THE STEERABLE LUNEBURG LENS AS A COMMUNICATION LINK ANTENNA

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ABSTRACT

A review of the Luneburg Lens and its use as an antenna aperture is presented. Also discussed are methods of electromechanical and electronically switchable operation along with design criteria. Applications in the field of data link communications and telemetry are suggested and the performance of several operational systems are outlined.

INTRODUCTION

Luneburg Lenses have long been used in passive augmenters. In this function, they receive far field energy in a plane wave and focus this energy to a small area of a reflector on the opposite side of the lens. The reverse process takes place and the energy is re-radiated as a plane wave. The size of the reflector determines the field of view in which the lens responds with a monostatically reflected return. Typical lenses have high gain (radar cross section) over conical fields of view of about 120 degrees. The gain depends on the physical size of the lens and the materials used.

There are several ways to use the Luneburg Lens directly as an antenna. One methods is to substitute a properly matched feed for the reflector and transmit or receive from this feed. By using multiple feeds, multiple beams or electrically scanned beams can result. Another method is to slice the lens in half, place a circular reflector plate in the center and excite this configuration from a slightly displaced RF feed. The hemispherical lens/plate can then be gimbled and the beam mechanically steered. In this case, the beam is steered at twice the angle of the lens/reflector plate. This latter technique has been successfully demonstrated as a component of an airborne communications data link.

LENS THEORY

In the true Luneburg Lens, the dielectric constant, is a function of the radius in accordance with the relationship shown in Figure 1. Theoretically, the path lengths AF, BF, and CF are essentially equal due to the greater phase delays of rays travelling through the higher dielectric center of the lens when compared to those further out travelling through areas of lesser dielectric. Thus, a plane wave on line ABC will focus to a point at F. In practice, it is difficult to achieve perfect focus due to materials inhomogeneities and mechanical tolerances.

It is an expensive process to maintain a varying dielectric constant, especially if the radius is large. Figure 2 shows the commonly used stepped index approach where the variation in dielectric constant is approximated by stepped cores having dielectric constants between 1 and 2. A slight phase error results but large lenses can be easily fabricated by this technique. Teledyne Micronetics has manufactured stepped index lenses as large as 16 inches in diameter.

For small lenses, uniform dielectric constant material can be used and a reasonable focus achieved. Lenses of 1- and 2-inch diameters have been demonstrated using a uniform dielectric.

Some of the features of the lens are:

- The lens is frequency invariant; the feed structure is the bandwidth limiting component
- With polarization grids any circular polarization can be handled
- The parameters of the lens can be adjusted to achieve a tapered aperture for low sidelobes.
- The focus of the lens can be varied to produce a bistatic lens response
- High average power can be handled by careful selection of lens materials

When a hemispherical lens is backed by a reflector plate, the feed can be offset and the lens steered as illustrated in Figure 3. Electromagnetics image theory shows the actual feed appearing as a virtual feed behind the reflector plate giving the virtual source effect.

The gain of the virtual source lens is approximated by the relationship

$$G = \frac{4\pi^2 r^2}{\lambda} \eta$$

where r = the radius of' the lens aperture
λ = the wavelength of operation
η = the efficiency of' the lens

The value of η for a virtual source lens is approximately 0.40.

The attenuation (in dB/m) through a lens can be estimated by the relationship

$$\alpha \simeq 9.1 \times 10^{-8} f (\tan \delta) \varepsilon^{1/2}$$

where f = the frequency in Hertz
$\tan \delta$ = the loss tangent of the lens material
ϵ = the dielectric constant of the lens material

Lens materials have a loss tangent of 0.001 or less. Polystyrene, teflon ceramic and polymethylpentene are typical materials. Lenses can be fabricated at frequencies from L-band to 94 GHz.

Complete gimbaled mechanisms with servo control have been fabricated to steer the virtual image lens antenna. A single lens can be used for hemispherical coverage. This results in a high gain system and can be used to reduce vulnerability to link jamming.

ANTENNA DATA LINK TELEMETRY APPLICATIONS

The steerable virtual image lens antenna can be applied to enhance the RF transmission of sensory information because of its ready incorporation in mobile platforms where weight and size limitations are critical and multiple functions are required of the telemetry data link. In addition, because of its rapid steering characteristic and space stabilization capability in roll, pitch and yaw, it is particularly useful in both seaborne and airborne data acquisition vehicles. The ability to provide full hemispherical capability with a single antenna or full spherical coverage with two antennas mounted in opposition makes the steerable lens particularly attractive for unmanned aircraft operating as a data link relay. Over-the-horizon RF transmissions in unmanned or remotely-piloted vehicles (RPV's) which may assume many attitudes are improved by this steerable technique allowing the accumulation of real-time data. The system has the advantage of a man-in-the-loop to rapidly control and alter the data acquisition mission and objectives based on the real-time data transmitted by the steerable antenna.

The obvious use of the lens antenna is in telemetry by the military in high threat environments. A mobile unmanned system in RF contact with a secure remote location can eliminate the loss of an expensive manned system or lower the risk of damage in environemnts where the utilization of a manned vehicle is too hazardous.

The advantages of utilizing the steerable lens antenna in RPV's for near-term uses with ground focus is that it extends the target acquisition and damage assessment from the ground level visual limitation of three miles under ideal condition to twenty or more miles. The operational commander, whether in a mobile army command van or on a ship engaged in onshore bombardment, has real-time telemetry available because of the data link and the onboard sensor of the RPV. This greatly enhances the effectiveness and precision in attacking military positions without relying on highly indescriminate saturation techniques used in the past.

The flexibility of the RPV mounted lens antenna can be further demonstrated by its use in conjunction with manned aircraft which can act as data relays foe telemetry, thus greatly extending the effective range of the real-time data link. The RPV can be used as a target designation or mid-course guidance control for air-or ship-launched stand-off missiles, relieving pilots of the need to optically or electronically perform these functions.

The lens antenna, with its very rapid beam steering, pointing accuracy and capability in bandwidth compression and spread spectrum modulation, provides effective anti-jamming to preclude distortion, disruption or blockage of data transmission between the RPV and its control unit.

A miniaturized anti-jam steerable data link antenna system has been developed by Teledyne Micronetics for the primary telemetry system for the Army/Lockheed AQUILA remotely-piloted aircraft. The antenna system, consisting of two steerable hemispherical lens antennas and a servo control card, is part of the Harris Corporation Modular Integrated Communications and Navigation System (MICNS) Unit of the AQUILA.

The AQUILA's missions include:

- Reconnaissance
- Command and Control
- Navigation
- Targeting

The AQUILA usefulness in a battlefield environment requires it be readily deployable, highly maneuverable, able to maximize sensor payload and be inherently reliable over the spectrum of its missions. The airborne anti-jam data link antenna contributes to meeting these design and operational objectives by incorporating the following features:

- Light weight
- Rapid beam steering
- Digital control capability
- Very compact angle swept volume
- Roll, yaw, and pitch stabilization
- Elimination of rotary joints
- Full spherical coverage with top and bottom interchangeable units

Table I summarizes the miniature lens antenna physical and performance parameters.

TABLE I

ULTRA MINIATURE LENS ANTENNA
PHYSICAL AND PERFORMANCE PARAMETERS

Operating Frequency Range	Ku-band
Gain	14 dB nominal
Beamwidth	20 deg. x 20 deg.
VSWR	Less than 1.8 to 1
Power Handling Capability	10 watts max.
Axial Ratio	5 dB max.
Azimuth Scan	360 deg.
Elevation Scan	+90 deg. to -20 deg.
Pointing Accuracy	±2 deg.

DYNAMIC BEAM POINTING CHARACTERISTICS

	Angular Velocity	Angular Velocity
Acceleration (azimuth and elevation)	60 deg/sec max.	120 deg/sec^2 max.
Weight	Single antenna/radome	170 grams
	PC board for servo control	160 grams
	Two antenna/radome units with one PC board	500 grains
Size	Radome volume	550 cm^3
	PC board volume	220 cm^3

ENVIRONMENT

Temperature Operating	-40 deg. C to 55 deg. C
Temperature Non-operating	-56 deg. C to71 deg. C
Altitude Operating	5,000 m
Altitude Non-operating	12,000 m
Shock	15 g's for 11 ms
Vibration	5 g's over the range (5 - 500 Hz)

DESCRIPTION OF SYSTEM

Figures 4 and 5 are illustrations of the antenna, radome and gimbal units. They are pictured in Figure 6. The antenna roll axis is the inner gimbal axis with the outer gimbal being the pitch axis. The circularly-polarized feed is fix-mounted in the radome and fed by a solid coaxial cable routed down the side of the radome. Very little blockage results from transmitting directly through the feed or the cable.

The servo drive systems consists of miniature DC motors with 400:1 gear trains and variable potentiometers for position sensing. The servo control card is a four-channel plug-in printed circuit board capable of driving four individual antenna axes for the two antenna system. The servo control electronic system requires digital command information from an external source in an 8-bit X-Y format. This independently commands each antenna to a position about which a position feedback is employed to ensure accuracy.

The servo controller is capable of maintaining a commanded pointing trajectory when mounted on an RPV having an angular velocity of 60 deg/sec and an angular acceleration of 120 deg/sec/sec.

A go/no-go status indication is provided from each channel of the antenna assembly for built-in test (BIT) purposes. Status indicates a fault any time an axis has greater than 3 degrees ±1 degree error from the commanded position.

CONCLUSION

The steerable Luneburg Lens antenna can add a new dimension to communication data links. It is far less costly than an electronically-steered phased array, can reduce the jamming vulnerability and improve the link budget gain. As previously discussed, there are many mission advantages using systems of this type. The lens system is relatively simple and, by having a fixed feed, eliminates the need for unreliable rotary joints.

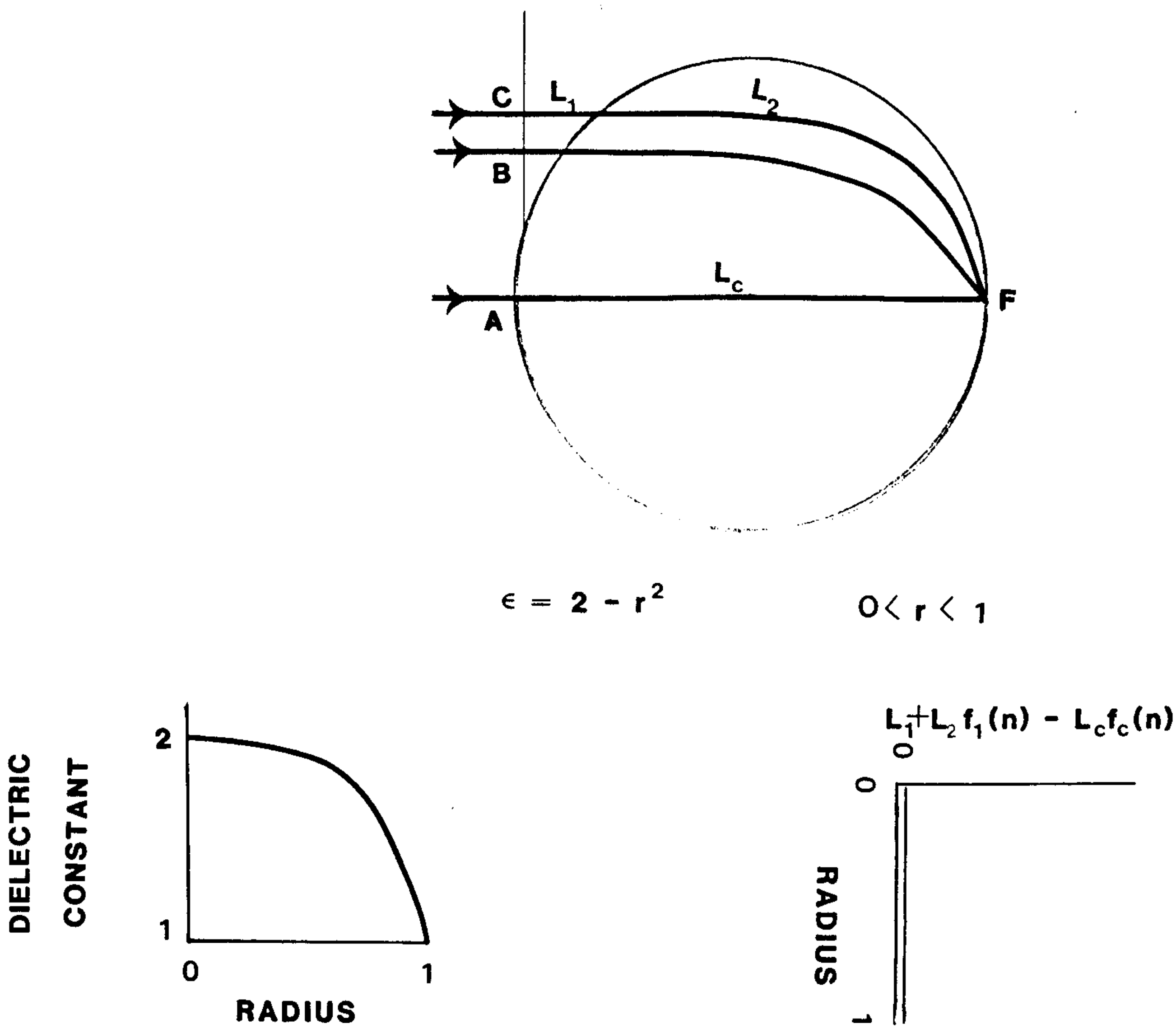

FIGURE 1 LUNEBURG LENS

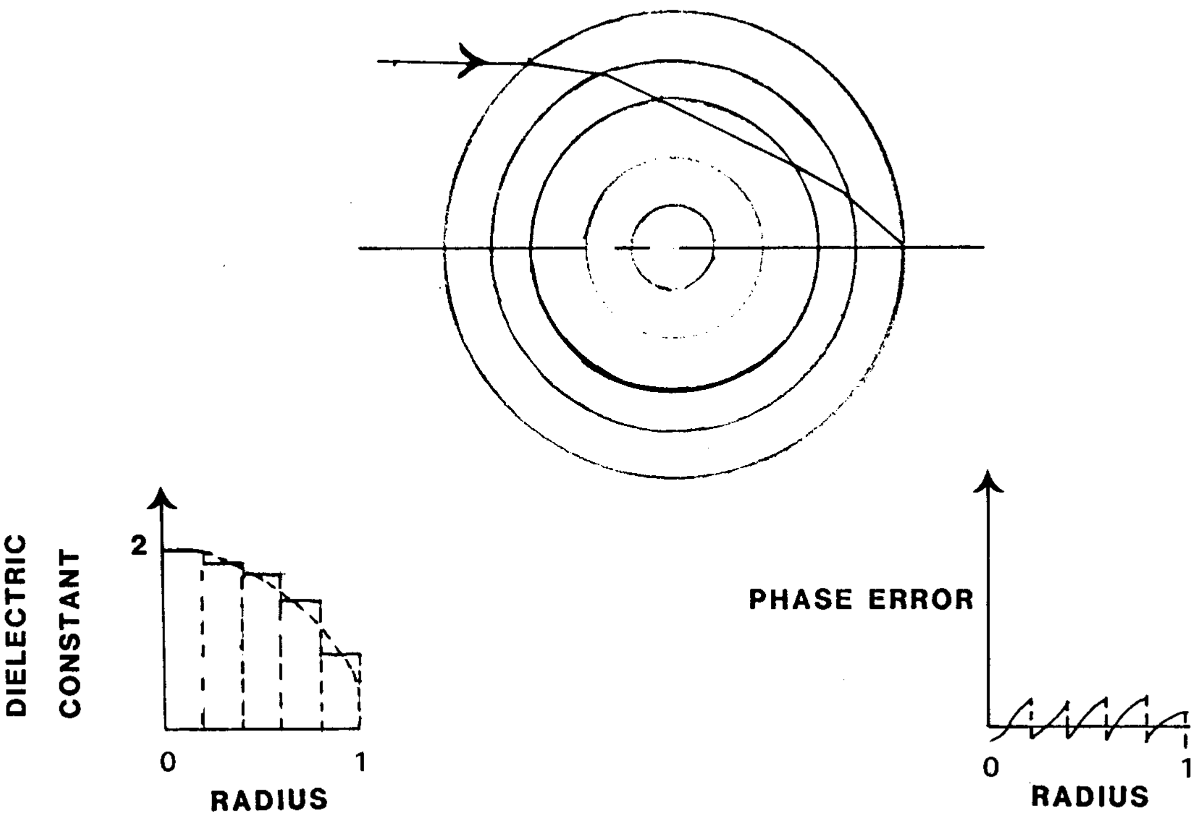

FIGURE 2 STEPPED INDEX LUNEBURG LENS

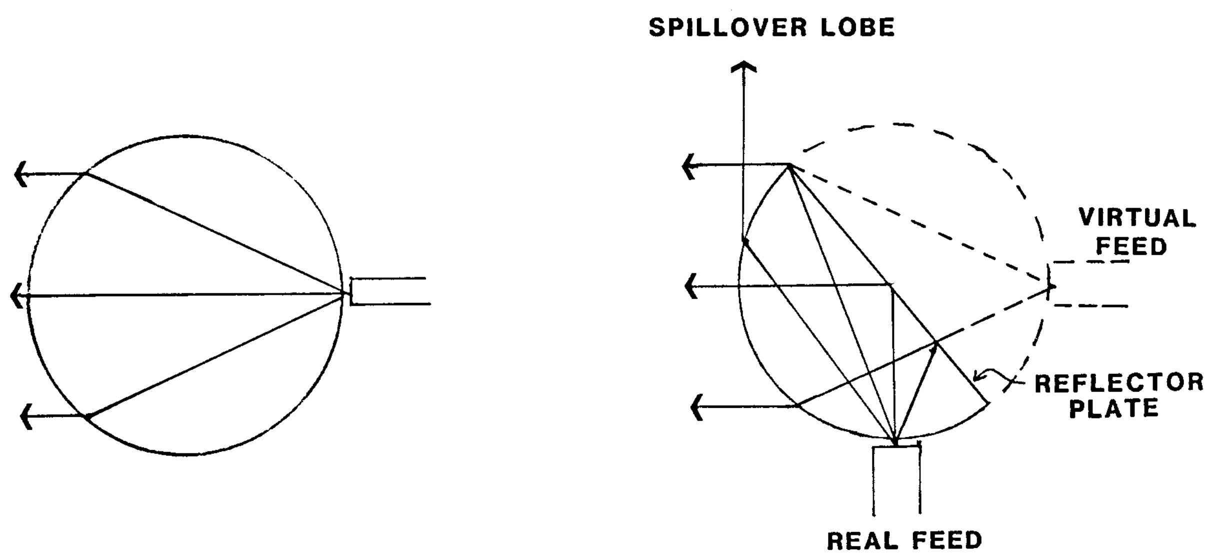

FIGURE 3 VIRTUAL SOURCE LENS ANTENNA

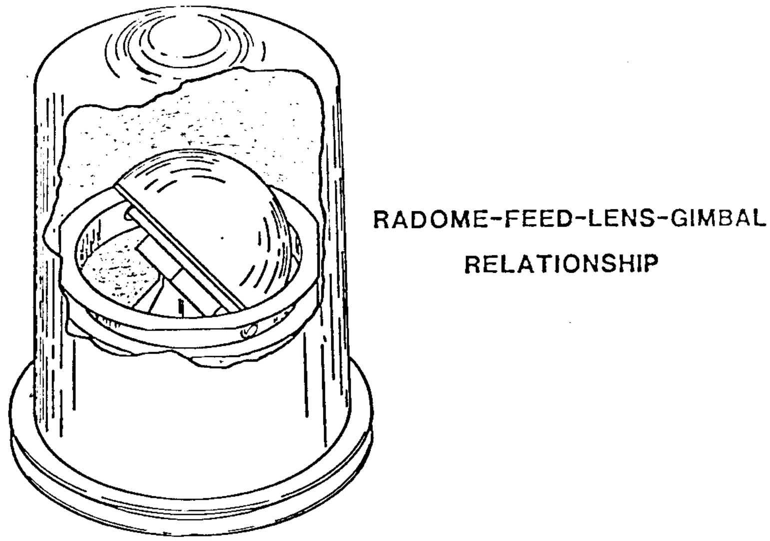

FIGURE 4 ANTENNA/RADOME UNIT

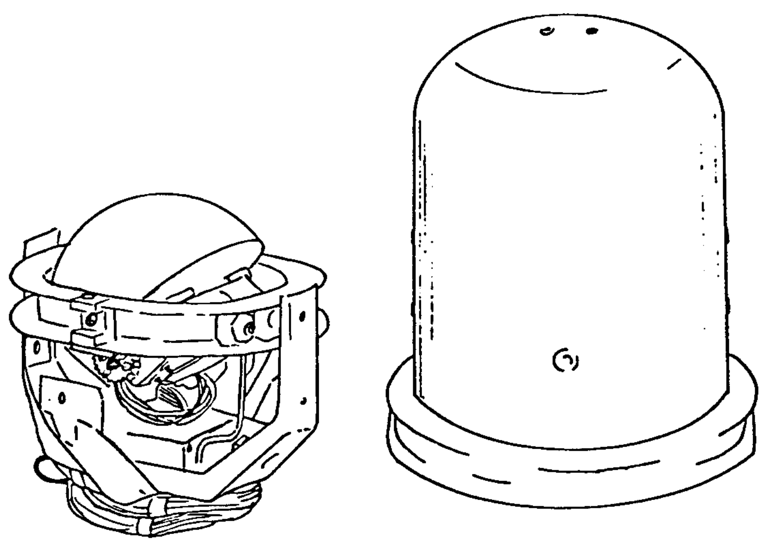

FIGURE 5 DRIVE SYSTEMS & GIMBALS

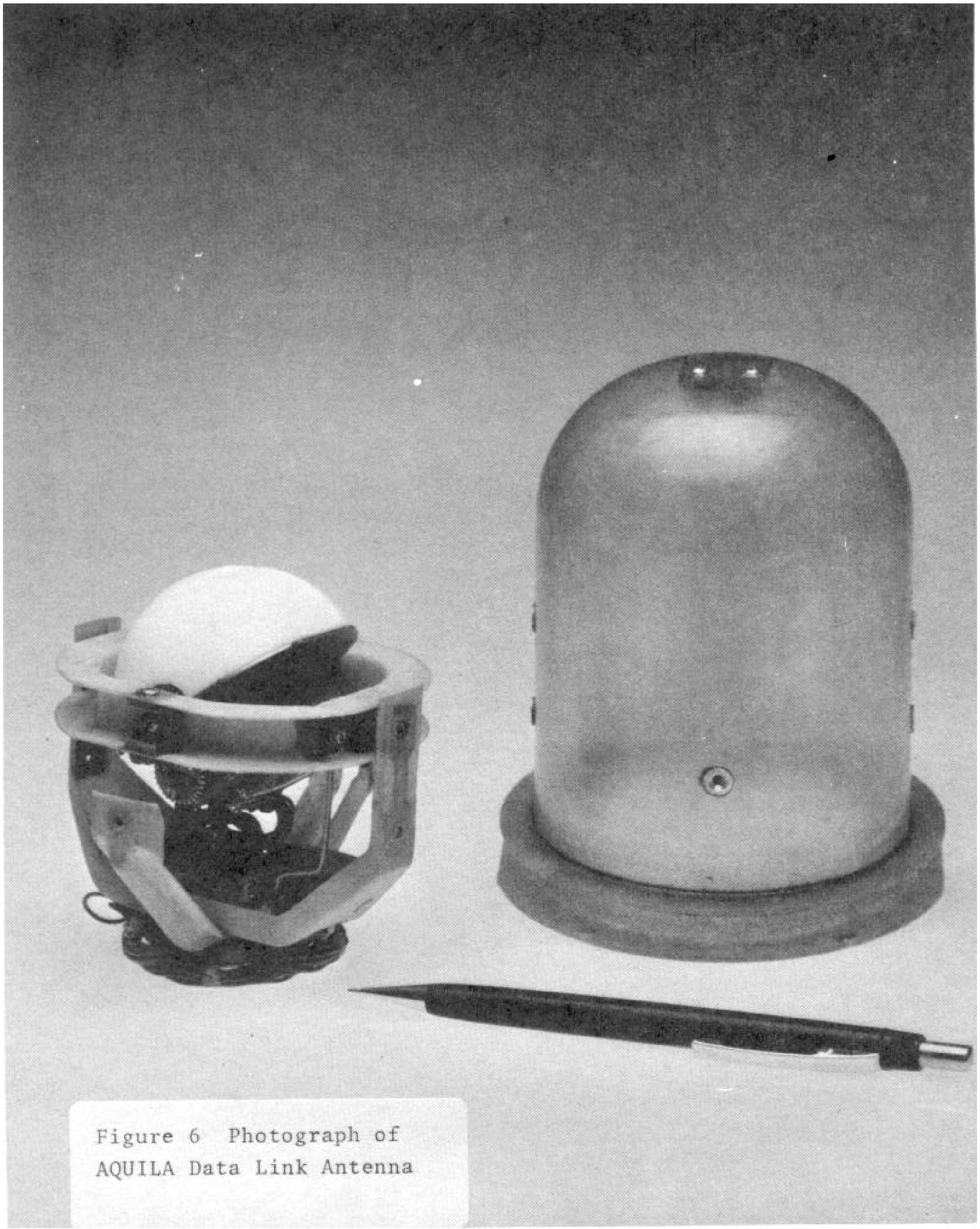

Figure 6 Photograph of AQUILA Data Link Antenna