•

A New Concept in Helicopter Communications Antennas

- A Concept Paper* -

September 29, 1995

JPL

POC:
Dr. Ronald J. Pogorzelski
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-3835

* Concept Papers from the Jet Propulsion Laboratory are intended to stimulate discussion of the topic described. They arc not commitments to work, but arc precursors to a formal Task Plan if they generate sufficient mutual interest.

A New Concept in Helicopter Communications Antennas

R. J. Pogorzelski
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 911.09-8099
(818)354-3835

Background

Modern military helicopters require communications capability in a number of frequency bands including HF, VHF, and UHF including both AM and FM. A major problem in providing such capability has been identifying appropriate antenna types and locations. The difficulties are due to interference both internally and externally generated, rotor blade modulation, and propagation effects in the operational environment. Antennas currently in use include blade type monopoles, towel bars, and whips and these are located in a wide variety of positions on the airframe. While some perform better than others, all suffer from rotor blade and airframe effects which reduce their effectiveness. One location which has not been used to our knowledge is the main rotor itself although its attractiveness from an rf point of view has been recognized by many designers working in this arena. The main deterrent to use of the rotor has been the possible deleterious effects on the aerodynamic effectiveness of the rotor. A secondary deterrent has been the issue of conveying the rf power from the transmitter to the rotating blades. We believe that the concept proposed here deals effectively with both of these issues and provides a flexible high performance antenna suitable for all relevant frequency bands and for both horizontal paths and satcom applications.

The Concept

We consider a five blade rotor and envision an array with one element mounted on each rotor blade. These elements may be dipoles or horizontal. slots depending upon the desired polarization characteristics. For example, slots would provide vertical polarization on horizontal paths. The array is excited through a novel type of rotary joint located on the rotor shaft. For a five blade rotor this rotary joint would have five input probes and five output probes protruding into a pair of concentric interpenetrating disk shaped parallel plate radial waveguides as shown in Figure la. Figure lb shows a more compact folded design for lower frequencies at which the simple design may be too large. Figure 1c shows an even lower frequency design. Considering the transmitting case, the input probes connected to the transmitter and the input radial waveguide remain stationary with respect to the helicopter body while the output probes and output radial waveguide rotate with the rotor blades. The two radial waveguides are coupled at the non-contacting overlap region where a set of folded choke rings may be necessary to limit rf leakage to negligible levels. The receive case is accessible via reciprocity.

In operation, the input probes are driven through a beamforming network so as to set up an appropriate radial standing wave mode in the waveguide. The output probes are then excited by this mode and the energy is coupled to the array elements and radiated. The radiation pattern is determined by the mode in the output waveguide. A beam forming network can be designed to provide appropriate mode excitation. As the rotor rotates, the probes are exposed to a waveguide mode which, by virtue of having been excited by the nonrotating input probes, does not rotate. Thus , while the array elements rotate in space, the radiation pattern of the array does not rotate. It is believed that this automatic “de-spinning” effect will greatly reduce rotor blade modulation.

Examples

The array in question has five fold rotational symmetry and, as such , has five eigenmodes of excitation. Regardless of the type of element used, these eigenmodes may be described in terms of the complex weight, $W_{re}n$, assigned to the m^{th} element in producing the nth mode. For the lowest order mode, all the elements are in phase and all the W’s are unity. However, for the other four modes, the phase of the weights progresses uniformly around the array in one direction or the other. That is,

Mode -2: $W_{-2,m} = e^{-4jm\pi/5}$

Mode -1: $W_{-1,m} = e^{-2jm\pi/5}$

Mode 0: $W_{0,m} = 1$

Mode 1: $W_{1,m} = e^{2jm\pi/5}$

Mode 2: $W_{-2,m} = e^{4jm\pi/5}$

or, more compactly,

$W_{mn} = e^{2jmn\pi/5}$, where m=0,4 and n=-2,+2.

The array factors, $F_n(\theta,\phi)$, for these modes can be expressed in terms of Bessel functions as follows. First,

$$F_n(\theta,\phi) = \sum_{m=0}^{4} W_{mn}\ e^{jkr_o \sin\theta \cos(\phi - \phi_m)}$$

where $\phi_m = 2m\pi/5$ and r_o is the radius of the array. Then, recalling that

$$e^{jA\cos\psi} = J_o(A) + 2\sum_{\ell=1}^{\infty} j^{\ell} J_{\ell}(A)\cos(\ell\psi),$$

one has,

$$F_n(\theta,\phi) = J_o(kr_o \sin\theta) \sum_{m=0}^{4} e^{jn\phi_m}$$
$$+ 2\sum_{\ell=1}^{\infty} j^{\ell} J_{\ell}(kr_o \sin\theta) \sum_{m=0}^{4}{}' e^{jn\phi_m}\cos[\ell(\phi-\phi_m)]$$

but, $\sum_{m=0}^{4} e^{jn\phi_m} = 0$ unless n=5p, where p is an integer, in which case it is 5, so,

$$F_n(\theta, \phi) = 5 \sum_{p=0}^{\infty} J_o(kr_o \text{ Sin } \theta)\delta_{n,5p}$$

$$+10 \sum_{p=0}^{\infty} j^{n+5p} J_{n+5p}(kr_o \sin \theta) e^{-j(n+5p)\phi}; \; n=-2,+2$$

For small values of r_o, that is, for electrically small arrays, only the p=O term is significant. Then,

$$F_n(\theta,\phi) \approx 10 \, j^n J_n(kr_o \sin \theta) \, e^{-jn\phi}; \; n=-2,-1,+1,\text{and } +2 \text{ and,}$$

$$F_O(\theta,\phi) \approx 5 \, J_O(kr_o \sin \theta)$$

If the elements were vertical electric dipoles on the rotor blades, the radiation patterns of the array would be these array factors multiplied by the element pattern; i.e., sin θ. Note that, because of the manner in which the array is fed; i.e., via the cavity rotary joint described above, the angle ϕ is measured with respect to the helicopter body, not with respect to the rotor blades. As a consequence, the patterns are not rotating and there is no significant rotor blade modulation. The polarization is vertical in the horizontal plane. Finally, since vertical dipoles are not aerodynamically convenient, one would probably use horizontal slots to achieve vertical polarization as described below.

Suppose now, that the array elements are horizontal dipoles, one along each of the blades and suppose that they are resonant at an operating frequency suitable for UHF satcom. Now, the pattern of the array becomes,

$$F_n(\theta,\phi) = \sum_{m=0}^{4} w_{mn} \left[\cos \theta \cos (\phi-\phi_m)\hat{u}_\theta - \sin (\phi-\phi_m) \hat{u}_\phi\right]$$

$$\times e^{jkr_o \sin \theta \cos (\phi - \phi_m)}$$

where the factor in brackets accounts for the element pattern of the horizontal dipoles. An algebraic procedure similar to that outlined above leads to,

$$F_n(\theta,\phi)\cdot\hat{u}_\theta \approx \frac{5}{2} J_O(kr_o \sin\theta)\ [\delta_{n1}\ e^{j\phi} + \delta_{n,-1}\ e^{-j\phi}]\ \mathrm{COS}\ 8$$

$$+\ 10\ J_n'(kr_o\ \sin\ \theta)\ \cos\theta\ 3^{n-l}\ e^{jn\phi}$$

$$F_n(\theta,\phi)\cdot\hat{u}_\phi \approx \frac{5j}{2} J_O(kr_o\ \sin\ \theta)[\delta_{n1}\ e^{j\phi} - \delta_{n,-1}\ e^{-j\phi}]$$

$$+\ 10j\ \frac{nJ_n(kr_o\ \sin\ \theta)}{kr_o\ \sin\ 13}\ j^{n-l}\ e^{jn\phi}$$

for the two transverse vector components of the far zone field of the n^{th} mode. Note the presence of the factor j in the ϕ component indicating that the principal polarization of all but the n=O mode is circular, a fortuitous circumstance for the satcom application. Identifying the principal sense of circular polarization for each mode leads to the following simple approximate expressions for the circular polarization radiation patterns.

Mode -2: $10j\ J_1(kr_o\ \sin\ \theta)\ \cos^2(\theta/2)\ e^{-j2\phi}$

Mode -1: $5\ J_O(kr_o\ \sin\ \theta)\ \cos^2(\theta/2)\ e^{-j\phi}$

Mode O: $10j\ J_1(kr_o\ \sin\ \theta)\ \cos\ \theta$

Mode 1: $5\ J_O(kr_o\ \sin\ \theta)\ \cos^2(\theta/2)\ e^{j\phi}$

Mode 2: $10j\ J_1(kr_o\ \sin\ \theta)\ \cos^2(\theta/2)\ e^{j2\phi}$

These principal circular polarization component modal radiation patterns are shown in Figures 2a - 2c for $kr_o=2$. All of these modes become purely linearly polarized in the horizontal plane, horizontal for horizontal dipole elements and vertical for horizontal slot elements. It is recognized, of course, that these patterns will be distorted somewhat by the airframe. It is expected that this distortion will occur primarily in the lower hemisphere.

Features and Potential Benefits

This antenna has several. beneficial features for application in helicopter communications. Four of the modal patterns radiate preferentially in the horizontal plane and, if horizontal magnetic dipole elements (slots) are used, these patterns are vertically polarized there as would be desirable for communications with ground-based terminals from low altitude. If either horizontal electric dipole or horizontal slot elements are used, the radiation skyward is circularly polarized as would be desirable for satcom applications. By virtue of the resonant dipole elements, the gain of the array is expected to be at least a few dBic.

Most important, however, is the fact that the pattern does not rotate with the rotor blades despite the fact that the elements are mounted thereon. This is due to the use of the unique multi-probe rotary joint described above. Since the pattern does not rotate with respect to the airframe or the receiver and since the rotor blades do not block the radiation, it appears that this antenna will exhibit a much lesser degree of rotor blade modulation, a deleterious effect seen in virtually all other helicopter antenna types. The rotor blade modulation effects for this antenna will be due only to the difference in blade/body coupling when the airframe is aligned with a blade and when it is aligned halfway between two blades. The antenna element / airframe coupling will be different in these two configurations giving rise to some modulation effects. It is believed that these effects will be small compared to the usual blockage effects.

Lastly, because of the phase variation of the modal radiation patterns with azimuthal angle, the relative phase of signals received via the n=1 and n=2 modes (or, alternatively, the n=-1 and n=-2 modes) is a direct measure of the azimuthal angle of arrival of the signal. Thus , while providing omnidirectional coverage in azimuth, this antenna also permits azimuthal direction finding, a capability which may be found very useful in the proposed applications.

Proposed Research Program

It is proposed that an initial theoretical study be conducted concerning design of the beamforming network and the rotary joint including computer modeling of these components. A simple prototype five blade rotating array would be fabricated and measured to assure that no details have been overlooked in formulating the concept and to yield a preliminary assessment of the rotor blade modulation effects. This would be a minimal unoptimized design using monopole elements to validate the general concept. Subsequently, a full breadboard model using horizontal dipoles should be designed, built, and measured with particular emphasis on assessing the rotor blade modulation immunity. This assessment will consist of measuring the radiation for two blade positions, one where a simulated airframe is aligned with a blade and one where it is aligned between two blades. For convenience and economy of fabrication, it is anticipated that this work would be done at a scaled frequency, probably X-Band. While the folded design would be applicable at lower frequencies and should be breadboarded, such a design represents a greater fabrication challenge with commensurately greater cost. Thus, optimization of such a design is left to future work after the basic properties of the coupler have been understood and validated.

JPL possess both computational, fabrication, and measurement facilities and expertise necessary for the undertaking of the above research program. Significant previous experience in the mobile satcom arena assures that the research will be focused on the objective of providing the Army with a significant advance in helicopter antenna design and a concomitant increase in communications capability. once the concept is proven to be of value in the proposed application, the design data can be confidently handed off to an appropriate contractor for manufacture of a production model.

The ROM cost of the above program is outlined in the the Table below.

ROM COST

Initial Study	3 Work-Months
Prototype Design	4.5 Work-Months
Rotary Joint	1.5 Work-Months
Beam Forming Network	1.5 Work-Months
Five Element Array	1.5 Work-Months
Prototype Fabrication	4.5 Work-Months
Rotary Joint	1.5 Work-Months
Beam forming Network	1.5 Work-Months
Five Element Array	1.5 Work-Months
Prototype Integration	1 Work-Month
Prototype Test	1 Work-Months
Reporting	1 Work-Month
Full Breadboard Design	5 Work-Months
Full Breadboard Fabrication	5 Work-Months
Full Breadboard Integration	2 Work-Months
Full Breadboard Test	3 Work-Months
Reporting	1 Work-Month

	Initial Study	Prototype	Breadboard	Total
Burdened Labor:	$45K	$180K	$240K	$465K
Fab Shop Services:		20K	40K	60K
Measurement Range:		15K	30K	45K
TOTAL :	$45K	$215K	$310K	$570K

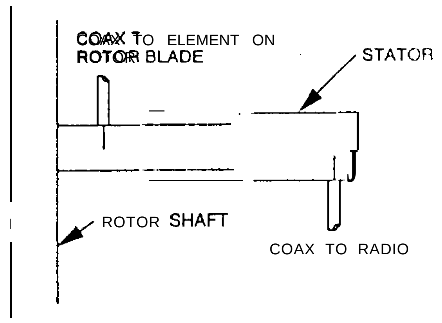

Figure la. Flat Design for High Frequencies.

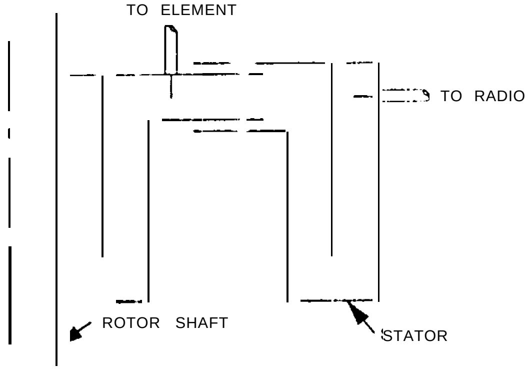

Figure lb. Folded Design for Lower Frequencies.

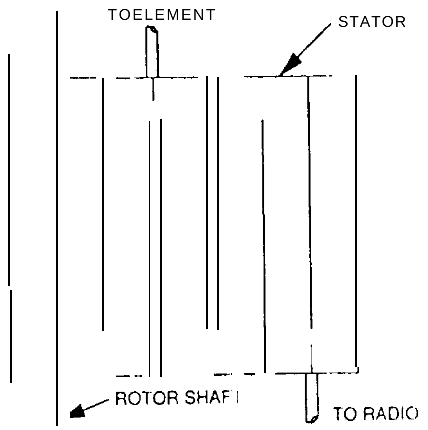

Figure lc. Folded Design for Still Lower Frequencies.

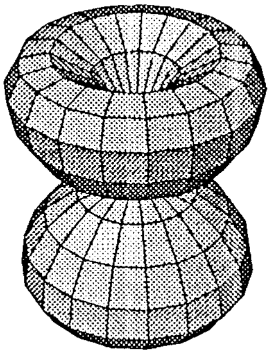

Figure 2a. Mode 0 Circularly Polarized Radiation Pattern.

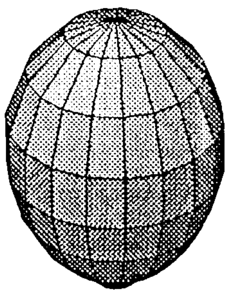

Figure 2b. Modes ±1 Circularly Polarized Radiation Pattern.

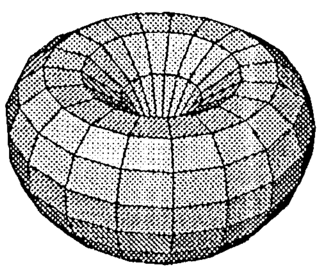

Figure 2c. Modes ±2 Circularly Polarized Radiation Pattern.