). DOT-TSC-NHTSA-73-8

DOT-HS-800968

MODEL 0102 FLAT PLATE ANTENNA FOR USE IN AUTOMOBILE RADAR ANTICIPATORY CRASH SENSORS

Kalman V. Toth and Ronald M. Rudish

SEPTEMBER 1973
FINAL REPORT

Prepared for
DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
OFFICE OF VEHICLE STRUCTURES RESEARCH
Washington DC 20591

Technical Report Documentation Page

1. Report No.: DOT-HS-800968

2. Government Accession No.:

3. Recipient's Catalog No.:

4. Title and Subtitle: MODEL 0102 FLAT PLATE ANTENNA FOR USE IN AUTOMOBILE RADAR ANTICIPATORY CRASH SENSORS

5. Report Date: September 1973

6. Performing Organization Code:

7. Author(s): Kalman V. Toth and Ronald M. Rudish

8. Performing Organization Report No.: DOT-TSC-NHTSA-73-8

9. Performing Organization Name and Address: AIL Division
Cutler Hammer
Deer Park, Long Island NY 11729

10. Work Unit No. (TRAIS): R3403/HS304

11. Contract or Grant No.: DOT-TSC-437

12. Sponsoring Agency Name and Address: Department of Transportation
National Highway Traffic Safety Administration
Office of Vehicle Structures Research
Washington DC 20591

13. Type of Report and Period Covered: Final Report
June-Sept. 1972

14. Sponsoring Agency Code:

15. Supplementary Notes: Report prepared under contract to: U.S. Department of Transportation
Transportation Systems Center
Cambridge MA 02142

16. Abstract

AIL has analyzed alternative methods of construction and production costs for a flat plate antenna based on the use of etched circuit techniques. The antenna is proposed for use in certain new automotive radar anticipatory crash sensor systems now under development.

The antenna is a minimal volume planar array structure, ideally suited for low cost production. Using a design approach that was previously developed for advanced battlefield radars, the antenna is unique in that the radiating elements and feed circuitry are etched on the same substrate.

The antenna is 2-5/8 x 4-5/8 x 15/16 inches (exclusive of output connector). Although its active region is only a fraction of this space, a breadboard version of this highly efficient antenna achieves more than 13-dB gain over the required one percent region of X-band, with radiation patterns having excellent suppression of side lobes.

A production design is postulated which is suitable for automated production processes. The resulting antenna is a simple sandwich of one printed circuit between two layers of foam; this sandwich is encased in a molded, metalized lexan housing, and is faced with a lexan radome.

In quantities of at least one million antennas, the estimated OEM selling price is under 3 dollars each, not including the cost of preparing for large-scale production. In quantities in excess of ten million antennas, the estimated selling price is under 2 dollars each, also not including the cost of preparing for large-scale production.

17. Key Words: Flat Plate Antenna, automobile radar anticipatory crash sensors

18. Distribution Statement: DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	36	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The work described in this report was performed in the context of an overall program at the Transportation Systems Center to evaluate anticipatory crash sensor concepts as applied to activation of automobile passive restraint systems. This report specifically examines the fabrication techniques and high-production-volume costs for antennas associated with a radar crash sensor. The program is sponsored by the National Highway Traffic Safety Administration, Office of Vehicle Structures Research, Department of Transportation. This program supports Government activities designed to promote greater safety on the nations highways and reduce injury and fatalities in traffic accidents.

We are grateful for the assistance provided by the AIL Division of Cutler-Hammer, Deer Park, N.Y., who conducted these studies.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

Under contract to the Department of Transportation (Number DOT-TSC-437), AIL has analyzed production costs for a flat plate antenna constructed using etched circuit techniques. The antenna is proposed for use in certain new automobile radar anticipatory crash sensor systems now under development.

The intended application requires the antenna to radiate a fan-shaped beam with half power width of 40 ± 5 degrees in the E-plane and 25 ± 3 degrees in the H-plane. The peak gain is required to be at least 10 dBi. In addition, it is required that the side lobes be suppressed by at least 12 dB and that the VSWR (at the coaxial connector input) be less than 1.5 over a 50-MHz frequency band centered about 10.525 GHz. To facilitate installation of the antenna in the front grill area of an automobile (near the headlamps), the antenna should be unobtrusively packaged with integral mounting and pointing adjustment provisions. In particular, a flat plate that is less than 20 square inches in area and 1/2 inch thick was suggested by the Department of Transportation as a viable form factor.

These requirements can be met by use of an unusually cost-effective design approach, one demonstrated by a family of printed circuit antennas of various sizes previously built by AIL in connection with an IR&D program. A notable outgrowth of this program was a large printed circuit array intended for use in an advanced battlefield radar; the large array later served as a design prototype for flat plate antennas delivered to the Department of Transportation (Contract Number DOT-TSC-376) for use in certain new railroad grade crossing protective systems.

All of the printed circuit antennas in this family, both large and small, are unique in the manner in which both the radiating elements and their feed circuitry can be etched on the same ultrathin substrate without mutual interference. This permits fabrication of an array of greater than 100 square wavelengths in extent by a single etching operation; it limits assembly operation to the making of connections at a single pair of terminals and the subsequent stacking and sealing of the active sheet, packing fillers, and protective closures. Furthermore, this constructional simplicity does not restrict performance capability. Quite to the contrary, the approach is elegant in that force-feed principles are used to guarantee a specific amplitude taper for suppression of side-lobe responses. The key to the AIL approach is the geometry of the etched conductors. AIL has applied for patents on this proprietary approach.

One of the smaller members of this printed circuit family is shown in breadboard form in Figure 1-1. It is an etched copper-clad sheet of irradiated polyolefin sandwiched between layers of foam and backed by a metallic reflector. Its H-plane and E-plane radiation patterns at 10.5 GHz are shown in Figures 1-2 and 1-3, respectively. Its measured gain at this frequency is 13.5 dBi and its VSWR is 1.6. As may be noted, this breadboard antenna performs nearly as is required for the automotive application. Minor perturbation of appropriate dimensions would allow adjustment of beam widths and improvement of VSWR. Thus, this antenna was chosen as the base line approach for tradeoff studies to determine a mechanical design suitable for large-scale production.

This technical report endeavors to describe the recommended method of construction and to present an analysis of production costs for quantities of 1 million and 10 million antennas yearly.

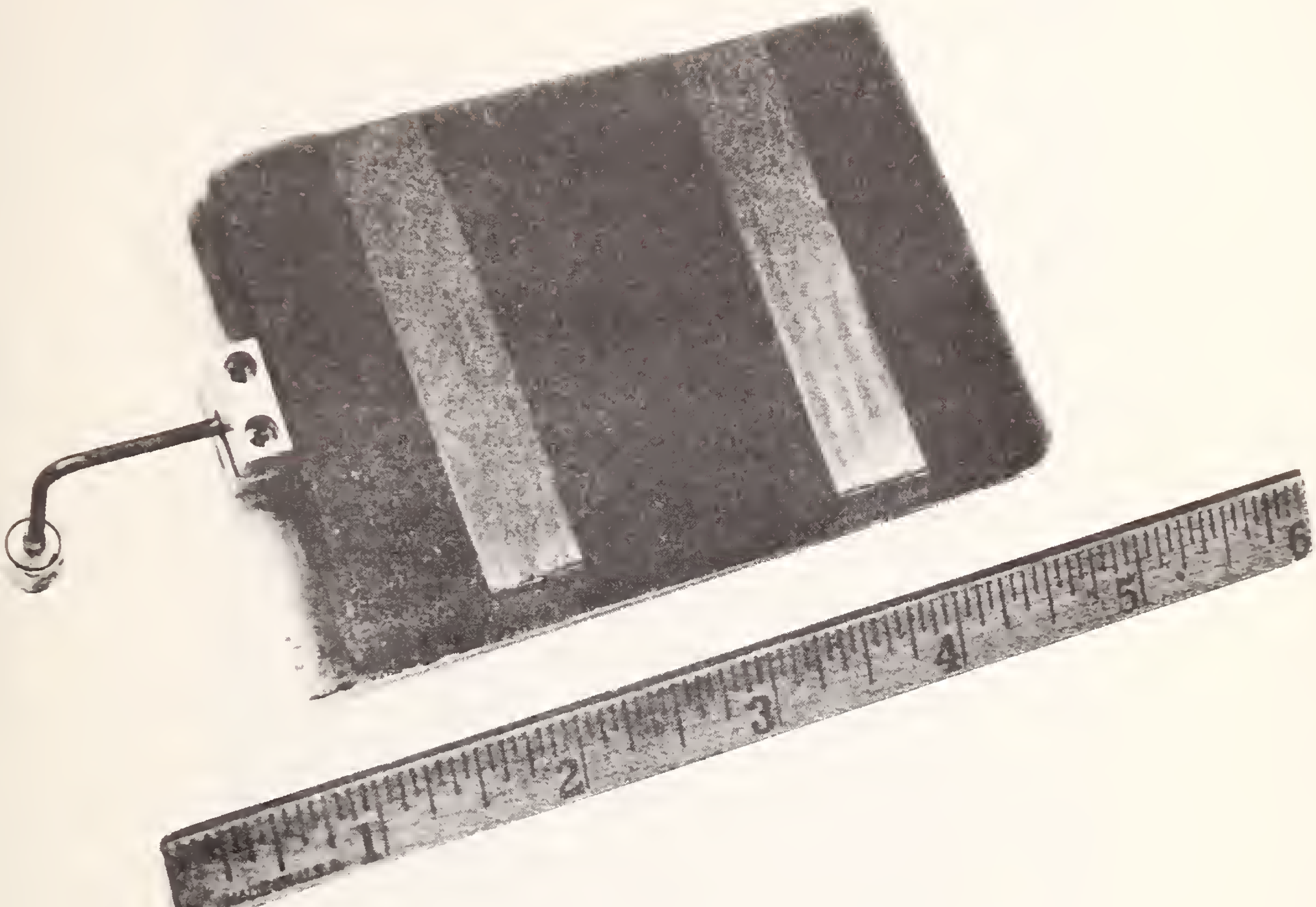

FIGURE 1-1. BREADBOARD ANTENNA

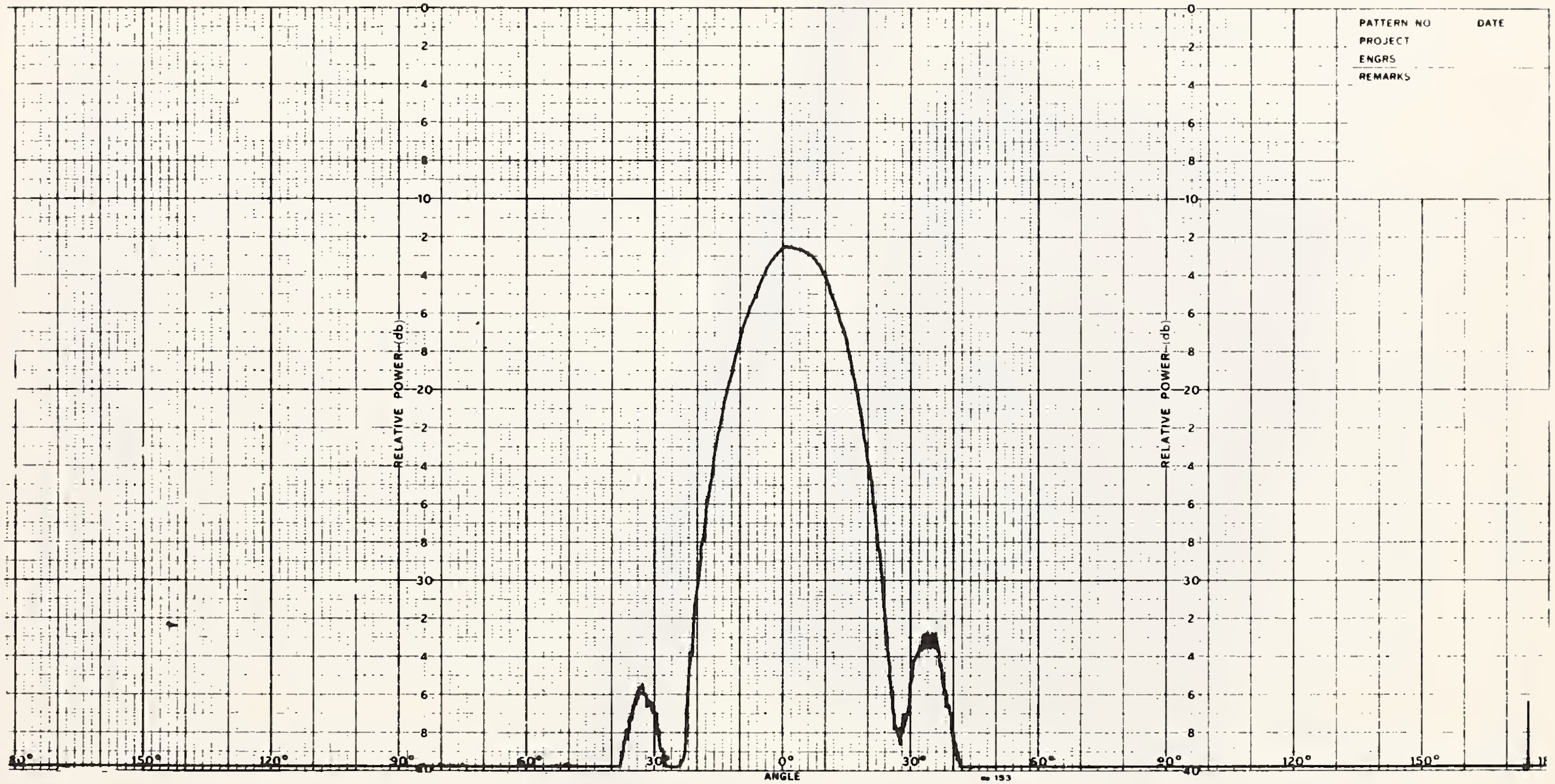

FIGURE 1-2. RADIATION PATTERN OF BREADBOARD ANTENNA--H-PLANE, 10. 5 GHz

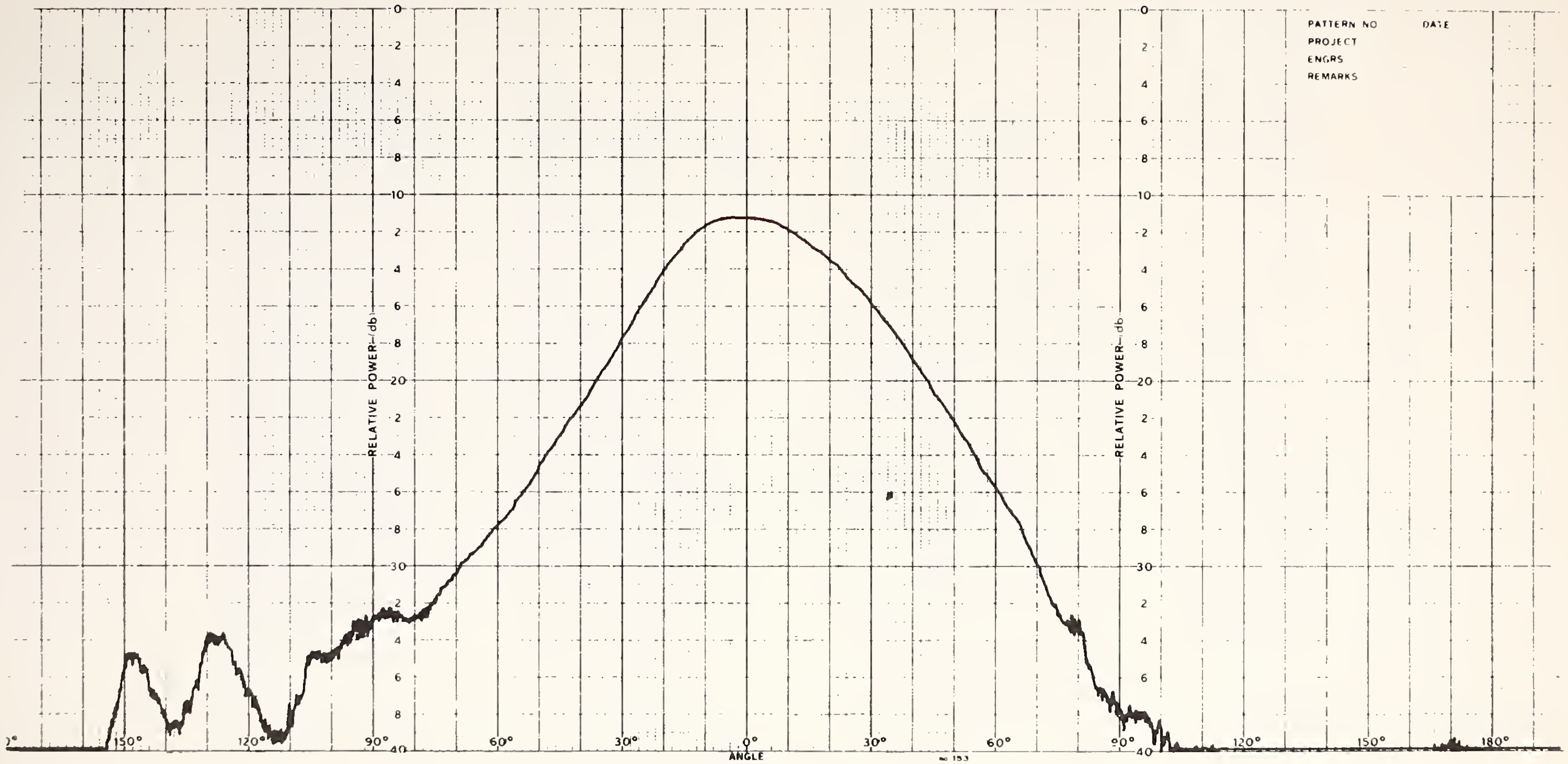

FIGURE 1-3. RADIATION PATTERN OF BREADBOARD ANTENNA--E-PLANE, 10.5 GHz

II. DESCRIPTION

The mechanical design of the antenna should be appropriate for extensive use of automated processes and high-volume tooling in production. AIL studied many alternative mechanical designs and methods of antenna construction. Based upon this study, a mechanical design is described below. The design is shown in Figure 2-1.

The active portion of the antenna, an etched copper-clad sheet of dielectric material, is sandwiched between two layers of polyurethane foam. This entire assembly, upper foam, printed circuit, and lower foam, fits in a molded, metalized lexan (polycarbonate resin) housing. This housing will provide the ground plane, locking provisions for the connector, and mounting pads. The front of the subassembly is closed by a protective radome consisting of approximately 5/16 inch thick lexan bonded to the housing. This radome will provide a weather-tight seal and provide protection against flying road debris and vandalism. A description of each item that constitutes an assembly follows.

A. ANTENNA HOUSING

Figure 2-2 shows the antenna housing. The housing will be molded of a black-pigmented lexan. The rear wall of the housing will be metalized to form a reflective ground plane. It will provide mounting pads, locking provisions for the connector, and solid protection from the rear against road hazards, weather and vandalism. The side walls (perimeter) will be an integral part of the housing. Nameplate type information can be molded to the back of the housing.

Joining the housing and the radome will be accomplished by ultrasonic welding. This process takes only 1 or 2 seconds and the parts may be handled for further processing almost immediately after they are joined. The bonding operation can be easily automated; required would be an ultrasonic energy source, a properly designed horn and holding fixture, a nesting fixture to localize the energy, a timer, a pressure applicator, and an alignment fixture. Ultrasonic welding can provide joint strength equal to that of the resin.

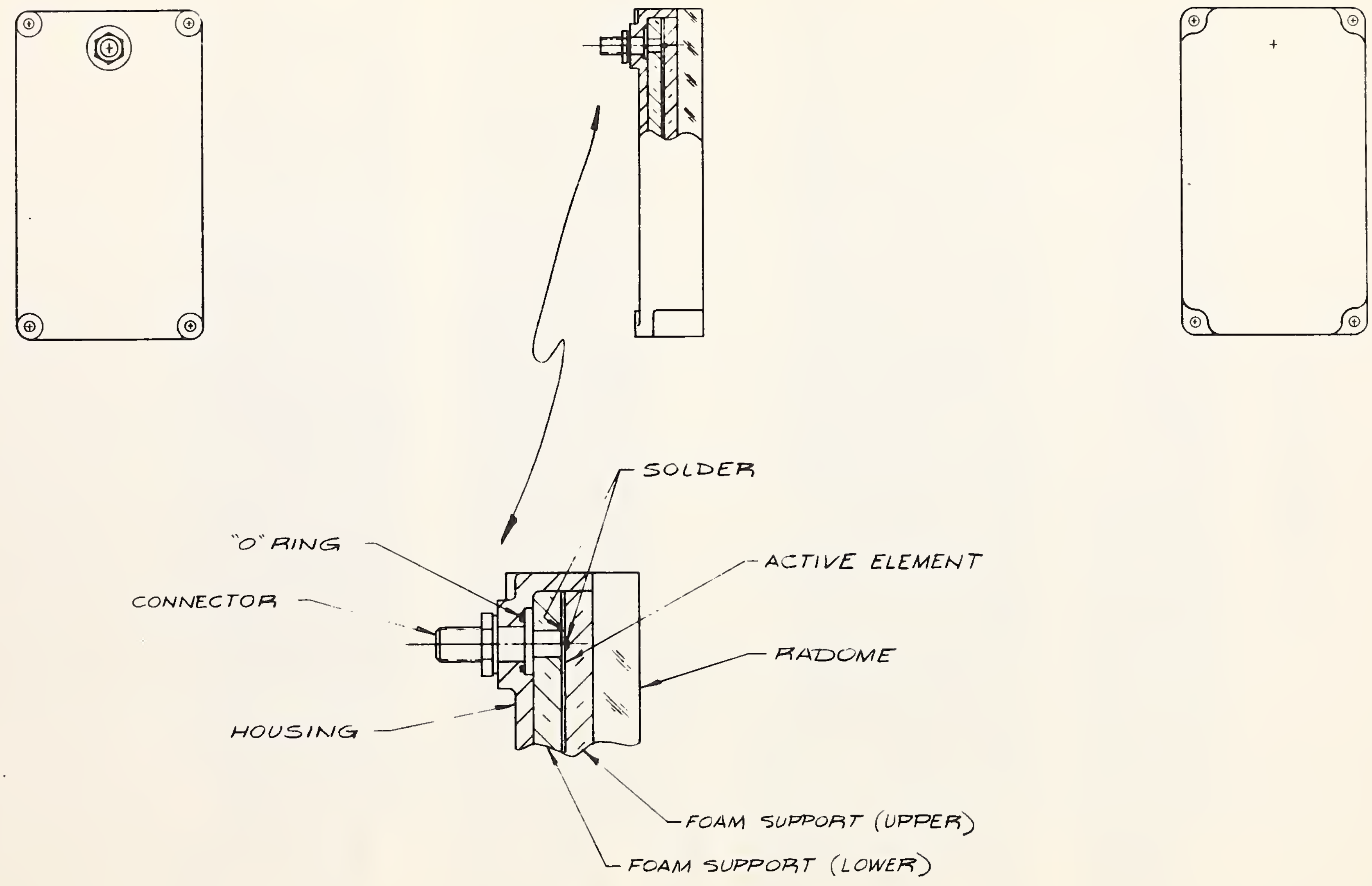

FIGURE 2-1. ANTENNA CONSTRUCTION

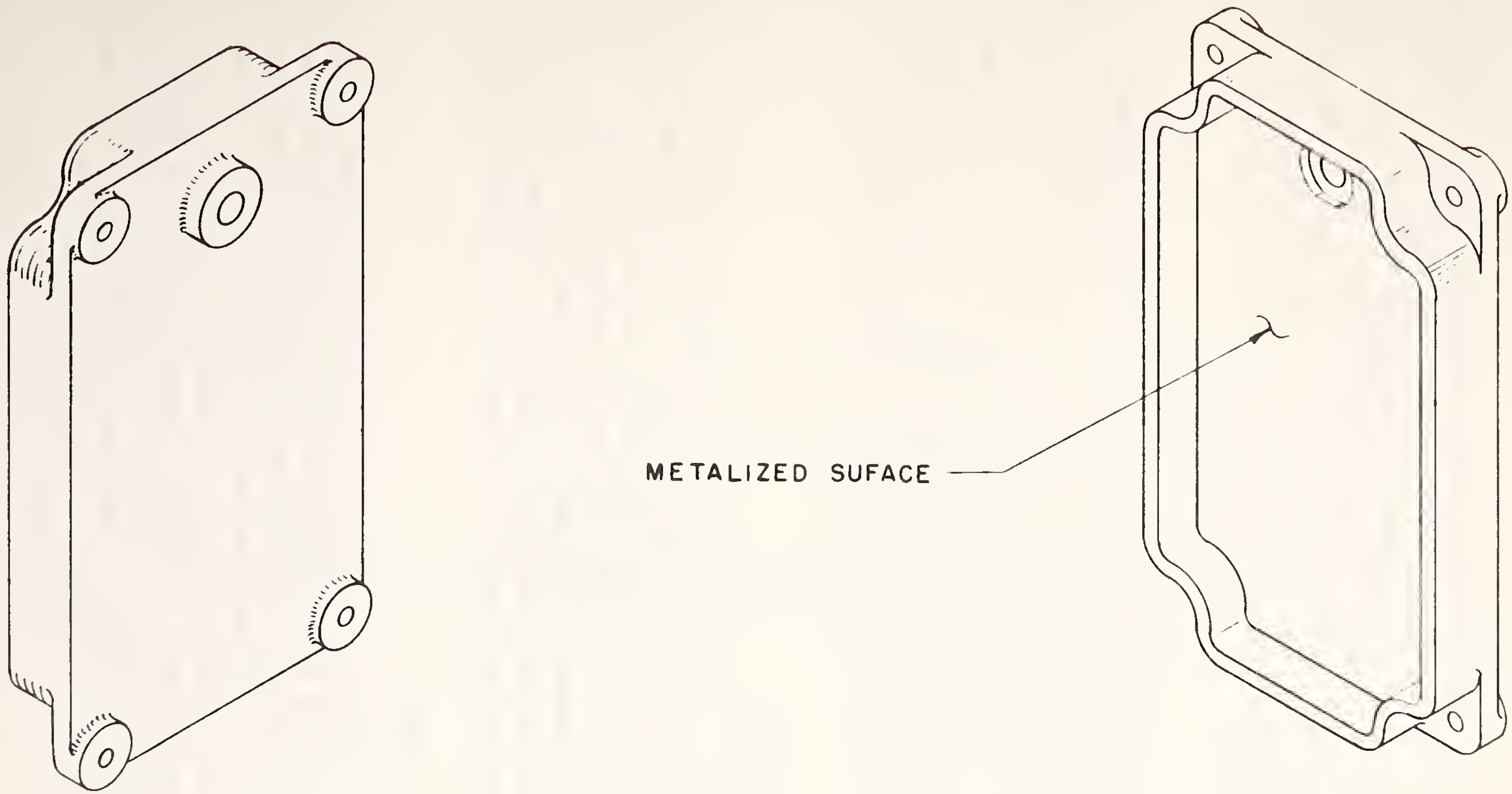

FIGURE 2-2. ANTENNA HOUSING

B. RADOME

The radome is a resonant window made of molded, nonpigmented lexan (Figure 2-3). Mechanically, lexan is a tough thermoplastic, with excellent high temperature performance, dimensional stability, outstanding impact strength, and self-extinguishing characteristics. A lexan radome will give excellent protection against weather, flying pebbles, road debris, and vandalism. The outer surface of the radome will be molded with a textured finish to render the radome opaque and to preserve an aesthetic appearance after exposure to flying road debris.

This radome has better than 95-percent power transmission when properly tuned. The latter condition occurs when the radome is 0.330 inch (one-half wavelength) thick assuming no interaction between the radome and the printed circuit array. Interaction can either be avoided by spacing the two sufficiently far apart (at least one-half inch) or it can be taken into account as a perturbation of the thickness value which produces radome resonance. Tolerances on average thickness of the radome are ±0.015 and on random variations from the nominal average thickness are ±0.025. Average thickness values outside of this tolerance range may be used if the impedance level of the antenna is suitably adjusted.

C. ACTIVE ELEMENT

The active element (Figure 2-4) is an etched copper-clad sheet of thin mylar with 1-ounce copper on both sides. The actual geometry of the etched conductors is proprietary information; therefore, a full description or pictorial illustration is omitted. The board is approximately 4 × 2-3/8 inches. The unique geometry is etched on both sides of the board and has an input requiring one solder connection. Approximately 80 percent of the copper is etched away on both sides of the board in forming the circuitry.

D. SUPPORTS (FOAM)

The foam supports (Figures 2-5 and 2-6) are made of polyurethane foam of two pound density and are approximately 1/4 inch thick. The supports are used to sandwich the active element between the metal ground plane and the radome. This is an inexpensive and a highly effective method of supporting, spacing and insulating the active element. The material is readily die punched, like sheet metal. Installation procedure for the support foam is simple; no special orientation or alignment is necessary. The cutout for the lower support is a noncritical, generous-clearance opening to permit the passage of the conductor.

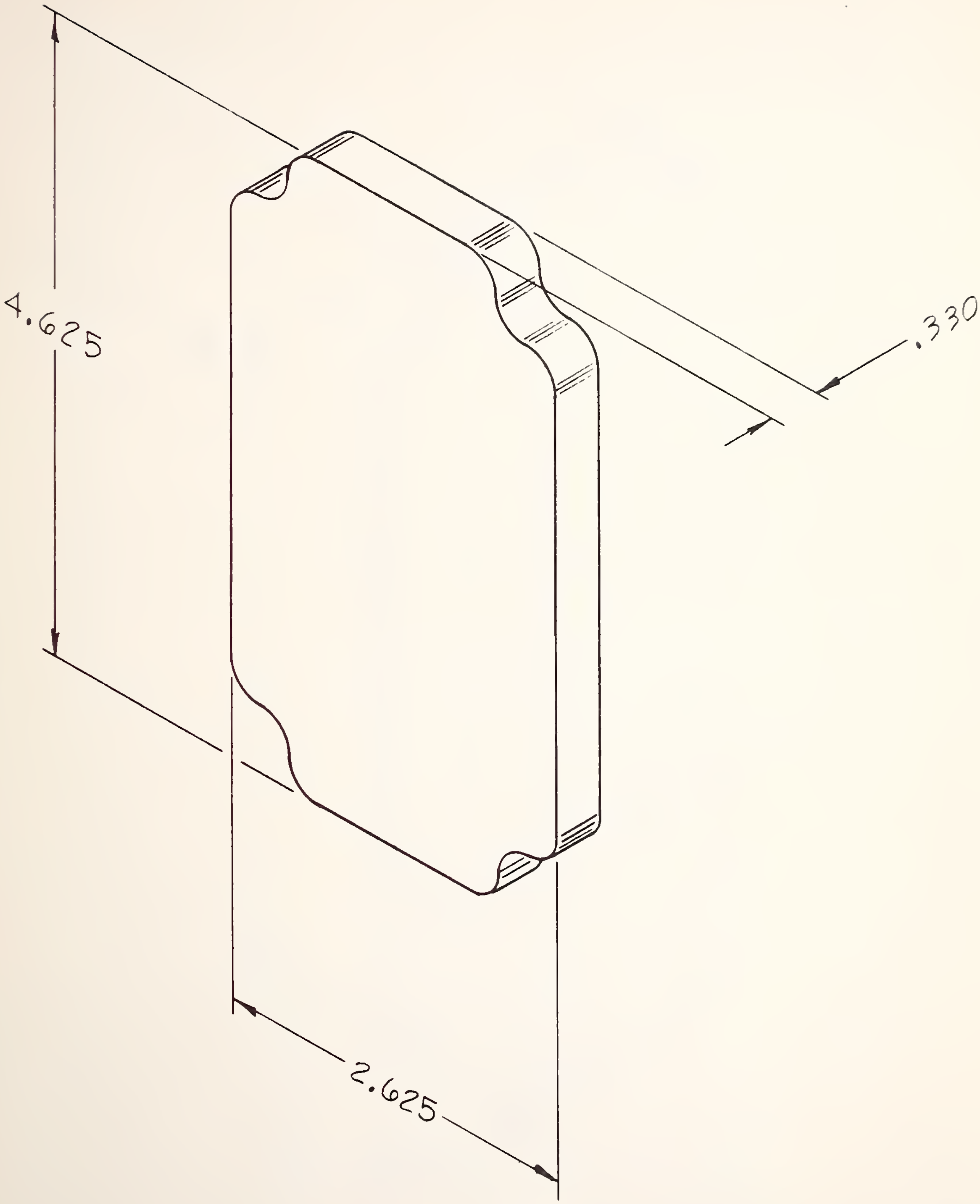

FIGURE 2-3. RADOME

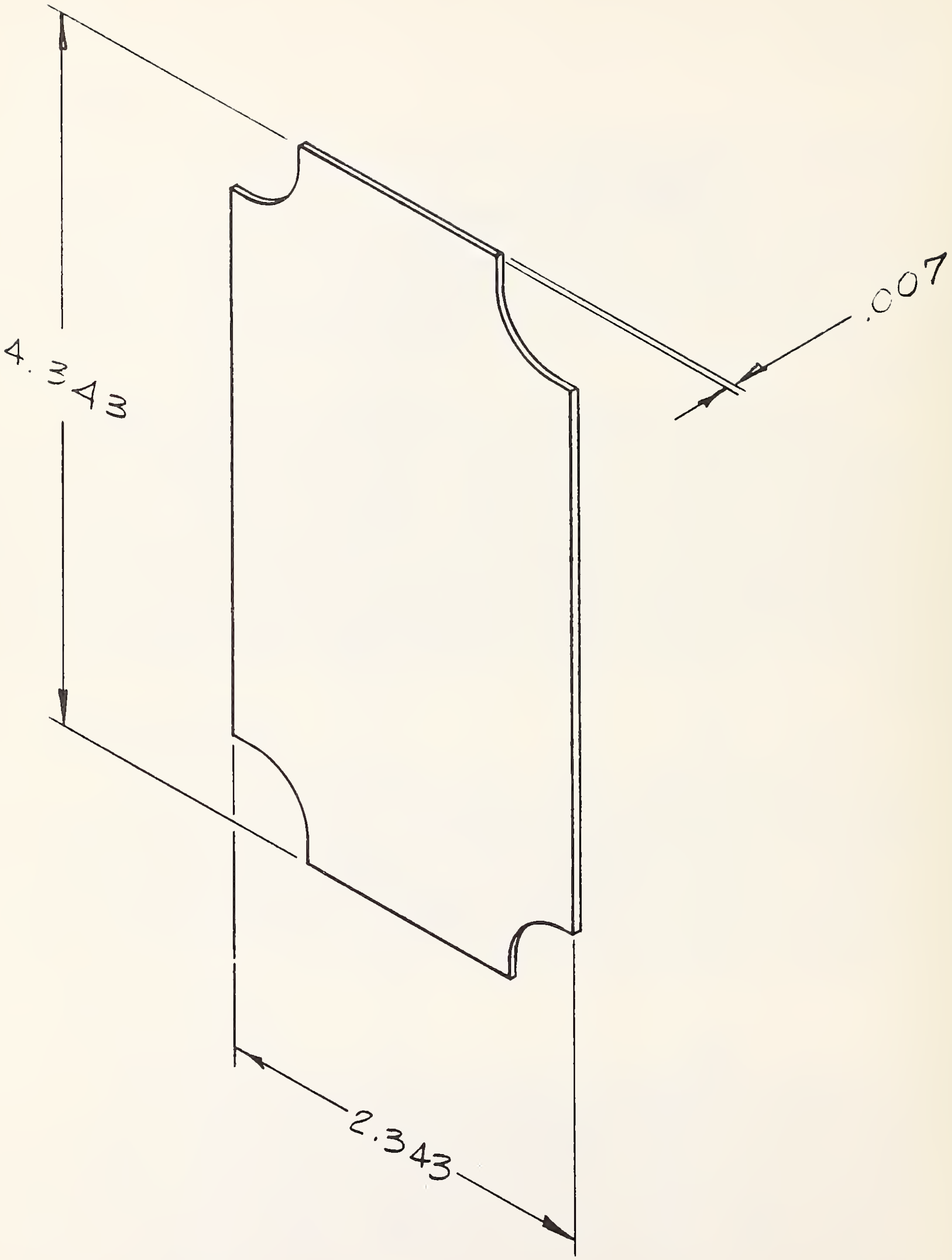

FIGURE 2-4. ACTIVE ELEMENT

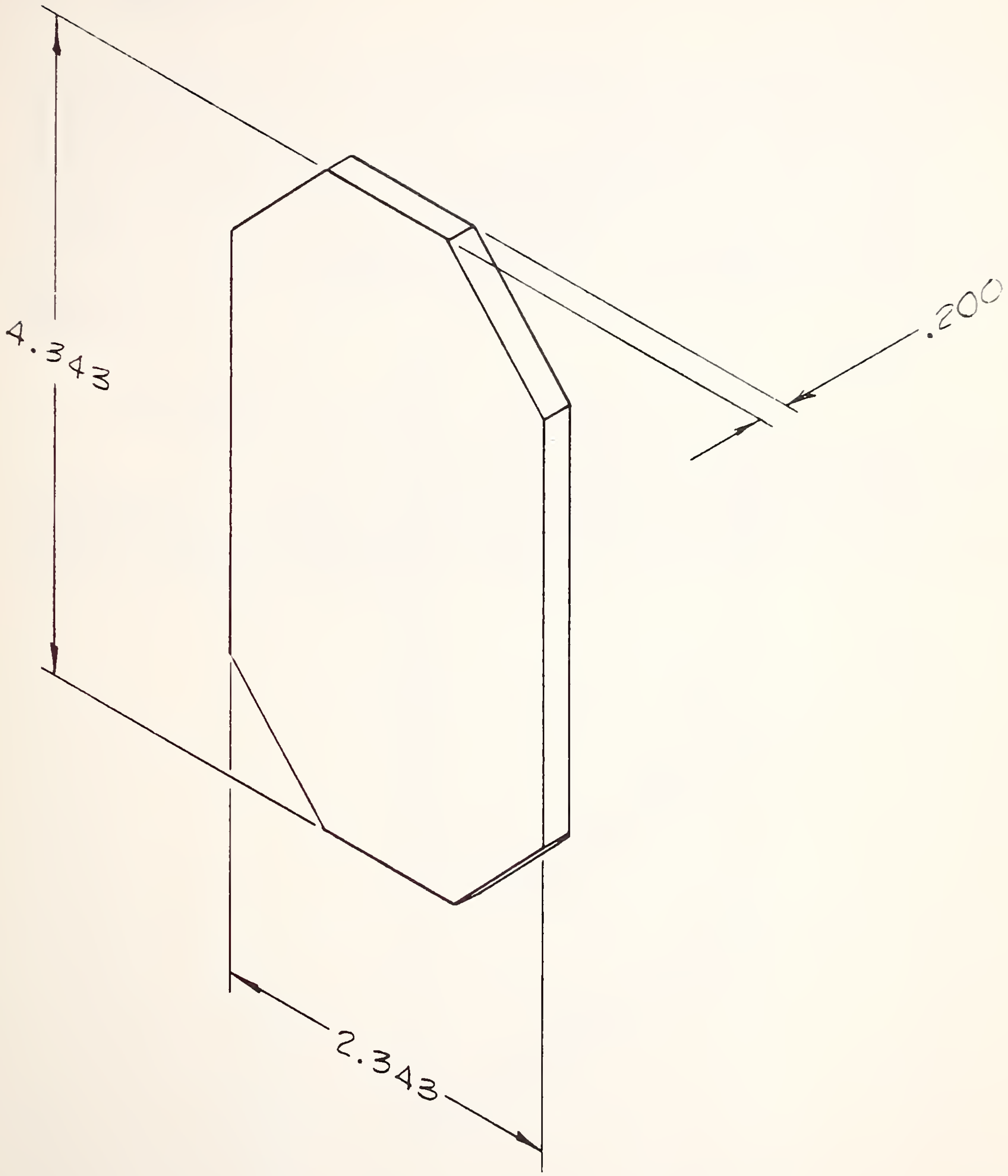

FIGURE 2-5. UPPER SUPPORT

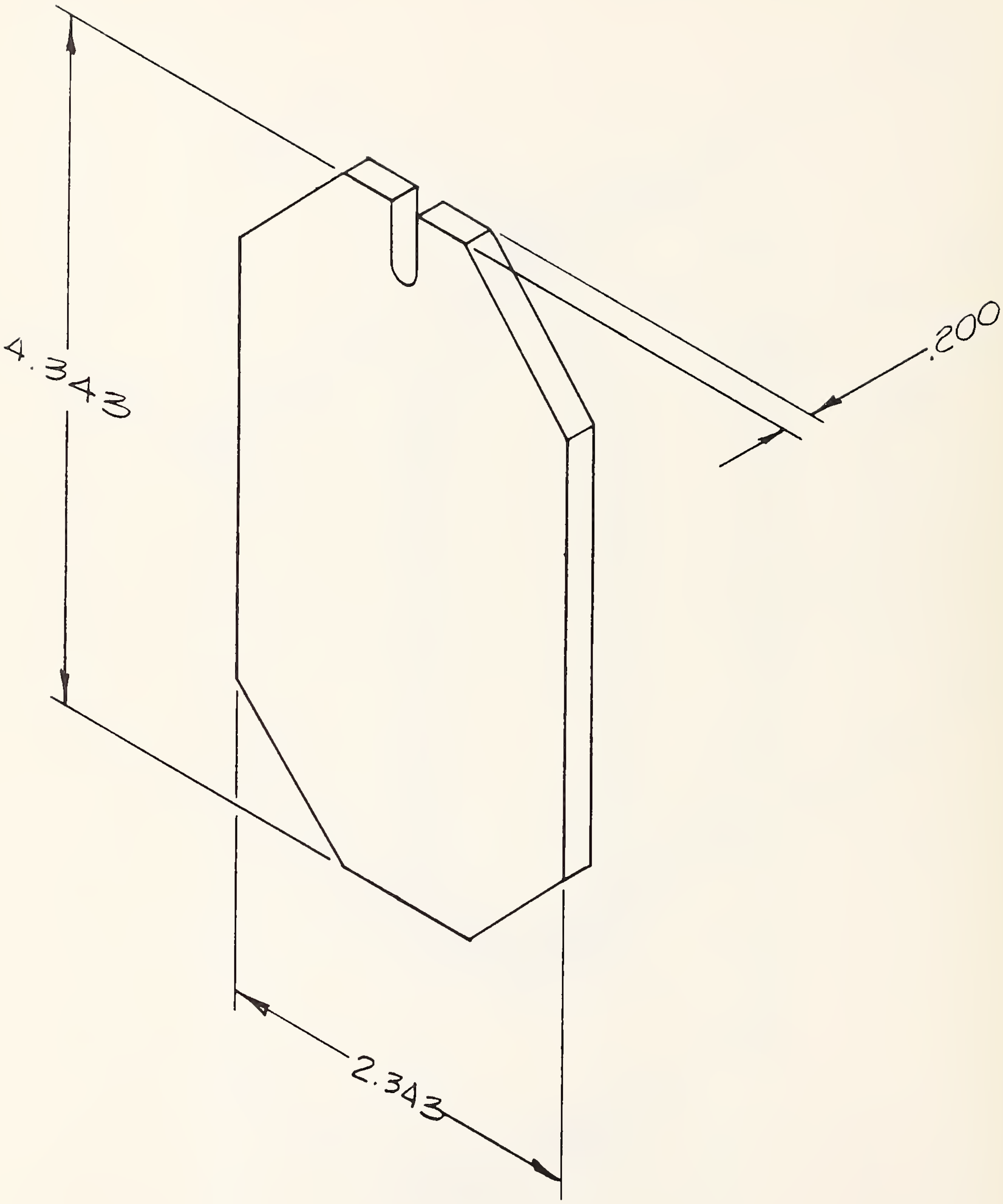

FIGURE 2-6. LOWER SUPPORT

E. CONNECTOR

Figure 2-7 shows the coaxial connector. The connector as shown is a modified version of a standard subminiature panel receptacle (SMA) made by several well-known manufacturers. This connector provides excellent electrical performance at X-band frequencies and is appropriately proportioned to the antenna size. The connector will have two flat surfaces on the flange which will lock into the housing to prevent rotation in the assembly when a mating connector is installed. The flange will provide a weather-seal against an "0" ring, made of neoprene (Figure 2-1). The center connector is soldered to the top side and the body of the connector is soldered to the underside of the active element.

F. OUTLINE AND MOUNTING CONSIDERATIONS

Figure 2-8 shows the outline dimensions and mounting provisions for the antenna assembly. The antenna mates with a standard SMA series plug connector. The antenna may be mounted and aimed by adjustment of four No. 6 screws that are spring loaded in a similar fashion to the approach used for headlamp retainers.

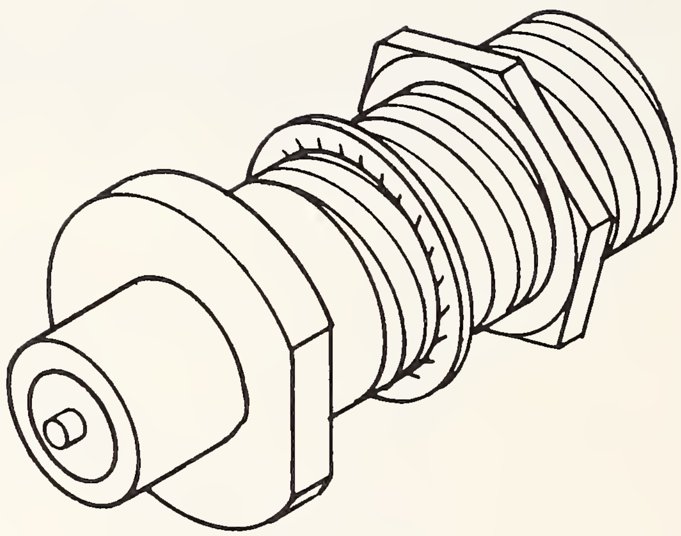

FIGURE 2-7. CONNECTOR

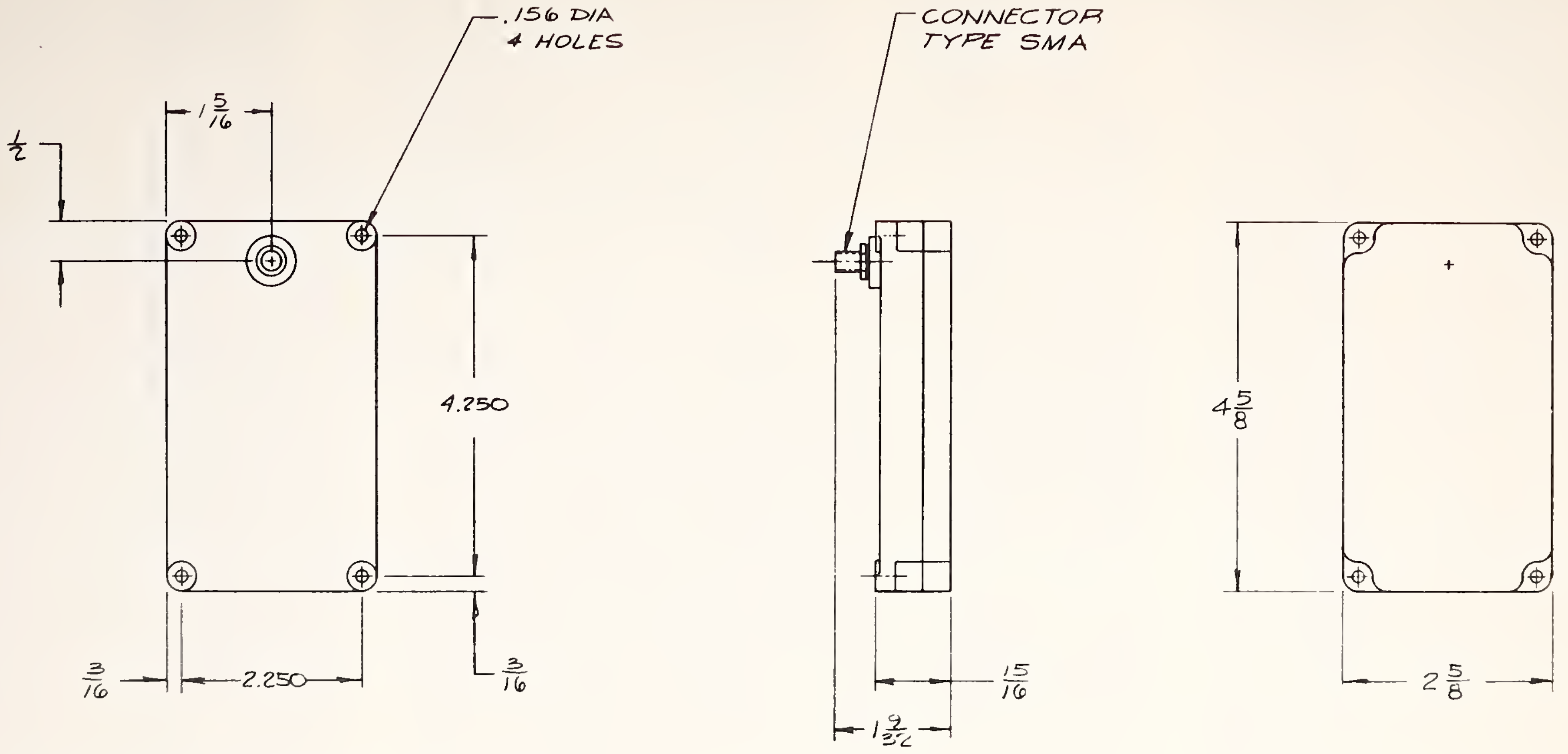

FIGURE 2-8. ENVELOPE DIMENSIONS AND MOUNTING HARDWARE

III. PROJECTED PRODUCTION COSTS

A study was performed to determine production costs over a range of procurement volume. Each part used in the antenna assembly was evaluated for production suitability, and alternative part designs and production processes were compared. As a result, preferred design alternatives and production methods were identified and their costs were carefully evaluated.

Production cost estimates had been gathered with the assistance of potential vendors in specific areas of specialization. These vendors had been carefully chosen as being capable of delivering the quantities of interest. Based on these production cost estimates the most cost effective antenna configuration and optimum manufacturing processes were selected for the 1 million per year and 10 million per year quantity range. The selected antenna configuration conforms to that described in Section II.

Fully automatic processing had been assumed for the purposes of cost estimates. An assembly line was envisioned which contained four basic types of machines in tandem with automatic intermachine feeding. It is also envisioned that one such assembly line operated on a single shift with a three man crew could produce 1 million units per year. Five such assembly lines with a total crew of 12 men per shift operated on a two-shift basis could produce 10 million units. These assumptions are based on a processing time of 6 seconds per unit per machine, 1/2 hour for two breaks for each crew, 1/4 hour average downtime per shift per assembly line for switchover to a standby assembly line when experiencing operating difficulties, and 5 percent overproduction for shrinkage. In addition to the assembly lines, it has been assumed that a separate test station will be set up for extensive testing of samples drawn from the line. This station will be manned, on a single-shift basis by a full-time technician and a half-time engineer trained in quality assurance procedures.

The first machine in the assembly line is an automatic dual-soldering machine. It will accept the etched active element and connector through automatic feeds and will solder the center conductor on the top side and the ground to the underside of the active element. After the operation is completed, probes will check for continuity. This machine will convey this subassembly to the next machine.

The second machine in the assembly line is a mechanical assembly machine. It will accept the above-formed subassembly, the housing, and the upper and lower foam supports through automatic feeds. Its function is to assemble them and convey the new subassembly to the next machine.

The third machine in the assembly line is a radome installation machine (ultrasonic welder). It will accept the above unit and the radome through automatic feeds. It will ultrasonically seal the antenna, thus completing the assembly procedure; then the antenna will be conveyed to the next machine.

The fourth machine in the assembly line is a testing and packaging machine. It will accept the completed antenna and test every unit for VSWR. It will be capable of automatically accepting or rejecting the antenna. Accepted antennas will be dropped into a packaging container. When this container is filled with 500 antennas, it will be automatically sealed and fed to a temporary storage area prior to shipment.

Periodically, samples will be drawn from the shipping containers for more extensive testing to ensure continued integrity of production. These samples will be taken to a separate test station where radiation patterns and gain will be measured.

Tables 3-1 and 3-2 present the results of the analysis of production costs for antenna quantities of 1 million and 10 million units, respectively. Recurring operations include:

A. PURCHASED PARTS AND SUBCONTRACTS

- Housing
- Radome
- Foam supports (upper and lower)
- Active element (etched)
- Connector and "0" ring
- Finishing and packaging

B. LABOR

1. TECHNICAL AND ADMINISTRATIVE

- Project management

- Product acceptance testing
- Quality assurance monitoring

2. MANUFACTURING

- Manufacturing planning and control
- Incoming inspection
- Electrical assembly of antenna components
- Mechanical assembly of total antenna package
- Intermediate and final product inspection
- Packaging for shipping

Required quantities of subcontracted and manufactured items have been increased by 5 percent to account for shrinkage. In obtaining radome cost, it was assumed that the thickness of material will be within tolerance as cast. Additional costs for double-disc grinding may be necessary but are not anticipated.

The nonrecurring operations referred to in the table include:

C. PURCHASED PARTS AND SUBCONTRACTS

- Tooling for housing, radome, supports, connector, and active element
- Tooling for electrical and mechanical assembly operations

D. LABOR

1. TECHNICAL AND ADMINISTRATIVE

- Project management and vendor liaison
- Reconfiguration of antenna design for high volume production
- Preparation of procurement specifications
- Preparation of manufacturing drawings
- Preparation of sample testing plan

- Preparation of quality assurance plan
- Testing to verify correctness of tools and uniformity of run

2. MANUFACTURING

- Methodization of manufacturing procedures
- Design and installation of tooling
- Manufacture of miscellaneous tools not included in group C above

The antenna design reconfiguration includes the redefinition of the active element geometry for use of a mylar substrate in lieu of the more costly polyolefin substrate used in the breadboard antenna (reference Section I).

As it may be noted from the tables, the per unit OEM selling price is well under 3 dollars for quantities in excess of 1 million and is under 2 dollars each for quantities in excess of 10 million, not including costs for preparing for large scale production.

TABLE 3-1. PRODUCTION COSTS FOR 1 MILLION UNITS

	Labor Hours	Labor Dollars* Through Profit	Materials and Subcontracts* Through Profit	Dollar Total
Recurring Operation	16,000	250,000	2,100,000	2,350,000
Nonrecurring	10,750	210,000	690,000	900,000

TABLE 3-2. PRODUCTION COSTS FOR 10 MILLION UNITS

	Labor Hours	Labor Dollars* Through Profit	Materials and Subcontracts* Through Profit	Dollar Total*
Recurring Operation	66,200	900,000	15,300,000	16,200,000
Nonrecurring	11,300	200,000	1,300,000	1,300,000

* Labor rates, overhead, and G & A are those currently prevailing at AIL. No allowance has been made for escalation or inflation. Freight costs are not included.

IV. CONCLUSIONS

An antenna design with required electrical and mechanical performance has been defined that lends itself to completely automatic production using inexpensive purchased subassemblies. As a result, the antenna can be supplied to the automotive industry at a price that is low enough to permit its unrestricted application in every automobile.

These conclusions are based on paper studies using preliminary information. Reduction of the price estimates would require further refinement of individual component designs using information supplied by subassembly vendors to promote greater production savings. Also, reduction of recurring costs would require competitive bidding by the many suppliers of purchased subassemblies. In the area of automated tooling, refinement of the cost estimate would require detailed design of the tooling.

The printed-circuit array approach will meet the electrical performance requirements with adequate margin to ensure a high-production yield with reasonable tolerances. With respect to a DOT-TSC inquiry about higher frequency operation, if the AIL design approach was scaled to the 20-GHz band that is popular for inexpensive Gunn-diode intrusion alarms, adequate margin would not exist. Electrical performance specifications would have to be recast more leniently to prevent much greater costs from being incurred in obtaining more stringent production tolerances. Also contributing to degraded performance at the higher frequency are the increased ohmic losses (1.4 times as great) to be suffered in the antenna feed circuitry. Lastly, the smaller size of the etched geometry at the higher frequency represents a diminished power handling capacity. For these reasons, the 10.5-GHz band is preferred.

V. ACKNOWLEDGEMENTS

Morrin Hazel, Ross Holmstrom, and Dr. John Hopkins, the engineers at DOT-TSC connected with this project have been most helpful in setting criteria for relative importance of various factors which enter into production design tradeoffs.

At AIL, K. Toth performed the study of production alternatives and cost analysis. This work was carried out under the direction of R. Rudish, with general guidance and program review by H. Jasik. The invention which forms the basis for the printed-circuit approach was conceived jointly by H. Jasik, R. Myslicki, and R. Rudish.