RADAR ANTENNA PATTERN ANALYSIS FOR THE SPACE SHUTTLE USING NEC-BSC

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ABSTRACT

In order to improve tracking capability, radar transponder antennas will be mounted on the space shuttle solid rocket boosters (SRB). These four antennas, each being identical cavity-backed helices operating at 5.765 GHz, will be mounted near the top of the SRB's, adjacent to the intertank portion of the external tank. The purpose of this study is to calculate the roll-plane pattern (the plane perpendicular to the SRB axes and containing the antennas) in the presence of this complex electromagnetic environment.

The large electrical size of this problem mandates an optical approach, thus a general purpose code, the Numerical Electromagnetics Code - Basic Scattering Code, was chosen as the computational tool. This code is based on the modern Geometrical Theory of Diffraction and allows computation of scattering of bodies composed of canonical shapes such as plates and elliptic cylinders.

Apertures mounted on a curved surface (the SRB) cannot be accommodated by the code, so an antenna model consisting of wires was devised that approximated the actual performance of the antennas. Although the method of moments (MM) was not used in developing the antenna model, the code's MM input option proved instrumental in implementing the scheme. The improvised antenna model matched well with measurements taken at the NASA/Marshall Space Flight Center (MSFC) range. The SRB's, the external tank, and the shuttle nose were modeled as circular cylinders, and the code was able to produce what is thought to be a reasonable roll-plane pattern.

INTRODUCTION

The locations for the radar transponder antennas on the shuttle cluster are shown in Figure 1. The antennas are assumed to be operating at a frequency of 5.765 GHz and to be circularly polarized.

Previous to this effort, an estimate of the shadowing due to the cluster was made using a line-of-sight shadowing code [1] - [2]. In addition, some preliminary work was done to model the antennas in the presence

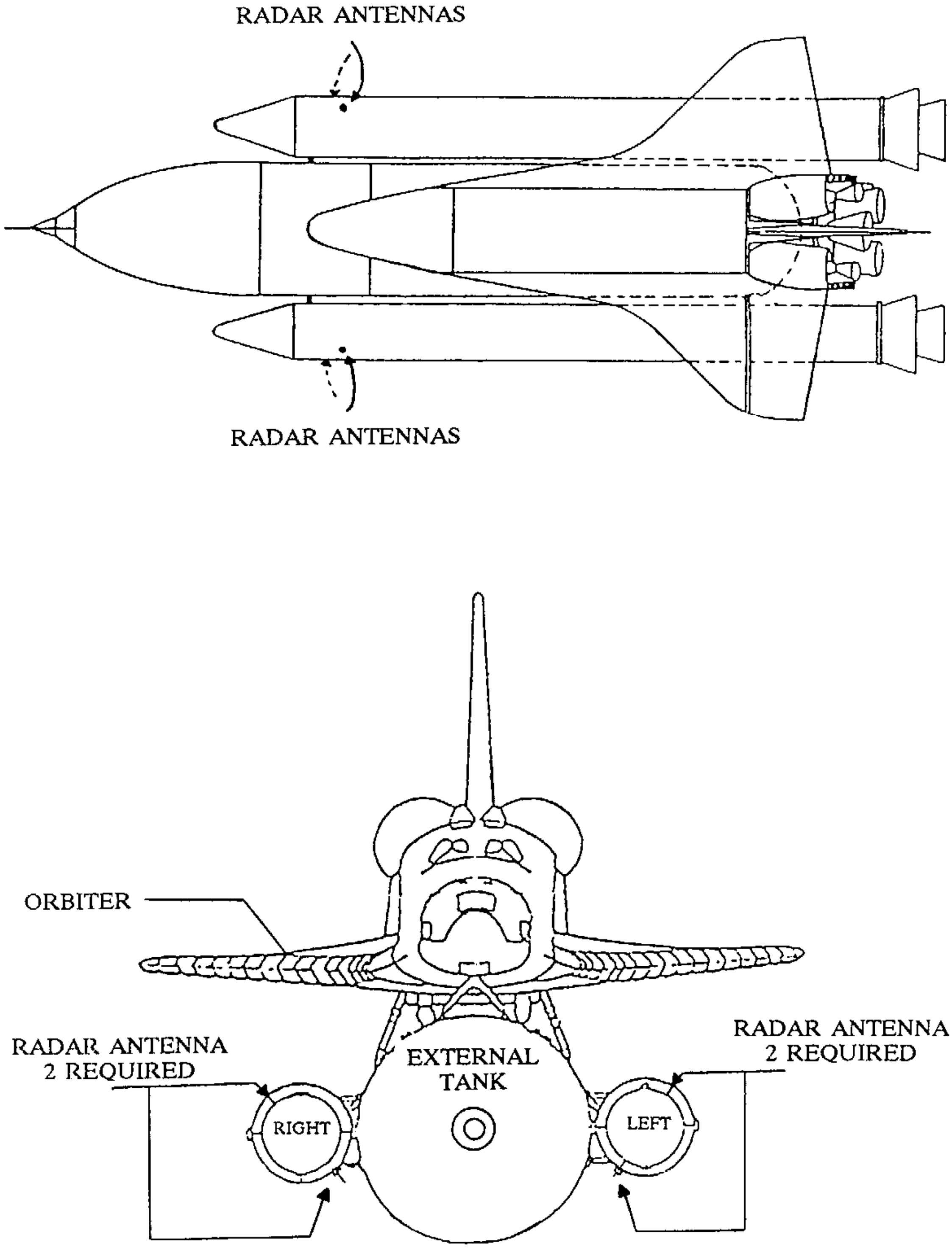


Figure 1. Antenna locations amid the cluster.

of two cylinders [3], and the effects of corrugations of the external tank were partially examined [4].

Determination of the pattern from scale modeling is impractical due to the extremely high frequency that would be necessary to allow construction of a shuttle model that the MSFC anechoic chamber will accommodate. The MSFC antenna range can accomodate a full scale section of the SRB with two antennas installed; this was performed and measurements were taken. The philosophy adopted in this study was that if a computational model that produces patterns that agree with the measured patterns for the full scale SRB section could be developed, then that model could be used, with a high degree of confidence, to compute the pattern for the complete shuttle cluster.

Due to the large electrical size of the problem, we are forced to use an optics approach. The integral equation and differential equation methods require far too much computer memory and time for a problem of this size [5]. Physical optics could be applied, but we are aware of no general purpose physical optics code in the public domain. Thus, the only technique readily available to us is geometrical optics and the associated Geometrical Theory of Diffraction (GTD). It is a high-frequency asymptotic technique and becomes more accurate as the frequency of operation becomes higher. Given the radar antenna wavelength and the size of the shuttle cluster, GTD can be expected to give good results for this problem.

The aspect of NEC-BSC that applies to this problem is its ability to calculate the far field pattern of an antenna array in the presence of complex structures, provided the structure can be modeled as a combination of canonical geometries [6]. In reality, it is possible that many ray paths exist between the source and observation point; the code handles only the lower-order paths. For example, the code will compute direct, singly-reflected, singly-diffracted, doubly-reflected, reflected-diffracted, and diffracted-reflected rays, but not doubly-diffracted ones.

These limitations in ray tracing can be significant, but the code does have a limited capability which warns the user when a particular mode which is not calculated may be significant. This was not encountered during the course of this investigation. We will see that it may, however, introduce small discontinuities in the final pattern.

ANTENNA MODELING

Much of this effort was devoted to modeling the helix antennas, and is along the lines of that in [3]. Figure 2a represents the two antennas mounted on an SRB, with the aperture flush with the cylinder surface. NEC-BSC allows the user to specify an aperture as a source, but it cannot be mounted on a curved surface (Figure 2b). This is because the problem of a source mounted on a curved surface is a different type of diffraction problem (the "radiation" problem), and the code does not incorporate this diffraction theory. (The aircraft code NEWAIR [7] allows antennas to be mounted on the surface of a cylinder; it does not, however, allow the presence of other cylinders.)

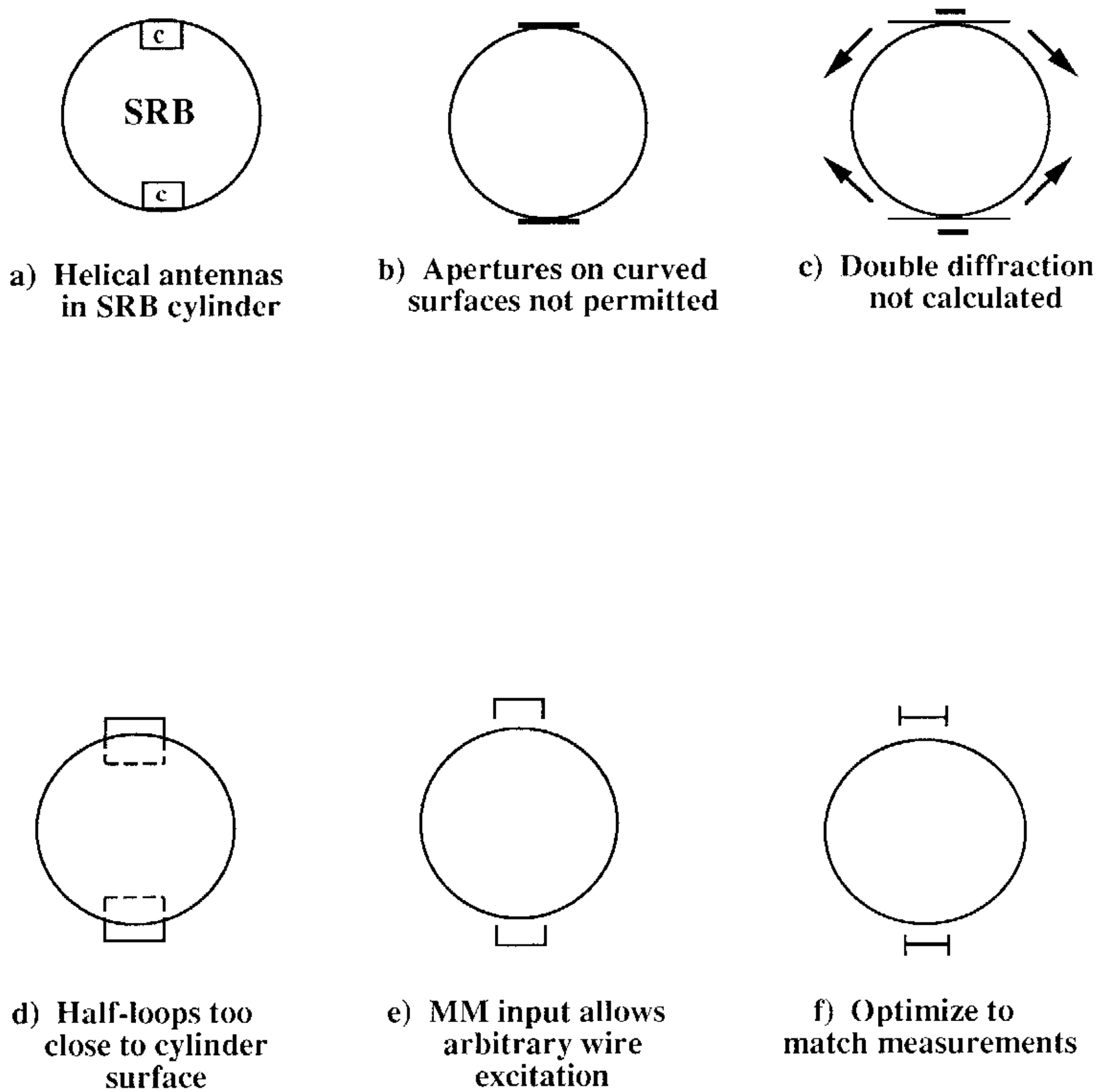


Figure 2. Antenna model development.

Apertures are permitted to be mounted on flat plates, however. It seems logical, then, to mount an aperture on a small flat plate placed a small distance above the circular cylinder representing the SRB (the circular cylinder is another canonical shape which the code handles). Unfortunately, this will not work because doubly-diffracted fields are not computed, and thus the cylinder would not be illuminated by the antenna.

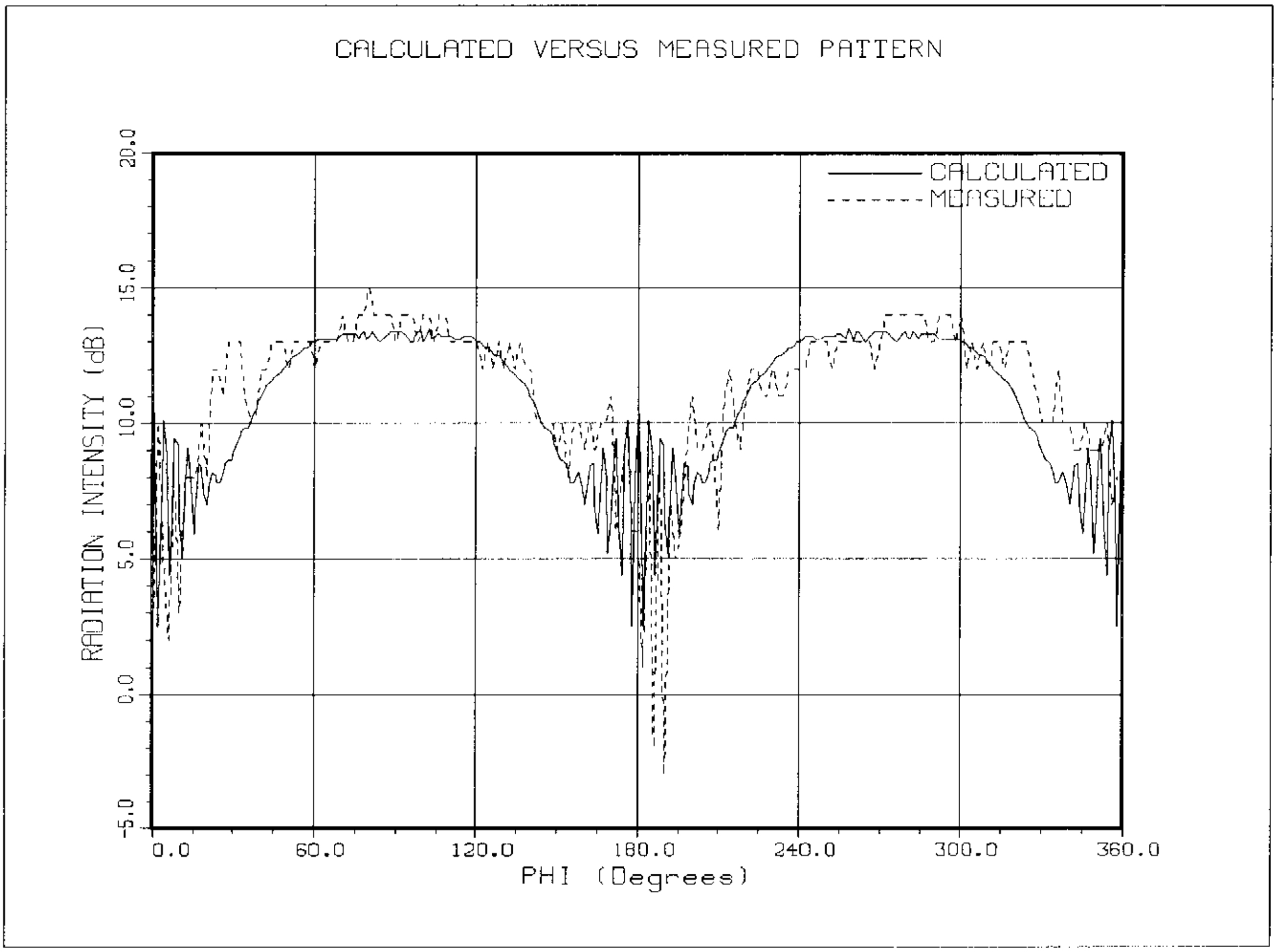
Since the actual helix antennas are circularly polarized, our model must be also. Circular polarization can also be obtained by crossed dipoles or crossed slots. It is known that a half-loop and its associated image can produce a field similar to that of a slot mounted on the cylinder surface [3]. Two of these half-loops are shown in Figure 2d; to create the other slot would require two more perpendicular to those drawn.

This model should not be used, however, because this would place the sources too close to the cylinder. Since NEC-BSC is based on a high-frequency asymptotic theory, no two objects should be closer than one-quarter wavelength apart. This problem could be alleviated by raising the loops one-quarter wavelength off the cylinder surface, as shown in Figure 2e.

This is obviously not a physically possible situation. That is irrelevant though, since the code allows wire segments to be placed anywhere with any current magnitude and phase desired. In reality, the currents would interact and redistribute themselves to satisfy boundary conditions, but this input option is intended to allow the results from a method of moments analysis to be used as a source. In other words, any wire segment interaction would have already been included in the method of moments calculation (NEC-BSC cannot perform the current interaction calculation since it is not based on an integral equation approach). So, even though the currents used on the half-loop model are not derived from a method of moments procedure, we can still take advantage of this input option to create our antenna model.

The next step was to adjust the relative phasing, magnitude, and distance from the cylinder of the wire segments in an attempt to obtain a model that matched well with measured data taken at the antenna range. This was done on what was essentially a trial-and-error basis (Figure 2f).

To make the measurements at the antenna range, two of the cavity-backed helix antennas were mounted on a 4.5 foot high cylinder having the same diameter as the SRB. Thus, when developing the antenna model, a 4.5 foot high cylinder was assumed. When only one antenna was modeled, some discontinuities were evident on the side opposite the antenna. This is because of the fact that the code has some difficulty dealing with caustics (places where an infinite number of rays intersect). It so happens that the location of the caustic is at the maximum of the second antenna's pattern; fortunately this drowns out the discontinuity and yields an essentially continuous pattern. The final modeled pattern of two antennas mounted on a 4.5 foot high SRB section is given in Figure 3. The radiation is very close to being circularly polarized.



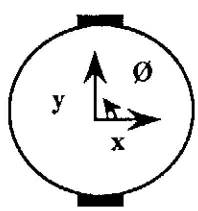


Figure 3. Comparison of measured pattern with calculated pattern (circular polarization).

The measured pattern for the same situation is also given in Figure 3. The calculated and measured patterns agree moderately well almost everywhere.

Figure 4 gives the final roll-plane pattern calculation, obtained by using the input file which created Figure 3 for each SRB and adding cylinders to represent the external tank and the cross section of the orbiter's nose in the roll-plane.

There are some small discontinuities. These may be due to the basic limitations in the code's ray tracing procedure or to the fact that computations can only be done at a minimum of 1 degree increments. But this pattern is believed to be reasonable and accurate to within the code's limitations and the simplifying assumptions.

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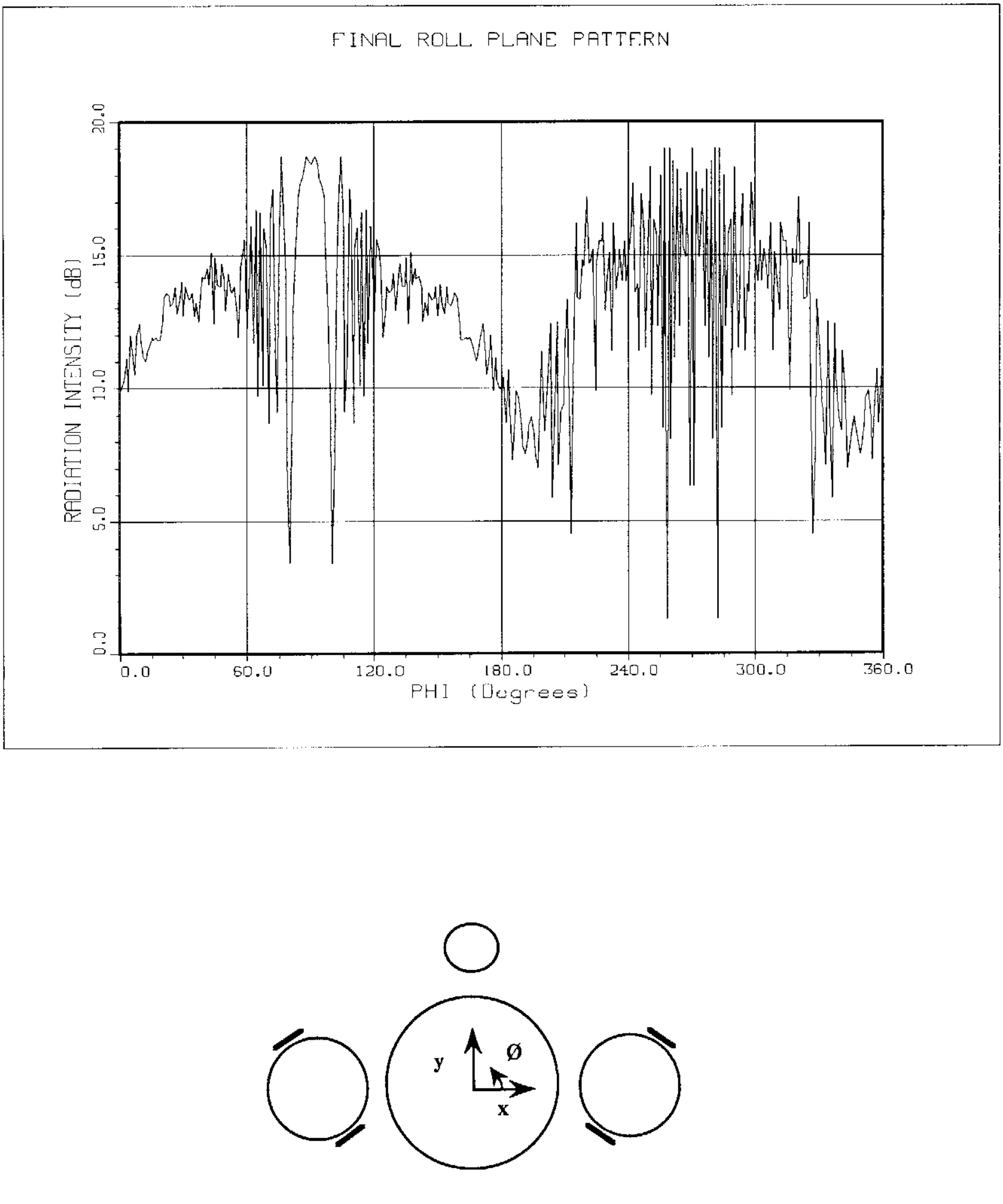

Figure 4. Final result (circular polarization).