF downlink test, 1 October 1983.

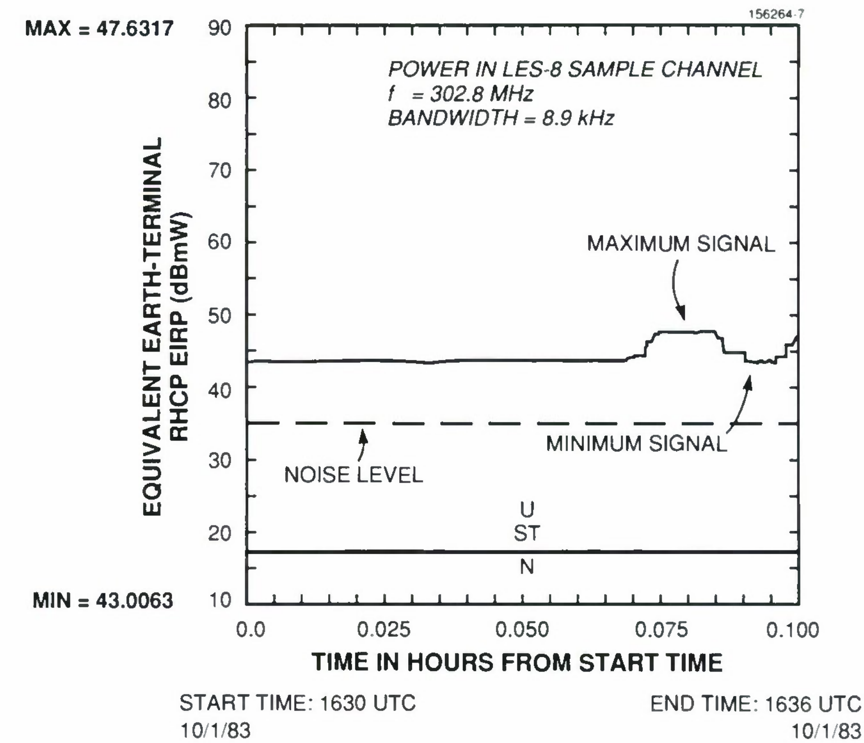

Figure 7. LES-8 UHF uplink test.

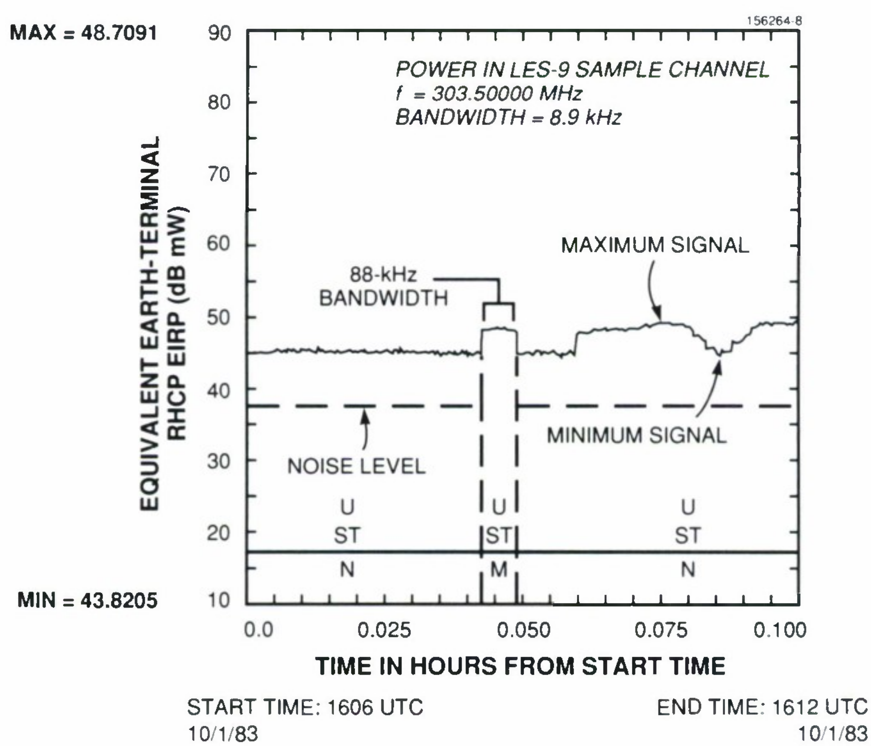

Figure 8. LES-9 UHF uplink test.

The results of measurements made when LES-8/9 were at high elevation angles are summarized in Table 2.

TABLE 2

Axial Ratios of LES-8/9 UHF Antennas*

	LES-8	LES-9
Downlink (≈250 MHz)	8 to 10 dB	4 to 6 dB
Uplink (≈300 MHz)	5 dB	5 dB
*Results of Lincoln Laboratory tests made in 1983.		

1.3 IMPLICATIONS OF THE TEST DATA

It is apparent from these results that there has been a degradation in the circularity of LES-8's UHF antenna system. The degraded axial ratio has been found to be frequency-sensitive. What could have caused this, and when did it happen?

Figure 9 shows the configuration of LES-9; LES-8's is the same. A photograph of one of the UHF antenna arrays is shown in Figure 10. At each dipole there are open- and short-circuited stubs used in impedance matching. Changes in this circuit configuration could cause an impedance mismatch. Turning to the schematic of the UHF-array feed network (Figure 11) and recalling that the three-way power dividers are reactive-type power splitters, we see that there is little isolation between the ports of a divider. Any mismatch will result in a mismatch in coaxial lines W-71 or W-72. The 90-deg hybrid junction splits the power from the transmitter evenly and provides the needed 90-deg phase shift only if its output sees 50-ohm impedance matches. It would not be surprising if this circuit—modified by some mechanical failure in the matching stubs, for example—were frequency sensitive over its broad range of operation (most of the military UHF band, which is 225 to 400 MHz).

When might such a change in the matching stubs have happened? This is harder to say. Assume that Lincoln Laboratory's measured value of as much as 10 dB for the axial ratio of LES-8's UHF antenna near 250 MHz is correct. Let the ground terminal have an antenna system with 0-dB axial ratio (perfect RHCP, the same sense as the satellite). Then the received downlink signal would be down by only 1 dB from that which would have been obtained if LES-8 had a perfect RHCP UHF antenna system. If the nominal RHCP ground-terminal antenna has 3-dB axial ratio, the maximum polarization-mismatch loss would be 2 dB. These values are small, considering the accuracy with which received-power measurements are ordinarily made. So, a change in the axial ratio of LES-8's UHF antenna system may have gone unnoticed for several years. (LES-8/9 were launched on 15 March 1976.)

Table 3 shows the maximum and minimum polarization-mismatch losses to be expected for a link between an antenna with a 10-dB axial ratio and other antennas covering the gamut of axial ratios. The implications of this degradation in LES-8's UHF downlink performance for link operation are not catastrophic, provided the receiving terminal has a reasonably good axial ratio.

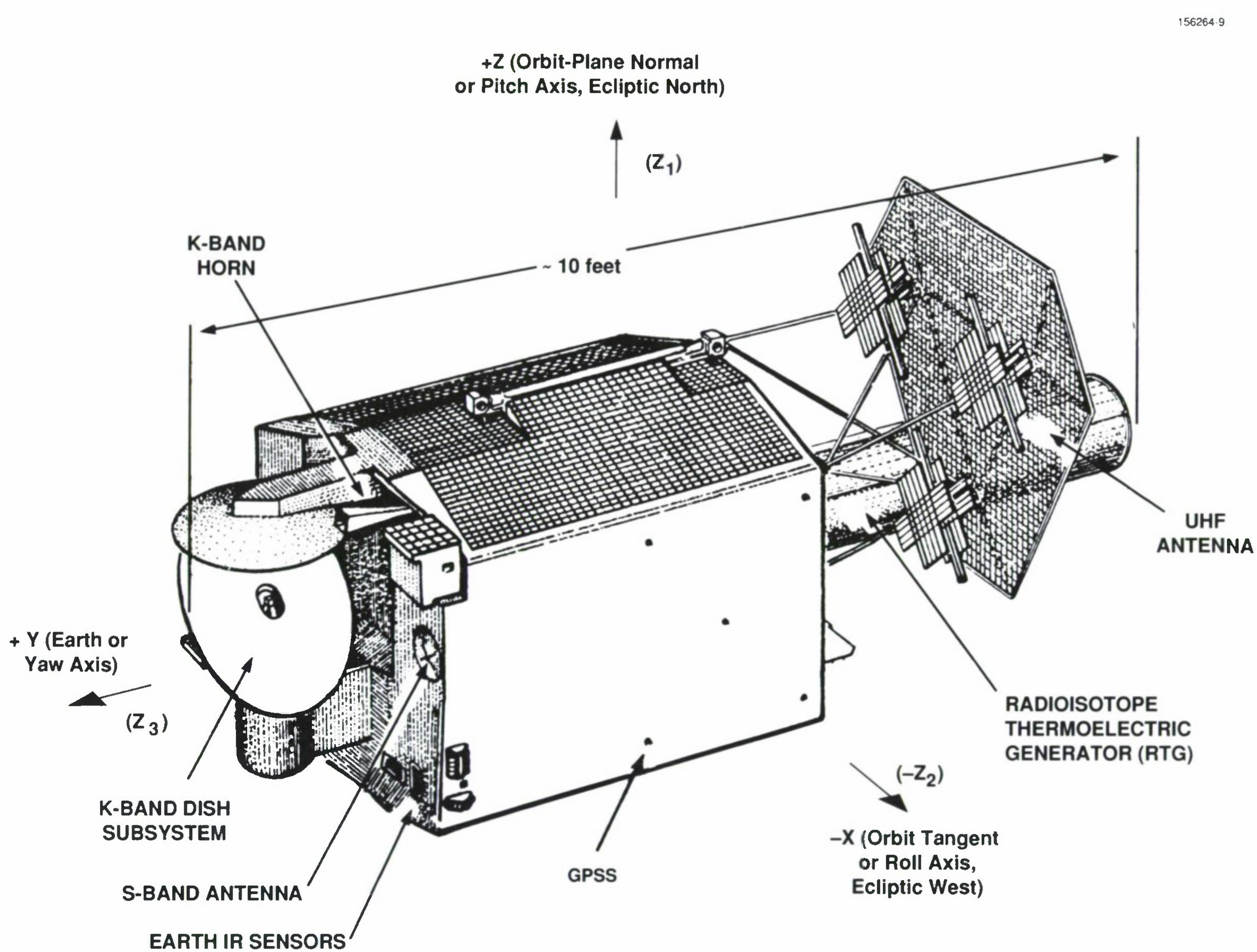

Figure 9. Illustrated arrangement LES-9.

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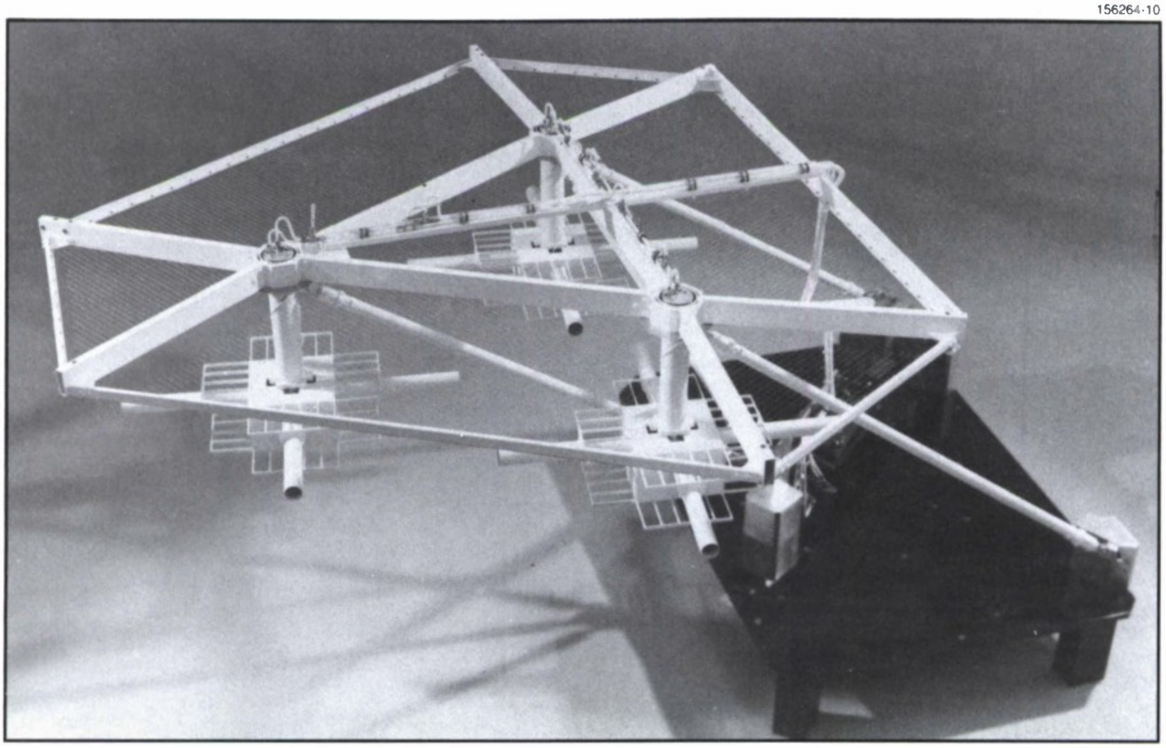

Figure 10. LES-8/9 UHF antenna array.

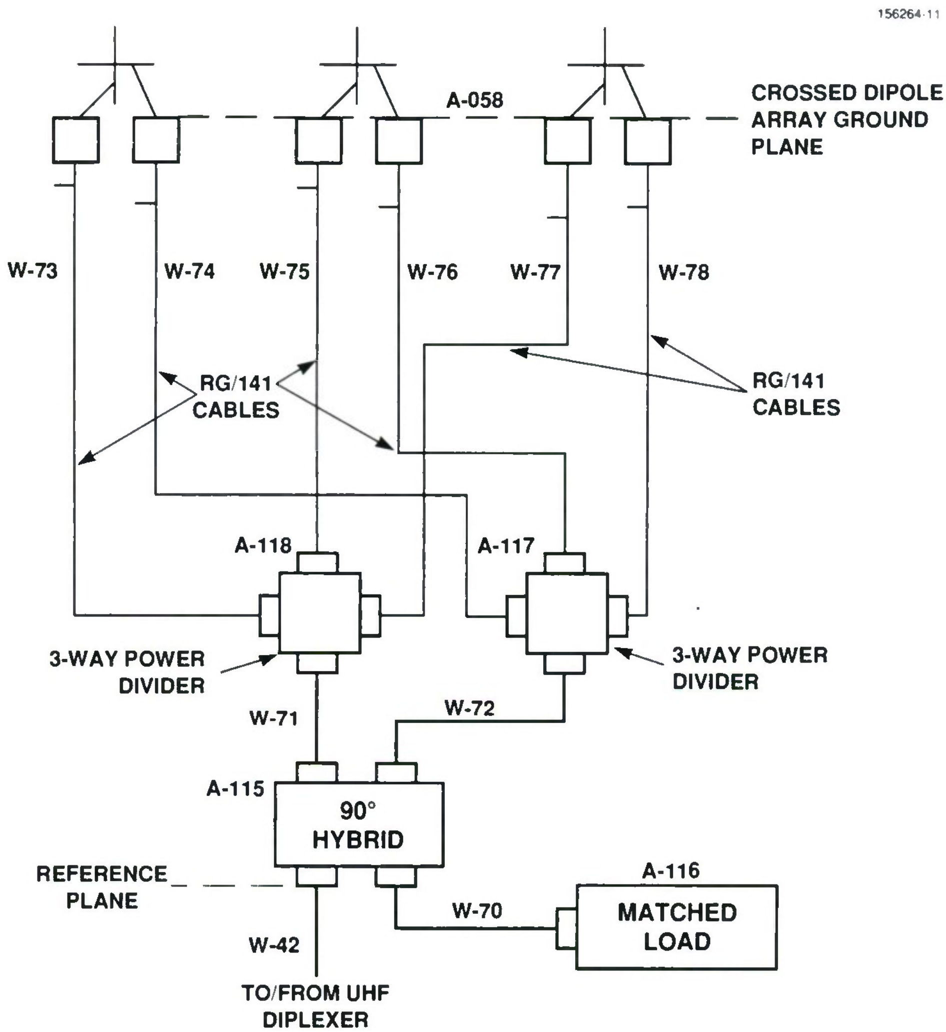

Figure 11. UHF-array feed network.

TABLE 3

Downlink Loss for LES-8*

Axial Ratio of Nominally RHCP Terminal (dB)	0 (circular)	3	5	10	∞ (linear)
Maximum Link Loss (dB)	1.0	2.0	2.7	4.8	10.4
Minimum Link Loss (dB)	1.0	0.4	0.2	0.0	0.4

*10-dB axial ratio.

The variation between maximum and minimum link loss depends on the relative orientation of the major axes of the polarization ellipses of the transmitting and receiving antennas. For reference, the polarization-mismatch losses are given by:

$$\text{Minimum loss (dB)} = -10\log_{10}\left[\frac{(1 \pm r_1 r_2)^2}{(1+r_1^2)(1+r_2^2)}\right] ,$$

$$\text{Maximum loss (dB)} = -10\log_{10}\left[\frac{(r_1 \pm r_2)^2}{(1+r_1^2)(1+r_2^2)}\right] ,$$

where r_1 and r_2 are the (voltage) axial ratios of the two antennas. The formulas are valid whether axial ratio is defined as major-axis-to-minor-axis or as minor-axis-to-major-axis. These results come from the standard formula [4]

$$\frac{P_{received}}{P_{matched}} = \frac{1}{2} \pm \frac{2r_1 r_2}{(1+r_1^2)(1+r_2^2)} + \frac{(1-r_1^2)(1-r_2^2)\cos 2\theta}{2(1+r_1^2)(1+r_2^2)} ,$$

where θ is the angle between the major axes of the polarization ellipses of the two antennas. In these formulas, the "±" is chosen in this way:

Antennas have the same sense of elliptical polarization "+".

Antennas have opposite senses of elliptical polarization "-".

2. CONCLUSIONS

The results of Lincoln Laboratory's measurements substantiated the observations made by AFWAL about the UHF antenna system of LES-8. A plausible way in which the increase in axial ratio (going from near-RHCP to near-LP) might have come about was identified. There is nothing to be done about it. Users of LES-8 must be cautioned to keep this shortcoming in mind. It is particularly significant for spectrum-scanning applications [5]. Signals that reach LES-8 orthogonal to its near-linear polarization at particular frequencies will be underreported.

GLOSSARY

AFWAL	Air Force Wright Aeronautical Laboratories
AZ	Azimuth
EHF	Extremely High Frequency
EL	Elevation Angle
FLTSAT	UHF Military Communications Satellite
GPSS	Gas-Propulsion Subsystem
K-Band	Frequencies in the range 20 to 40 GHz
LHCP	Left-Hand Circular Polarization
LES	Lincoln Experimental Satellite
LESOC	Lincoln Experimental Satellite Operations Center
LP	Linear Polarization
MHz	Megahertz
RHCP	Right-Hand Circular Polarization
S-Band	Frequencies in the range 1.55 to 3.90 GHz
TTCP	The Technical Cooperation Program
UHF	Ultra-High Frequency
WRDC	Wright Research and Development Center

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Lincoln Experimental Satellites 8 and 9 (LES-8/9) were launched together in 1976. On-orbit tests made shortly after launch indicated that their UHF communications systems were working properly. In particular, the RHCP characteristics of their UHF antenna systems on orbit were found to be close to those measured before launch. Several years after launch, however, a user of LES-8/9 UHF functions found discrepancies at some frequencies between the test data and what was expected to be observed, based on RHCP antenna characteristics. Subsequent measurements made at Lincoln Laboratory indicated that the UHF antenna system of LES-8 has changed in its polarization characteristics. It is nearly linearly polarized at some frequencies. A possible cause for this failure has been deduced. So far as is known, LES-9 remains unaffected in this regard.

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