

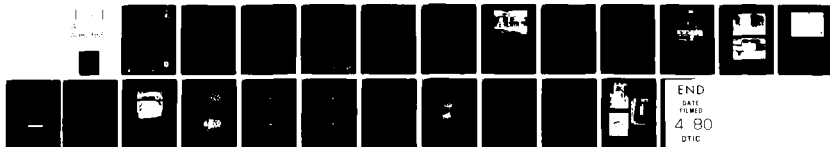
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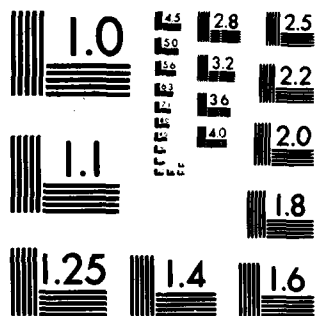
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SEP 79 R E WILTON, A WATERMAN
AFGL-TR-79-0205

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Contents

1. INTRODUCTION	5
2. STRIPLINE ANTENNAS	6
3. ANTENNA SYSTEMS REQUIREMENTS	7
4. DESIGN APPROACH	8
5. TELEMETRY ANTENNA ARRAY DESIGN	11
6. ANTENNA ARRAY FABRICATION	13
7. ANTENNA SYSTEM TEST RESULTS	14
8. CONCLUSION	18

Illustrations

1. Aries Rocket Prelaunch at White Sands Missile Range	6
2. Aries Mock-up at PSL/NMSU Antenna Range	9
3. Telemetry Antenna and Heat Shield Installed on Aries MSMP Vehicle	10
4. Flush-Mounted Telemetry Antenna Installed on Aries SPICE-IRBS Vehicle	10
5. Surface-Mounted Telemetry Antenna Subarray Installed on Aries Payload	11



Illustrations

6. Stripline Circuit for Telemetry Antenna Subarray	12
7. Surface Mounted Subarray After Recovery	14
8. VSWR Curve Eight-Element Subarray	15
9. VSWR Curve 48-Element Array	15
10. Gain Reference Eight-Element Subarray	16
11. Roll Plane Eight-Element Subarray	16
12. Gain Reference 48-Element Array	17
13. Roll Plane 48-Element Array	17
14. Contour Plot of Eight-Element Subarray	19
15. Contour Plot of Aries With Nose Cone	20
16. Contour Plot of Aries Without Nose Cone	21
17. Aries With Sensor Module Doors Open	22
18. Aries With Sensor Module Doors Closed	22
19. Aries Installation at PSL/NMSU Antenna Range	22

Telemetry Antennas for Large Diameter Sounding Rockets

1. INTRODUCTION

Antenna systems for research sounding rockets often require a compromise between optimum electrical performance and the configuration limitations dictated by a specific experimental payload. This report will illustrate the approach used during development of telemetry antennas for large diameter rocket payloads similar to those flown on the Aries rocket.

The Aries rocket was developed by using the solid propellant, second-stage motor (M56A1) from the obsolete Minute Man I system (Figure 1). Fins are provided and the vehicle is modified for low altitude performance. The rocket motor has a nominal diameter of 44 inches and a standard interstage coupling provides a transition to 38.5 inches for the payload. This is a guided rocket vehicle and, typically, the experimental payload will be attitude-controlled during flight. This new vehicle required a different approach for payload integration because of its size and the complexity of the experimental payload.

This report describes the accomplishments under In-House Work Unit 76590103, titled Telemetry Antennas for Large Diameter Sounding Rockets. The objectives, approach, and final results will be discussed. This report does not describe the completion of antenna developments for large diameter payloads, rather, it should serve as a basis for further improvements in performance, reliability, and effectiveness.

(Received for publication 4 September 1979)



Figure 1. Aries Rocket Prelaunch at White Sands Missile Range

A number of rocket payloads are being instrumented at AFGL for use with the Aries vehicle. Among the scientific programs currently using the Aries vehicle are the MSMP, IRBS, and SPICE projects.

2. STRIPLINE ANTENNAS

Since 1970, AFGL has used printed circuit type antennas. The stripline circuit antenna has been the principal design used with AFGL payloads. Stripline designs have not only provided several standardized 2200 to 2300 MHz telemetry antenna systems, they have been used with radar transponder systems and UHF ranging receiver systems. The stripline antenna has proven highly successful on AFGL research rockets, and the concept has been aerodynamically desirable in that the antenna system can be integrated into the payload structure more effectively than other types of antenna systems.¹ A wide range of aerospace vehicles of varying configurations have been instrumented with stripline antennas developed under Air Force contract by the Physical Science Laboratory (PSL),

New Mexico State University.² Technology developed for the smaller diameter payload was used in solving the antenna problems associated with the Aries rocket programs.

3. ANTENNA SYSTEMS REQUIREMENTS

The large diameter Aries rocket was introduced to AFGL following the first launch of the vehicle in 1973. Because of its large size, it has a payload capacity far in excess of the sounding rockets previously instrumented. Several scientific programs with unique flight requirements were to use this rocket vehicle, including payloads having very complex and costly experiments. The quantity of instrumentation planned for each payload indicated that multilink telemetry systems would be employed. The program costs and technical importance mandated that the telemetry systems have extremely high reliability and performance characteristics. The initial design of the telemetry antennas for the first Aries vehicle to be instrumented was complicated by a limited experience with the vehicle. It was apparent that with several telemetry systems on board, a multicoupler would be required as well as an antenna system that covers the entire 2200 to 2300 MHz band. Investigations of possible telemetry multicouplers resulted in using units from both Acronetics, Sunnyvale, California, and Wavecom, Northridge, California. Telemetry systems were anticipated to be up to 10 W, with bandwidths in excess of 1.0 MHz. Based on previous experience it was determined that these experimental payloads would require antenna systems capable of being sealed to reduce outgassing or microscopic dirt from contaminating the field of view of sensitive instruments.

The aerodynamic requirements were not fully defined for all planned flights, so a cautious approach was required for the initial antenna designs. The launch site location, flight plans, ground telemetry station support, and many other operational considerations were undefined, so more than one type of antenna system was to be investigated. Because of the importance of the Aries program to AFGL, a separate work unit was established to investigate three different types of telemetry antenna systems.

1. Wilton, R. (1975) Antenna Developments for Aerospace Research Vehicles, AFCRL-TR-75-0239, Instrumentation Papers, No. 232, AD A014 778.
2. Waterman, A., and Henry, D. (1978) Research and Development of Antennas for Rockets and Satellites, AFGL-TR-78-0095, AD A058 710, Physical Science Laboratory, New Mexico State University.

4. DESIGN APPROACH

A series of large diameter Aries type rockets were to be used to test several telemetry antenna design concepts. The three basic design considerations were: (1) An aerodynamically flush-mounted antenna system having an omnidirectional pattern; (2) A surface-mounted antenna system with similar omnidirectional characteristics; and (3) A directional antenna system for use when the attitude of the payload could be determined in relation to the ground receiving station. Because testing during the various phases of this work depended on installing antennas on vehicles of opportunity, the work was accomplished in a series of separate developments that satisfied specific Aries payload requirements.

The first task in this development was to fabricate a telemetry antenna for the 38.5-inch-diameter payload section of the Aries that would satisfy the omnidirectional pattern requirements. Details on the antenna array design will be discussed later in this report. A stripline system was constructed and installed around the circumference of the payload. The prototype for this antenna was initially installed on a mock-up and pattern measurements were made on the PSL antenna range (Figure 2). The results were better than anticipated, and a flight antenna was installed on an Aries rocket payload. In that high aerodynamic performance of the vehicle was of concern, a heat shield was provided for the flight-model antenna. The possibility of using an ablative system was dismissed because of the outgassing it would produce. A heat shield consisting of a series of aluminum retaining clamps was determined to be the most effective approach. Only the radiating portion of the antenna was left exposed (Figure 3). This is a relatively complex construction technique, but it did provide a reliable flush-mounted antenna system for high heat applications.

The next antenna system was of a similar design, but it required a less complex installation (Figure 4). Using techniques that were effective on smaller diameter rockets, the Aries payload skin was machined to accept the stripline sections. The antenna sections were installed using blind holes, and they were seated in a high temperature RTV base to reduce the possibility of contaminants being emitted during flight.

This design is currently standard on most AFGL Aries payloads. These two antenna systems have resulted in a choice of flush-mounted systems. Although the normal Aries flight does not require special protection from heating, some of our future launch plans include higher performance vehicles that will require the segmented retaining clamp heat shield system.

Investigating the use of a surface-mounted antenna system was accomplished with a test flight and recovery of a single telemetry antenna section (Figure 5). This antenna features the same type elements as the flush-mounted system, except

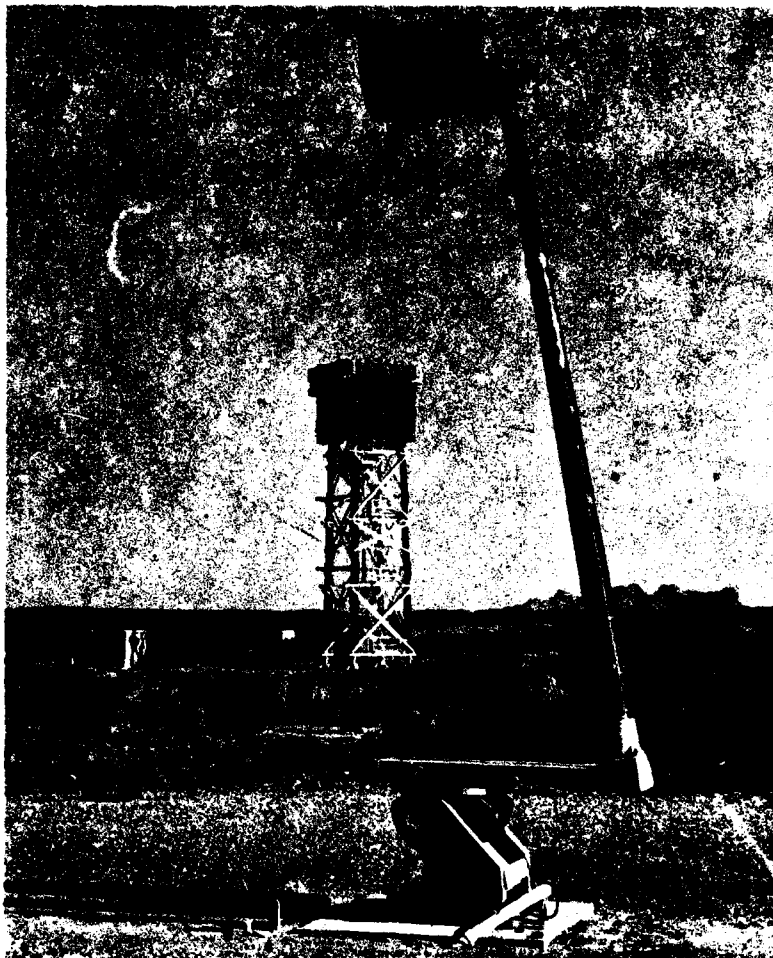


Figure 2. Aries Mock-up at PSL/NMSU Antenna Range

for the tapered edges. Temperatures measured on the antenna surface were 70° to 80°C during most of the flight. Examination of the antenna on a recovered payload proved that this concept is aerodynamically acceptable for the Aries rocket. The major concern for a surface-mounted antenna is damage during prelaunch operations; the most favorable feature is the ease of installation. This test with a single antenna section consisting of eight radiating elements also provided information that will be useful in the development of a directional telemetry antenna system.

The fact that most Aries-type payloads will be attitude controlled during flight allows the installation of an antenna system that can be oriented in a particular position. This results in an antenna that will radiate more energy in a specific quadrant. Limiting the beamwidth and orienting the antenna to favor reception from a known receiving location will increase gain within the quadrant. This not only allows use of lower-powered transmitters, but it makes possible the installation of an antenna system on a smaller portion of payload surface. For some flight and



Figure 3. Telemetry Antenna and Heat Shield Installed on Aries MSMP Vehicle

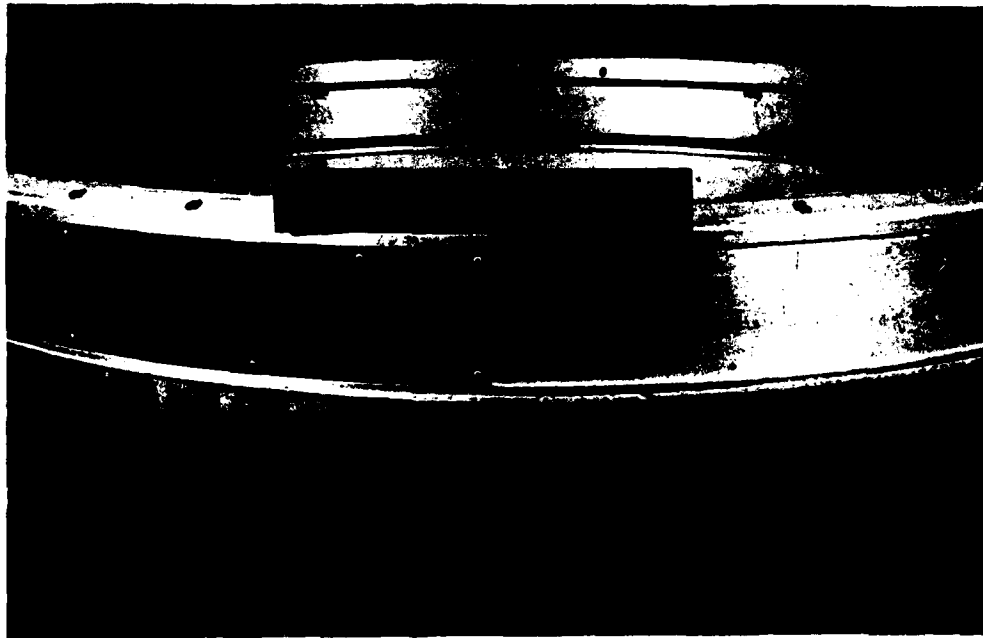


Figure 4. Flush-Mounted Telemetry Antenna Installed on Aries SPICE-IRBS Vehicle

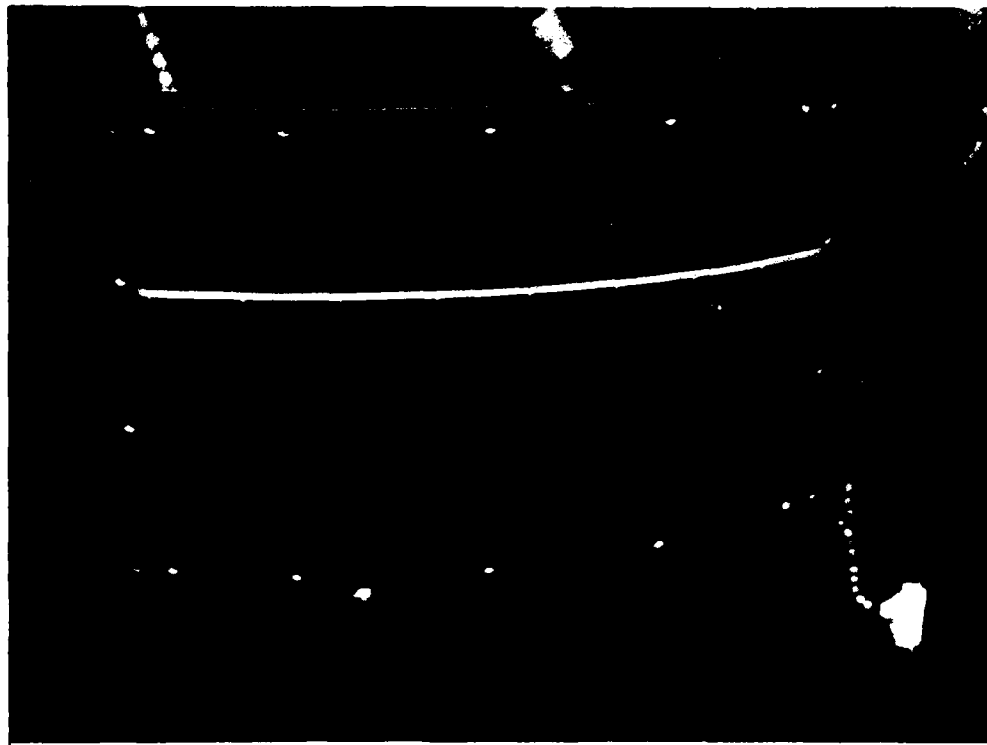


Figure 5. Surface-Mounted Telemetry Antenna Subarray Installed on Aries Payload

measurement applications it is not practical to install a completely circumferentially mounted antenna system. In these cases, the physically smaller antenna system may solve a payload configuration problem and be very cost effective. The only test data to date has been from the single stripline section; however, studies will continue on other types of antenna systems that may result in more desirable radiation characteristics.

These large diameter antenna design concepts are now being employed in support of several different AFGL programs. The stripline technique has been effective in satisfying these antenna requirements. All received signals from flight tests of these antennas have been of high quality and have met the design standards of the antenna systems under test.

5. TELEMETRY ANTENNA ARRAY DESIGN

The payload section for the Aries telemetry antenna is 38 inches in diameter. Possible high heat characteristics on future flights dictated that a 0.25-inch-thick aluminum heat shield be placed over a major portion of the antenna. The antenna

is approximately 0.125 inch thick. A simple calculation for the minimum number of radiating elements required for a reasonable roll plane pattern implied at least 45. Restrictions on the use of vehicle real estate meant that the array had to be as narrow as possible. Based on previous experience,³ it was decided to design a 48-element antenna array. Subsequently, the effort was reduced to the development of six identical subarrays of eight radiating elements each.

For the past several years PSL has been designing stripline antennas⁴ using shallow cavity backed radiating slots fed by a corporate structure. The slot array is usually circumferential and linearly polarized. The final stripline circuit layout for the MSMP vehicle is shown in Figure 6. The unit was held to an axial dimension of 2.75 inches. The radiating slots are centered with an open-ended line $\lambda/4$ past the top of the slot. The $\lambda/4$ open-ended line acts as an electrical short at the top of the slot, precluding the need for any mechanical connection. Center-feeding the slots at the high-impedance point serves two purposes: It negates the necessity for extremely close registration tolerances and it simplifies the feeding circuit. The corporate feed network uses a series of constant-impedance lines. By calculating line lengths and placing two parts in parallel, the last junction in an eight-element array becomes a $\lambda/4$ line. The final circuit rarely requires a matching transformer circuit. Power division and impedance changes become a matter of parallel combinations and line lengths. It is not necessary to hold extremely close tolerances on line widths; all of the lines are the same width and impedance, regardless of their value.

The SPICE and IRBS payloads flown on the Aries vehicles differ only slightly from the MSMP payload. No heat shields were required; therefore, it was necessary to modify the circuit layout slightly. The technique remains the same for all three payloads.



Figure 6. Stripline Circuit for Telemetry Antenna Subarray

3. Waterman, A., and Henry, D. (1975) Research and Development of Antennas for Rockets and Satellite Transmissions, AFCRL-TR-75-0181, AD A010 456, Physical Science Laboratory, New Mexico State University.
4. Waterman, A., and Henry, D. (1971) Stripline Strap-On Antenna Array, Twenty-First Antenna Symposium, University of Illinois.

6. ANTENNA ARRAY FABRICATION

The circuit design is carefully laid out on a piece of rbylith using a double edge cut and strip tool. The radiating slots and positions of the mode-suppressing holes are laid out on a second piece of rbylith. The rbyliths may be photocopies or used as is; in either case, the two pieces are registered to each other. The subarrays are fabricated from two pieces of 1-ounce, double-sided, copper-clad laminate.

At the etching shop, a copper-clad circuit board is placed between the rbyliths and treated in the same manner as a double-sided circuit board. Another board has the copper removed from one side only. This second board then has a small feed point access hole drilled in the appropriate area. The two boards are then joined together, using heat and pressure after a mylar film has been placed between them. The press used to join the two boards is in the shape of an arc that represents the vehicle diameter. The subarray is then trimmed to its exact dimensions at the machine shop. All of the mode holes are drilled and the feed point is very carefully installed. The unit is then ready for the plating shop. The array is first plated with an electroless copper. This places a very fine but easily removable copper on all of the board edges and through the holes. The unit then goes through a copper electroplate process which seals the first copper strike. A final nickel electroplate is then added to provide a finish that can be handled in the field.

Each array consists of six units and a coax harness. The harness was fabricated using commercially available two- and three-way power dividers. The subarrays are fed in phase using the necessary flexible coax line lengths. The arrays that were installed on the MSMP vehicles used EMI gasket material between the heat shields and the area closest to the radiating elements. The SPICE and IRBS vehicles were harnessed in a similar manner; however, they were installed without heat shields. Since these units were designed to be flush mounted, a machined payload was provided by AFGL. The subarrays were mounted in a channel 0.13 inch deep by 2.75 inches wide. The units were mounted with O-ring seals around the feed connectors so that the vehicle could be pressurized.

Prior to the final testing of the MSMP antenna array, an additional antenna unit was added to the mission. A single subarray was modified by extending the surface area of the circuit board. The original board edge-line plating was replaced by a series of plated-through holes. Beyond this region the extended board area was tapered at a 30° angle. Since the MSMP vehicle was to be attitude controlled, an appropriate mounting area was chosen. The tapered, single, eight-element subarray was then installed on the surface of a vehicle without heat shields. Figure 7 shows two views of this antenna after recovery.

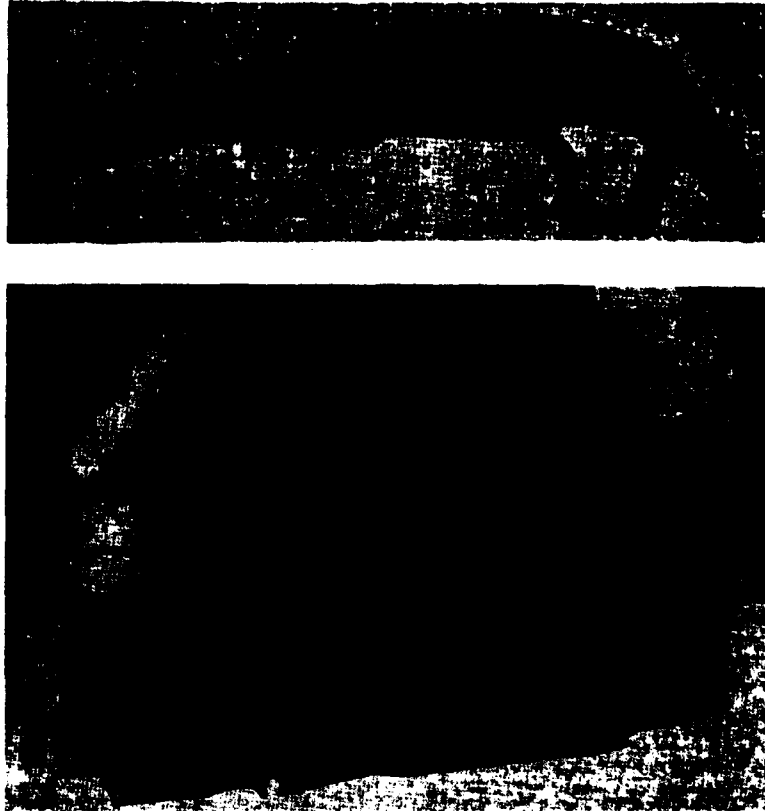


Figure 7. Surface-Mounted Subarray After Recovery

7. ANTENNA SYSTEM TEST RESULTS

Figure 8 is a VSWR curve taken at the antenna feed point of the single, tapered, eight-element array. Figure 9 is a typical VSWR curve taken at the final three-way power divider for the 48-element Aries array. The gain reference pattern for the single unit is shown in Figure 10. Figure 11 is the $\theta = 90^\circ$ or roll plane pattern for the single unit. A typical gain reference pattern for the 48-element Aries array is shown in Figure 12. Figure 13 is the $\theta = 90^\circ$ or roll plane pattern for the 48-element Aries array. It should be noted that the standard gain horn is +16 dB with respect to an isotropic source. The $\phi = 0^\circ$ designation is referenced to the feed point position on the single or lowest serial number subarray.

SWR CURVE COORDINATE-BOUNDED CHARACTER SWR CURVE

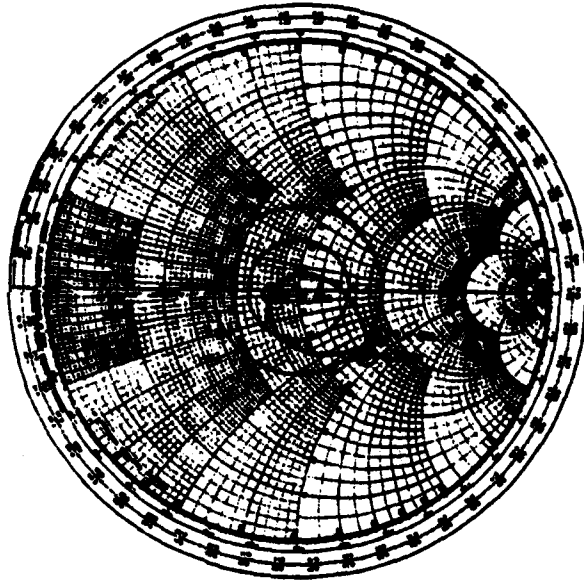


Figure 8. VSWR Curve Eight-Element Subarray

SWR CURVE COORDINATE-BOUNDED CHARACTER SWR CURVE

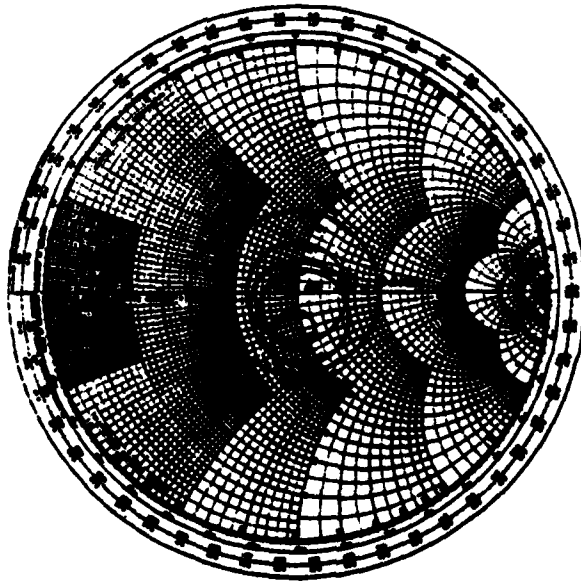


Figure 9. VSWR Curve 48-Element Array

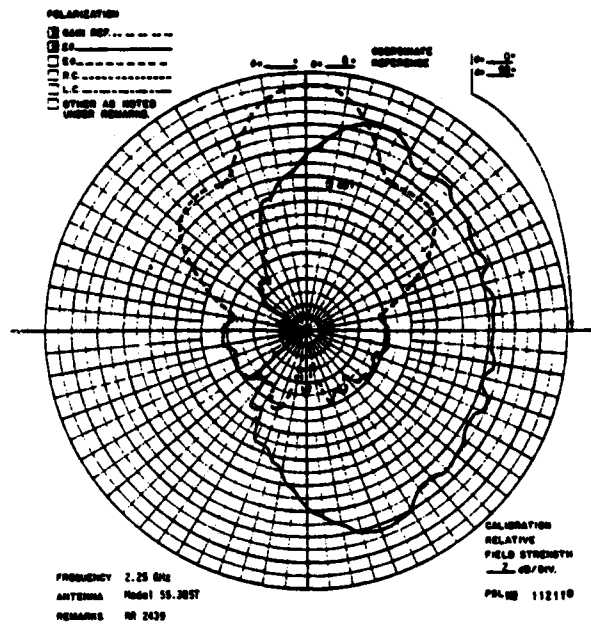


Figure 10. Gain Reference Eight-Element Subarray

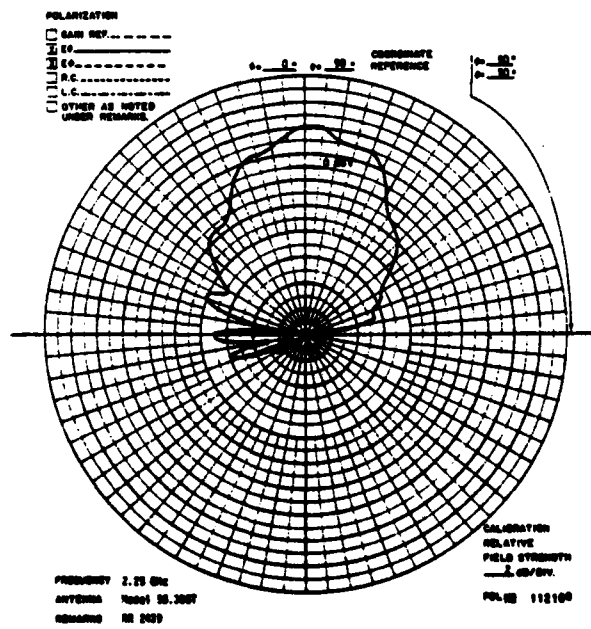


Figure 11. Roll Plane Eight-Element Subarray

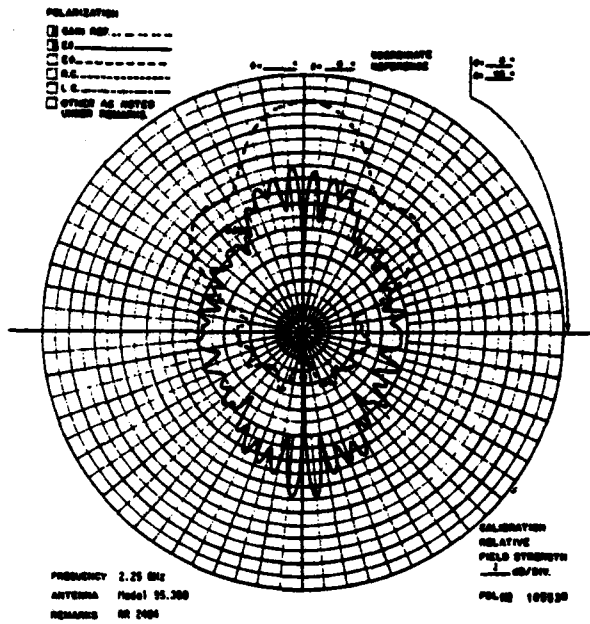


Figure 12. Gain Reference 48-Element Array

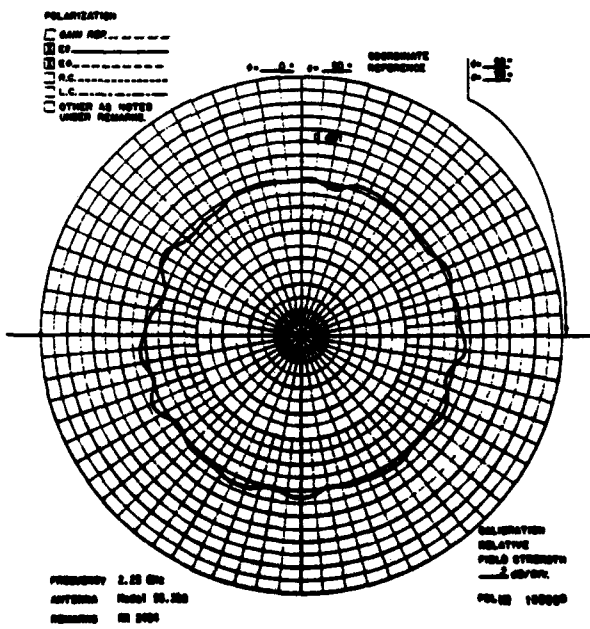


Figure 13. Roll Plane 48-Element Array

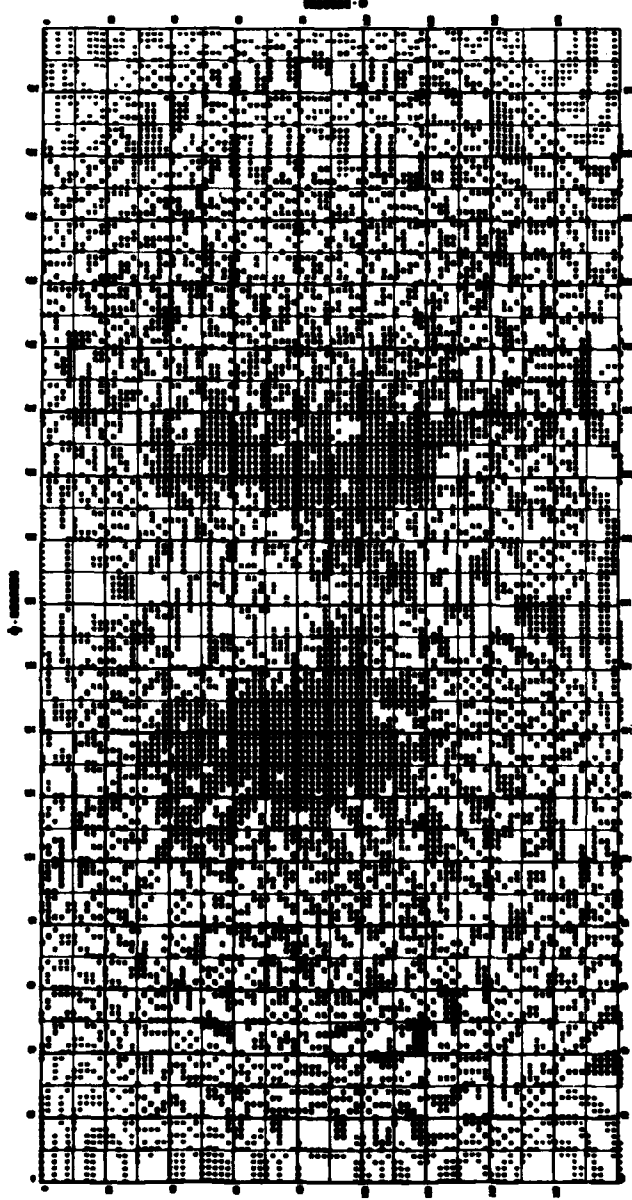
Figure 14 is a radiation contour plot for the single eight-element array. The directional qualities are readily apparent by imagining the center of the array at the $\phi = 0^\circ$ ($\phi = 360^\circ$) point. A cone of radiated power at least 60° wide is shown to have power levels of isotropic or greater. If one considers all of the power down to -10 dB below isotropic, then the included angle becomes 120° wide. The -10 dB level is also available beyond the fore and aft vehicle area.

Figure 15 is a radiation contour plot of the 48-element array. The data shown were taken when the array had a nose cone, and simulates the Sensor Module of the MSMP vehicle. This condition is also typical for the SPICE and IRBS vehicles. Figure 16 is a radiation contour plot of the 48-element array without the nose cone. The condition simulates the Target Engine Module of the MSMP vehicle. It should be noted that in Figures 15 and 16 the number 10 represents the isotropic level. Numbers greater than 10 are below isotropic, that is, the number 18 is -8 dB with respect to isotropic. Numbers less than 10 are levels greater than isotropic, that is, the number 6 is +4 dBi.

Figure 17 is a doors-open view of the Sensor Module flight payload for the MSMP. Figure 18 is a closed-door view of the vehicle. The telemetry antenna array is in the area just below the simulated nose cone. Figure 19 shows the vehicle ready for installation at the PSL/NMSU Antenna Range.

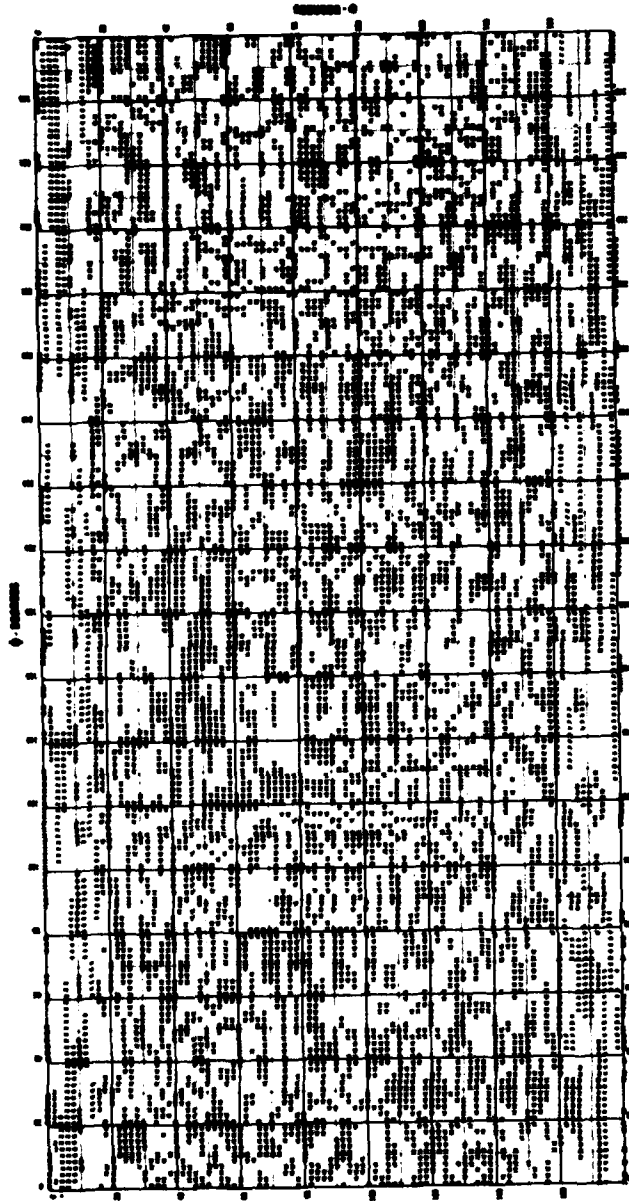
8. CONCLUSION

AFGL is currently conducting several major scientific programs that requires the instrumentation of Aries rocket vehicles. These large-diameter vehicles are carrying payloads in excess of 1000 pounds (454 kg) to altitudes above 250 miles (400 km). With the increases in altitude, bandwidth, and payload costs, the design of antenna systems becomes more important. The work described in this report represents antenna developments that have been flight tested. These concepts in developing systems for large-diameter rocket vehicles will provide reliable telemetry antennas for many future Air Force programs.



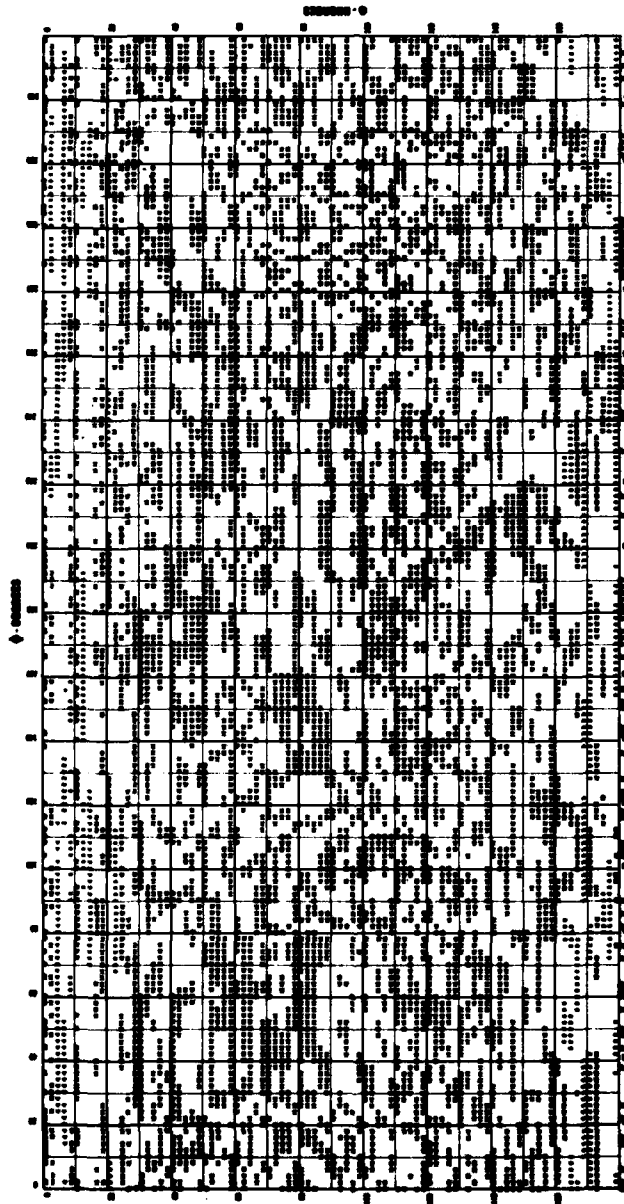
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 PATTERN MEASUREMENT FREQUENCY: PSL PHOTO NO: ANTENNA MODEL NO: MODEL SCALE:
 POLARIZATION COMPONENT RECORDED: ARRAY NO: ARRAY PHASING:
 GAIN REFERENCE ANTENNA: TYPE AND S/N: GAIN OF THE REFERENCE ANTENNA:
 DESCRIPTION OF TEST ANTENNA:
 DESCRIPTION OF VEHICLE MOUNT:
 THE NUMBER IN THE POWER CONTOUR GRAPH CORRESPONDS TO WITH RESPECT TO THE GAIN REFERENCE ANTENNA.
 CAPTION OF THE GAIN MEASUREMENT:

Figure 14. Contour Plate of Eight-Element Subarray



CONTRACT NO. JUNE 15-672 PSL FUND NO. 1281 RANGE REQUEST NO. 207 DATE: JUN 27
 PATTERN MEASUREMENT FREQUENCY: 1.13 GHz ANTENNA MODEL NO. 51.8 MODEL SCALE: 1:1
 POLARIZATION COMPONENT RECORDED: H ARRAY PHASING: IN PHASE
 GAIN REFERENCE ANTENNA: TYPE AND S/N: 281.1.1 GAIN OF THE REFERENCE ANTENNA: 51.8
 DESCRIPTION OF TEST ANTENNA: 1/4 WAVE STRIP ANTENNA WITH 1/4 WAVE FEED
 DESCRIPTION OF VEHICLE MOCKUP: 1/4 WAVE STRIP ANTENNA WITH 1/4 WAVE FEED
 THE NUMBER IN THE POWER CONTOUR GRAPH CORRESPONDS TO THE GAIN REFERENCE ANTENNA
 DESCRIPTION OF THE GAIN MEASUREMENT: 1/4 WAVE STRIP ANTENNA WITH 1/4 WAVE FEED
 REMARKS: None

Figure 15. Contour Plot of Artes With Nose Cone



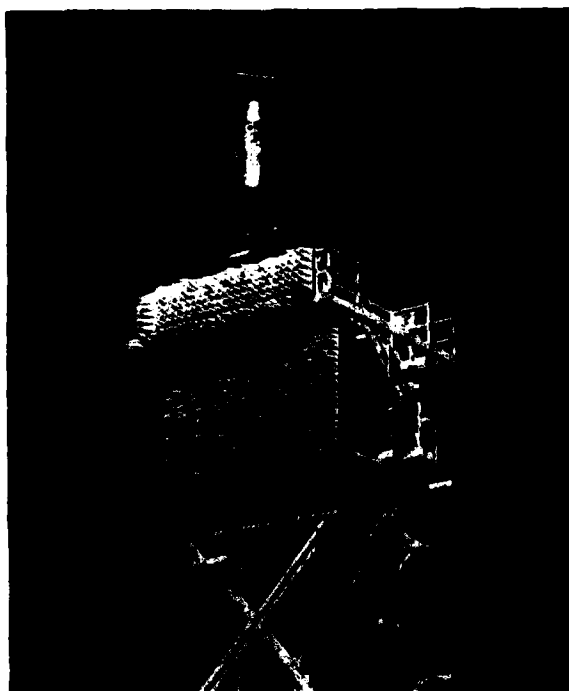
CONTRACT NO. 77-01-25-072 PSL FUND NO. 1381 RANGE REQUEST NO. 107 DATE: 1 Nov 77
 PATTERN MEASUREMENT FREQUENCY: 1.5 GHz PSL PHOTO NO. 5A ANTENNA MODEL NO. 5A-20 MODEL SCALE: 1:1
 POLARIZATION COMPONENT RECORDED: 0 ARRAY NO. 5A ARRAY PHASING: 0
 GAIN REFERENCE ANTENNA: TYPE AND S/N: 08 1.7 GAIN OF THE REFERENCE ANTENNA: 5A-20
 DESCRIPTION OF TEST ANTENNA: See test photo. It is a 20 element, 1.5 GHz, 20 dB, 20 dB, and 10 dB antenna.
 DESCRIPTION OF VEHICLE MOCKUP: See test photo. It is a 20 element, 1.5 GHz, 20 dB, 20 dB, and 10 dB antenna.
 THE NUMBER 5A IN THE POWER CONTOUR GRAPH CORRESPONDS TO 5A-20 WITH RESPECT TO THE GAIN REFERENCE ANTENNA.
 DESCRIPTION OF THE GAIN MEASUREMENT: See test photo. It is a 20 element, 1.5 GHz, 20 dB, 20 dB, and 10 dB antenna.
 REMARKS: See test photo. It is a 20 element, 1.5 GHz, 20 dB, 20 dB, and 10 dB antenna.
 P/6

Figure 16. Contour Plot of Aries Without Nose Cone



**Figure 17. Aries With Sensor Module
Doors Open**

**Figure 18. Aries With Sensor Module
Doors Closed**



**Figure 19. Aries Installation at
PSL/NMSU Antenna Range**