AN INNOVATIVE APPROACH TO A PERFORMANCE ENHANCEMENT MODIFICATION OF A TWO AXIS TELEMETRY TRACKING SYSTEM

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ABSTRACT

The design of a telemetry tracking system is generally centered around its desired RF performance which is typically specified in terms of beamwidth, gain and/or G/T. These parameters determine the size of the reflector used in a given application and consequently dictate the required size and performance of the associated pedestal.

Any subsequent improvement in the RF performance of such a system is primarily achieved by increasing the size of its reflector. The magnitude of the improvement realized is therefore limited by the load handling capability of the pedestal. In most instances, the substitution of a larger reflector with its increased inertia and wind loading causes a significant degradation in the dynamic performance of the tracking system.

This paper describes how the figure of merit (G/T) of a specific dual axis telemetry tracking system can be improved by a minimum of 7.3 dB/K° without impacting its dynamic performance or increasing its weight.

These impressive results are made feasible by the innovative pairing of a unique design planar reflector with a novel implementation of the conical scanner technology. The FLAPS™ reflector incorporates a newly developed concept which features lightweight construction and very low wind load coefficients [1, 2]. The conical scanner is a lightweight version of the DECS tracking feed system described in the referenced technical paper [3].

Keywords: telemetry tracking, performance enhancement, FLAPS reflector, conical scanner.

INTRODUCTION

This technical paper addresses the problems associated with significantly increasing the RF performance of an existing dual axis telemetry tracking system without causing any degradation in its tracking performance or in any of its other operational characteristics. It describes how a minimum 7.3 dB/K° improvement in the figure of merit (G/T) of the US Navy 56 Portable Medium Range Antenna (PMRA) system can be achieved in a unique and cost effective manner without replacing its pedestal.

The MARK 56 PMRA system is a dual axis telemetry tracking system featuring a 39" (1.0 meter) reflector illuminated by a pseudo single channel monopulse tracking feed. An outline of the system is shown in figure 1. Before modification, its gain and G/T values, at 2300 MHZ, are 20.5 dBi and -2.8 dB/K° respectively. Its pedestal is designed to drive the antenna at 20°/sec in winds in excess of 75 knots. Following modification, its gain and G/T values will be 27.4 dBi and +4.5 dB/K° respectively and the system will operate at 20°/sec in winds in excess of 90 knots. An outline of the system after modification is shown in figure 2.

TECHNICAL APPROACH

The requirement for an improved figure of merit (G/T) is typically addressed by increasing the antenna feed efficiency, minimizing its insertion loss, using a preamplifier with a lower noise figure and providing a larger antenna aperture. In the case of the MARK 56 PMRA system, use of the best tracking feed technology will yield a maximum 2.0 dB increase in gain by reducing the feed insertion loss; the additional 4.0 dB needed will be generated by increasing the diameter of the radiating aperture from 39" up to a minimum of 60" without increasing its windloading and its weight. These results are not compatible with the use of a conventional mesh type reflector.

The selected technical approach for this project consists of replacing the existing antenna reflector and feed assembly with a new assembly incorporating a FLAPS planar reflector illuminated by a high efficiency conical scanner. The FLAPS reflector, based on unique technology, is ideally suited for this application and yields the required gain increase within the weight and windloading constraints. The high efficiency conical scanner is a good complement to the FLAPS reflector because of its light weight and compact construction.

In addition to the use of these two new assemblies, the existing elevation rotator will be repackaged to interface with the larger size reflector. Table 1 lists the antenna and pedestal performance specifications before and after modification.

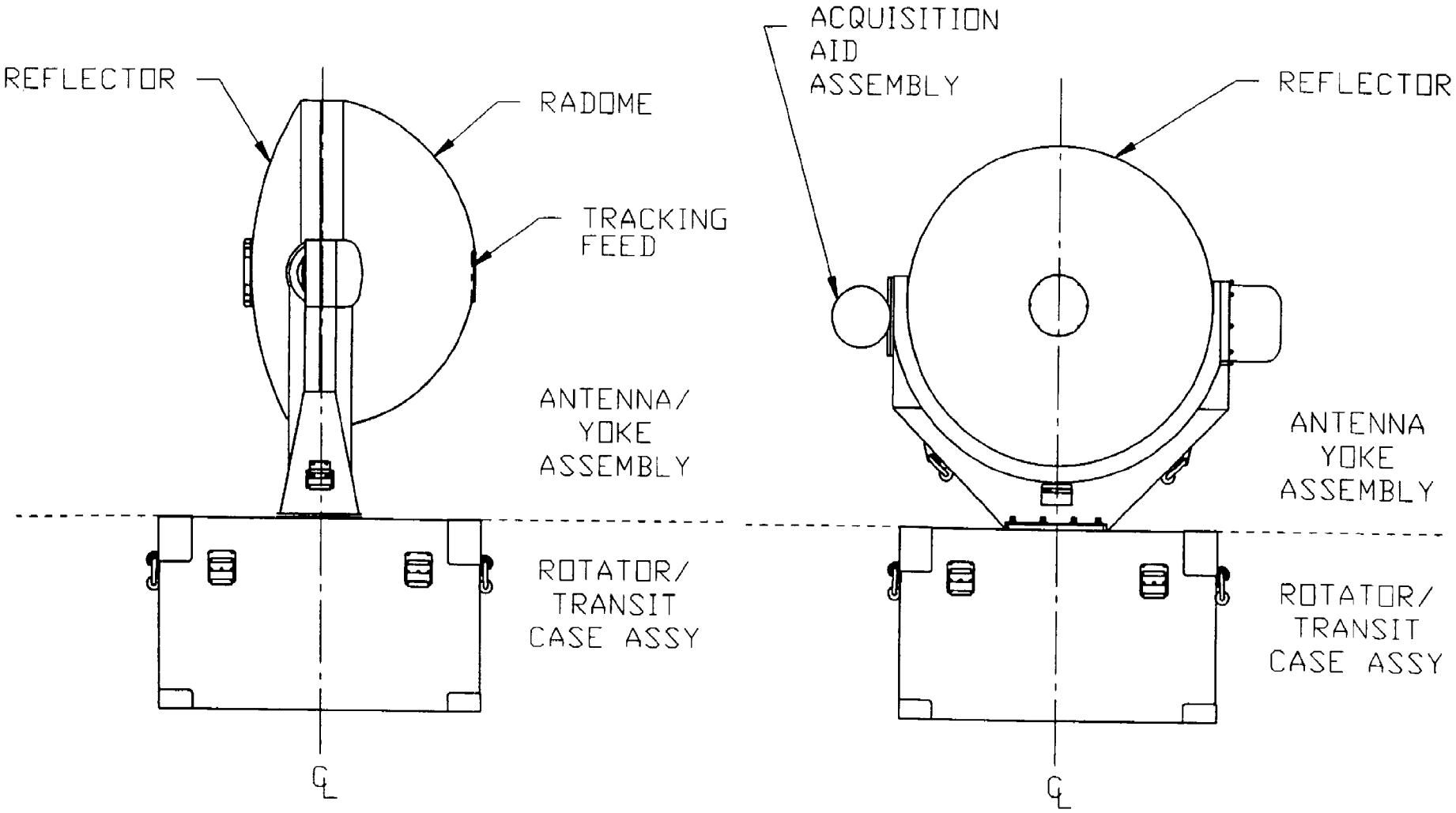

Figure 1: Antenna System Before Modification

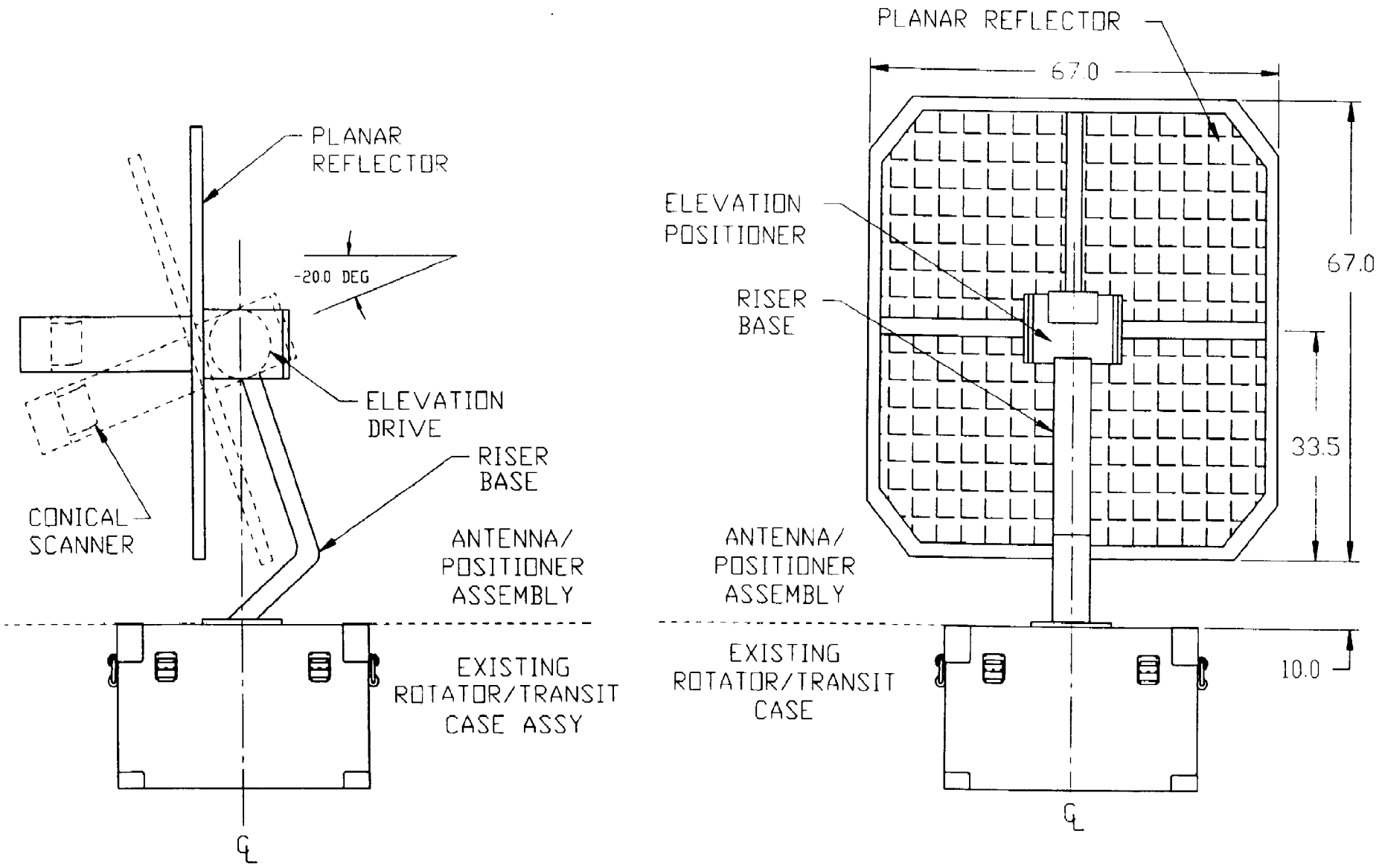

Figure 2: Antenna System Following Modification

Table 1: Antenna Performance Specifications

Performance Parameter		Specification	
		Before	After
Feed Type		quadrascan	conical scanner
Reflector Size		39" (1.0 meter)	67"x 67"(1.7m)
Operating Frequency		2200-2300 MHz	
Polarization		simultaneous vertical and horizontal	
Antenna Gain (@ LNA)	2200 MHz	≥ 20.5 dBi	≥ 26.5 dBi
	2250 MHz	≥ 20.5 dBi	≥ 27.4 dBi
	2300 MHz	≥ 20.5 dBi	≥ 26.5 dBi
Crossover Loss		.20-.50 dB	.20-.30 dB
Antenna Beamwidth (nominal)	2200 MHz	9.0°	6.5°
	2300 MHz	9.0°	6.5°
Sidelobe		≤ -18 dB peak ≤ -15 dB average	≤ -18 dB
Cross Polarization (on axis)		≤ -20 dB	
G/T	2200 MHz	≥ -3.1 dB/K°	≥ 4.5 dB/K°
	2250 MHz	≥ -3.5 dB/K°	≥ 5.4 dB/K°
	2300 MHz	≥ -2.8 dB/K°	≥ 4.5 dB/K°

Pedestal (Elevation-Over-Azimuth)		Specification
Angular Travel	Azimuth	continuous
	Elevation	-20° to +120°
Angular Velocity	Azimuth	≥ 20°/sec
	Elevation	≥ 20°/sec
Angular Acceleration	Azimuth	≥ 30°/sec^2
	Elevation	≥ 30°/sec^2
Overshoot	Azimuth	< 10%
	Elevation	< 10%
Wind	Operational	≥ 75 knots
	Non-Operational	≥ 100 knots
Weight	FLAPS Reflector	30 lbs
	Conical Assembly	20 lbs

ANTENNA ASSEMBLY

FLAPS Reflector. The FLAPS reflector concept is based on the premise that a geometrically flat surface can be designed to behave electromagnetically as though it were a parabolic reflector. This effect is achieved by introducing an appropriate phase shift at discrete locations on the flat surface as shown in figure 3. A typical implementation of the concept consists of an array of dipole scatterers positioned above a ground plane. Incident RF energy causes a standing wave to be set up between the dipole and the ground plane. The dipole itself possesses an RF reactance which is a function of its length and thickness. This combination of standing-wave and dipole reactance causes the incident RF energy to be reradiated with a phase shift which is controllable through variation of the dipole parameters. The exact value of this phase shift is a function of the dipole length, thickness, its distance from the ground plane, the dielectric constant of the intervening layer and the angle of incidence of the RF energy. Typical dipole lengths vary over the range of 1/4 to ½ of a wavelength and ground plane spacings are set between 1/16 and 1/8 of a wavelength.

Current implementations of this type of technology are limited to frequency bandwidths in the order of 8 to 10%. This is more than adequate for the current application and the specification for a FLAPS reflector operating in the 2200-2300 MHZ frequency band are listed in table 2. Ongoing research indicates that operational frequency bandwidths in excess of 25% are achievable with the incorporation of minor modifications in the basic FLAPS design.

The actual FLAPS reflector chosen for this application consists of an aluminum frame supporting a high strength Kevlar string grid with dipole elements located at chosen intersections. The frame is fabricated of 1.75" diameter thin wall aluminum tubing with maximum dimensions of 33.5" x 33.5" x 1.75" and with a total weight of 30 lbs. It is designed as four separate subframes hinged together to allow folding of the reflector assembly into a 33.5" x 33.5" x 8.5" package for ease of storage and transportation. The reflector is shown in Figures 4 and 5.

The Kevlar strings are strung inside the four frames and are interwoven in the style of a tennis racket to provide rigid support for the dipole elements. This type of structure is very strong and dimensionally stable over a wide range of temperatures and wind velocities. It can operate in winds in excess of 110 knots and survive exposure to winds in excess of 170 knots. Its wind load coefficients are much smaller than those of a conventional solid or mesh reflector of the same size and it experiences wind load forces 1/8 to 1/6 the magnitude of those associated with the parabolic units. This characteristic is a direct result of the use of low profile resonant dipole elements located approximately ½ wavelength from each other and mounted on thin wires. In

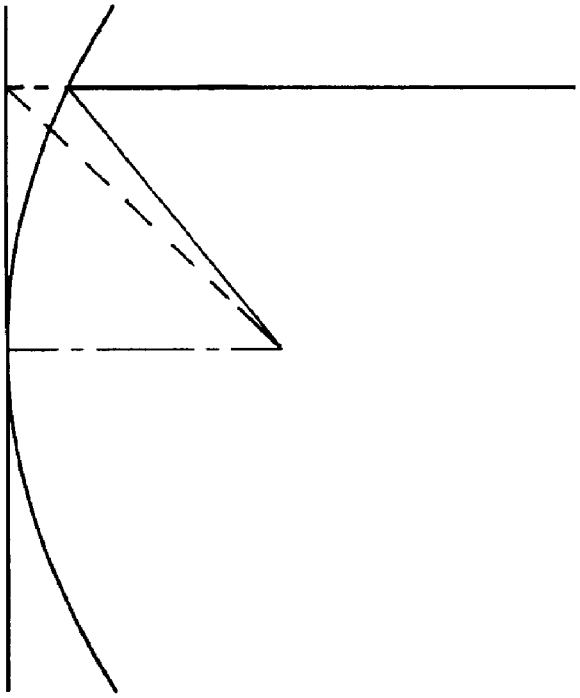

Figure 3: FLAPS Reflector vs. Parabolic Reflector

Table 2: FLAPS Reflector Specifications

Parameter		Specification
Reflector Size	Deployed	67" x 67"
	Folded	33.5" x 33.5" x 8.5"
Reflector Weight		≤ 30 lbs
Operating Frequency		2200 - 2300 MHz
Antenna Gain (Aperture)	2200 MHz	≥ 27.5 dBi
	2250 MHz	≥ 28.4 dBi
	2300 MHz	≥ 27.5 dBi
Antenna Beamwidth	2200 MHz	6.5° ± 0.5°
	2300 MHz	6.5° ± 0.5°
Sidelobes		≤ -18 dB

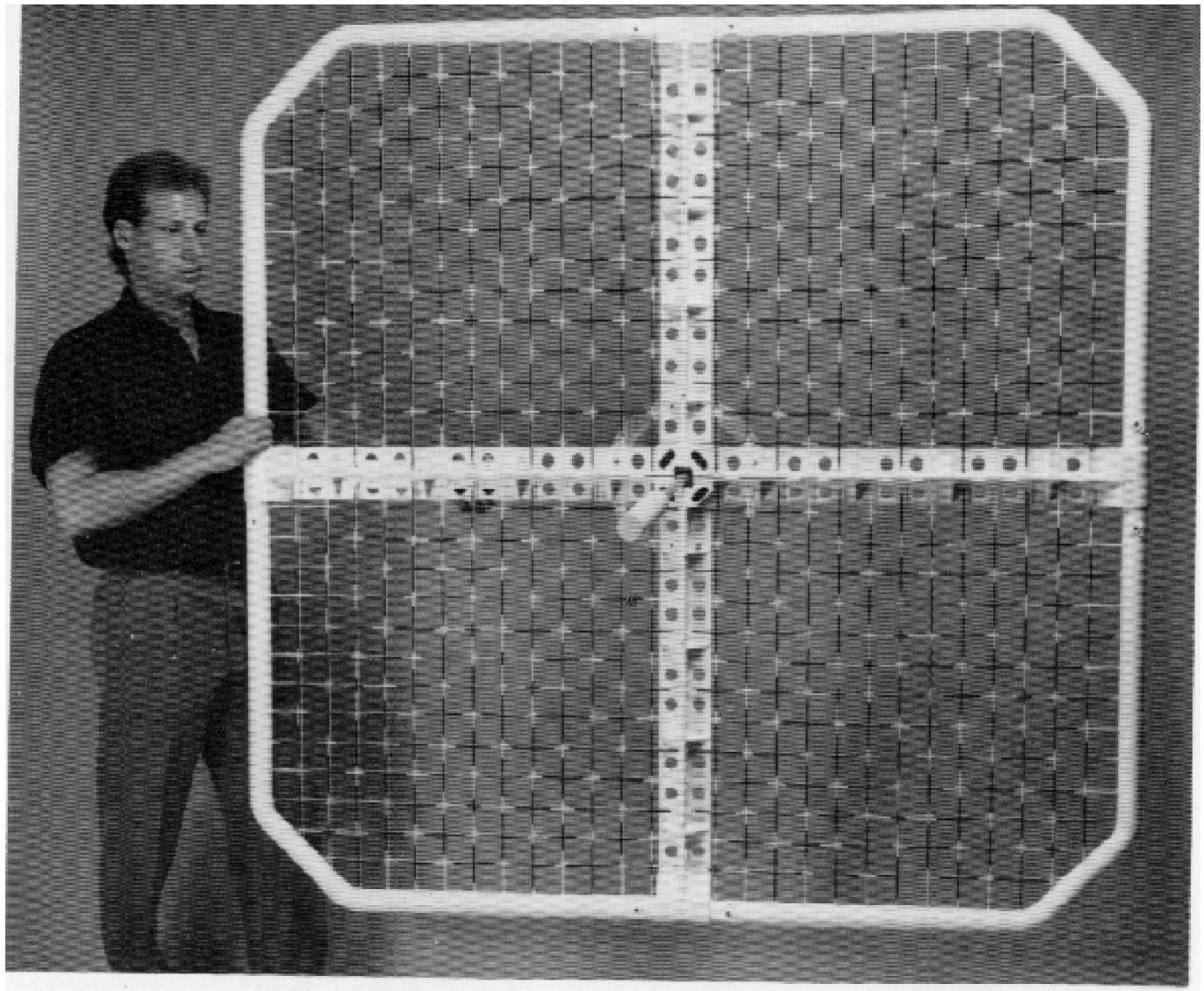

Figure 4: FLAPS Reflector (Front View)

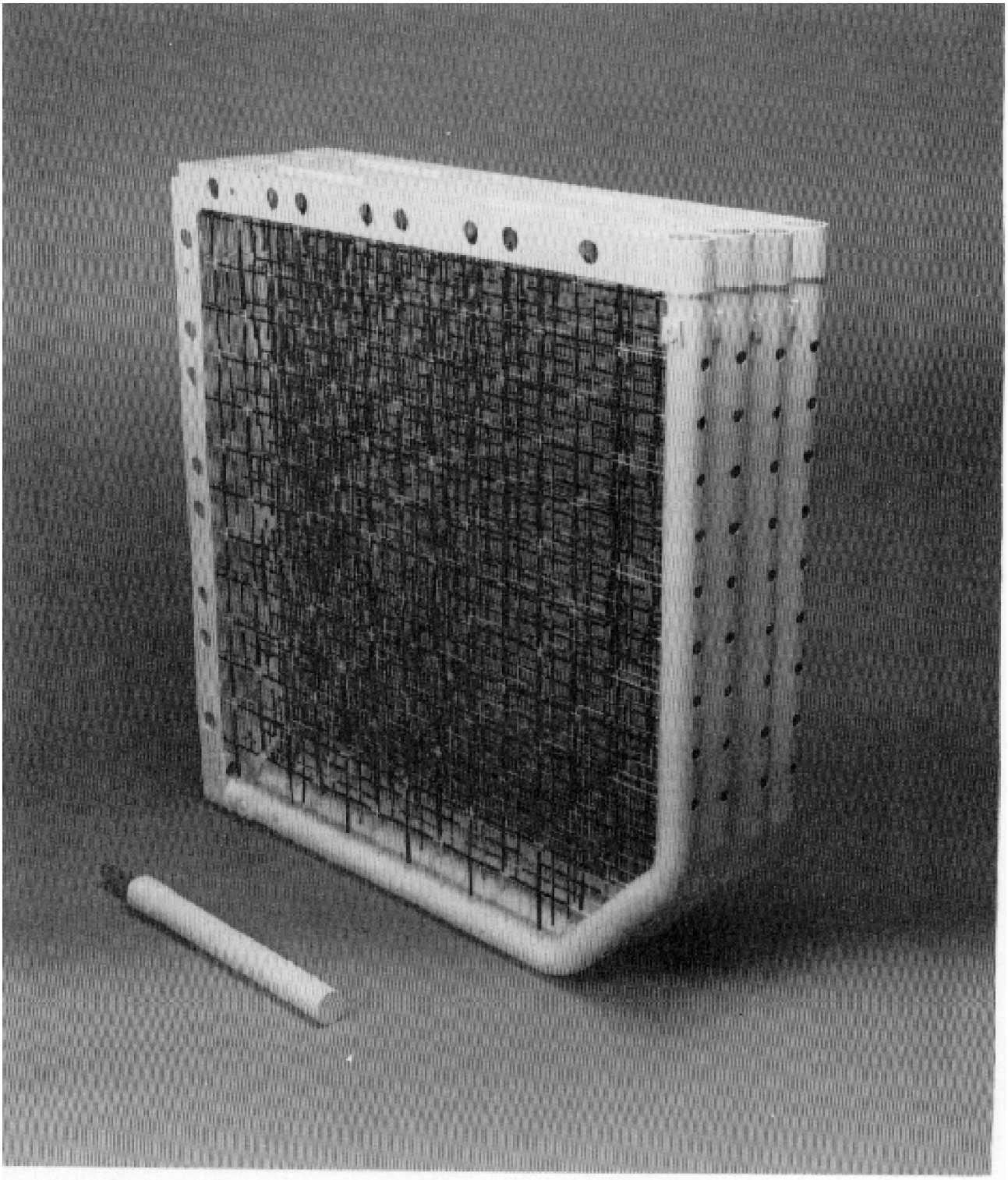

FIGURE 5: FLAPS REFLECTOR (TRANSPORT CONFIGURATION)

contrast, the conventional mesh type reflector requires a wire grid with openings no larger than 1/16 to 1/20 of a wavelength.

Conical Scanner. The conical scanner is a light weight version of the unit described in reference [2]. It is a new implementation of the well known conical scanner technology currently in use in a large number of telemetry tracking antenna systems.

The DECS conical scanner operates as a conventional conical scanner with a rotating aperture but its design is significantly different. It is centered about a stationary coaxial-to-cylindrical waveguide adapter and a rotating radiating aperture which is essentially limited to the offset section of the waveguide. This is in sharp contrast to the design of a typical conical scanner in which the rotating assembly includes not only the offset aperture but the nonoffset cylindrical waveguide, the RF choke section and the drive shaft.

The major subassemblies of the DECS conical scanner used in the current application are the coaxial-to-waveguide adapter and the radiating aperture. The coaxial-to-waveguide adapter consists of a stationary waveguide section fed by a pair of crossed dipoles at one end and fitted with an RF choke section at the other end. The diameter of the waveguide section is selected to keep the TE11 mode cutoff frequency below the lowest frequency of operation and its length is approximately 4". The crossed dipoles are optimized for the 2200 to 2300 MHZ frequency band and their base is hard wired to the waveguide end plate. The RF choke section uses well behaved loaded sections of coaxial lines to present a modulation free impedance at the interface gap between the waveguide adapter and the radiating aperture. It is interesting to note that, with this design, residual amplitude modulation is non existent. This type of modulation, traceable to modulation of the dipole input impedance, is generally caused by any asymmetry in the rotating conical scanner structure or in the RF coke section.

The radiating aperture consists of an offset horn assembly and a drive mechanism. The horn assembly is designed to provide a perfect match for the waveguide-to-cylindrical waveguide adapter and to illuminate the reflector in such a way as to produce an offset secondary beam with a cross over loss of approximately .20 to .30 dB. The waveguide section of the horn is a thin wall electroplated cylinder encased in an ultra lightweight honeycomb support structure. The entire rotating mass is supported on a pair of precision bearings and is capable of sustained operation in harsh environmental conditions. The rotating horn is driven by a hollow shaft brushless DC motor powered by a pulse width modulation amplifier which allows accurate control of the motor velocity over a wide temperature range.

Accurate determination of the horn position is performed by an optical encoder mounted behind the DC motor. The encoder generates the two +/- 15 volts square wave reference signals used by the demodulator to extract the azimuth and elevation error signals needed for autotrack operation. The frequency of these signals is dictated by the speed of rotation of the scanner. The reference generator is also designed to allow fine electrical adjustment of the feed tracking axes to minimize crosstalk.

The total insertion loss in this feed from the antenna aperture to the preamplifier is 0.75 dB. This value is at least 2.0 dB lower than that achievable with the current quadrascan feed.

PEDESTAL ASSEMBLY

Existing Pedestal Assembly. The existing pedestal assembly is configured as an elevation-over-azimuth unit with an elevation yoke supporting the antenna assembly. The pedestal uses identical gear motors and gear trains for each axis and the basic specifications for these units are listed in Table 5. Of special interest for this modification are drive train gear ratios, continuous and peak torque values and azimuth axis capacity to resist overturning forces. The gear reduction ratio for either drive train is 2,670:1; this value yields a maximum theoretical azimuth or elevation velocity of 26 to 31°/sec. Actual measured values are in the 23 to 26°/sec range. Similarly, the maximum continuous theoretical torque is of the order of 75 ft-lbs and the actual measured value is 80 ft-lbs. The maximum overturning moment which can be borne by the turn table/torque tube assembly in the azimuth axis is unknown but calculations show that, in its original configuration, the maximum overturning moment experienced in 100 knot winds is approximately 200 ft-lbs. This is approximately 15% of the overturning moment the system would experience with a 60" parabolic mesh reflector.

The torque available exceeds the 50 ft-lbs torque required to rotate the 39" reflector at 20°/sec in 75 knot winds. It is sufficient to perform this task in winds in excess of 90 knots but is only 15% of the value which would be required if a 60" reflector was used.

Modified Pedestal Assembly. The design for the modified pedestal assembly retains the azimuth rotator in its existing configuration but uses a repackaged version of the elevation rotator to be mounted on a new riser base. The riser base is a 48" tall lightweight aluminum weldment fitted at one end with an adapter plate designed to mate with the existing turntable on the azimuth rotator. The riser base is shaped to provide clearance for the -20° elevation motion of the FLAPS reflector.

The elevation rotator assembly is welded to the top end of the riser base and it uses the same DC gear motor with gear train, data pack assembly and limit switch assembly as in the current elevation rotator assembly. The design includes short yoke arms attached to each end of the drive assembly to support the reflector and provide a mounting surface for the counterweights. The overall dimensions of this assembly are 48" x 16" x 24" and its total weight is 40 lbs.

TABLE 5: DRIVE TRAIN SPECIFICATIONS

Component Parameter				Specification
Gear Motor Assembly	Drive Motor	Motor Rating		1/30 HP
		Torque	Continuous	5.5 ounce-inch
			Nominal Stall	42 ounce-inch
	Gear Box	Torque Rating		100 lb-in (continuous)
		Gear Reduction		445:1
Gear Train Assembly	Pinion Gear			18 teeth
	Bull Gear			108 teeth

PERFORMANCE OF THE MODIFIED MARK 56 PMRA SYSTEM

The data presented in this paper firmly supports the proposition that a minimum gain increase of 6.0 dB is achievable with the antenna modification described. As a result of the technical approach selected, a sizable increase in the figure of merit (G/T) of the MARK 56 PMRA system is also achieved.

With the FLAPS reflector, feed assembly and counterweights mounted on the modified elevation rotator the maximum torque required for operation in 75 knot winds is 50 ft-lbs for the azimuth axis and 35 ft-lbs for the elevation axis. These values are less than the 80 ft-lbs available and the performance of the system will not be affected when this antenna/positioner assembly is substituted for the 39" (1.0 meter) antenna. Similarly, the maximum overturning moment present at the azimuth turntable in 100 knot winds will be 125 ft-lbs; this value is approximately 62% of the moment experienced with the 39" antenna.

CONCLUSION

This technical paper introduces new technology to the field of telemetry tracking systems as part of a performance enhancement program for a system originally designed according to conventional wisdom. The results achievable are not only significant but they are attainable in a cost effective manner. This same technology is ideally suited to be used as the foundation for a family of new designs which answer the need for light weight and/or low cost telemetry tracking systems.

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