AMRAAM FLIGHT TERMINATION ANTENNA DESIGN AND DEVELOPMENT

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ABSTRACT

This paper reports on the design of a B-band flight termination antenna (FTA) for use on the Advanced Medium Range Air to Air Missile (AMRAAM). The antenna is a low profile structure composed of an etched circuit board measuring 1.6 by 10.0 by 0.010 inches mounted inside a 0.17 inch deep cavity formed in the back of the AMRAAM harness cover. There is a metallic cover over the cavity which connects to the metalized harness cover constituting a ground plane for the antenna. The antenna is easily tuned through use of two metallic slugs in close proximity to the ends of the antenna elements.

The active circuit of the antenna is composed of a 3-element folded dipole photoetched from copper clad Duroid. The center element is driven through a microstrip matching transformer which is printed on the opposite side of the antenna elements. A quarter wave open circuited stub is also printed opposite the elements to provide a virtual short such that no physical contacts are necessary between the transformer and the driven element. The matching transformer connects to the 50 ohm source at the center of the antenna through a side projecting microstrip tab which in turn is connected to a semi-rigid coaxial line.

The antenna exhibits improved bandwidth and excellent pattern coverage, particularly in the critical roll plane. All of the antenna parameters will be presented and discussed.

INTRODUCTION

As indicated in a paper given at the 1988 International Telemetry Conference[1], the Pacific Missile Test Center (PMTC) was given the responsibility to develop a new Telemetry (TM) package for the AMRAAM that is warhead compatible. In its original concept this package was to have included a flight termination system (FTS). Early on in the program the flight termination requirement was canceled because it was decided not to fly over land. Recently this requirement was reinstated. This provided us an opportunity to complete the FTA design which had been initiated for the original TM package.

In two previous papers the TM antenna proper[1] and the TM package[2] were discussed. System aspects of the FTS were not discussed previously since they were not part of the TM package. However, the FTS follows classical designs and will not be discussed here either. This paper treats only the design and development of the FTA proper.

The difficulty of this undertaking parallels that of the TM antenna since both antennas had to be mounted inside the harness cover and still leave sufficient room for the cable harness. As indicated previously[1] there had to be an increase in the height of the harness cover in order to accommodate the TM package. However, this increase was held to only 0.10 inches resulting in no significant change to the flight profile. Incorporation of the FTA resulted in no additional impact to the harness cover over that originally required for the TM package.

RADIATION COVERAGE REQUIREMENTS

Early in the AMRAAM TM package development, representatives of the Navy, the Air Force, and PMTC met to establish the radiation coverage requirements for AMRAAM. This took place prior to our involvement with the program. Figure 2 of the TM antenna paper[1] presents the agreed upon goal for both antennas except the FTA gain was 0 dBi. As with the TM antenna, the 90 degree sector in the roll plane below top dead center was summarily dismissed and the operating specification became that of the referenced figure with the lower 90 degree sector filled in. We perceived a design goal of 0 dBi as highly optimistic since most FTS antennas are linearly polarized and their receivers do not include diversity reception. This alone represents a penalty of approximately 5 dB for the FTS.

In an unpublished report by Eugene Law entitled “AMRAAM Link Analysis” an FTA gain of -12 dBi over 90 % of the surrounding sphere was used. Using this value, together with characteristic FTS receiver and range parameters, Mr. Law predicted a range of 120 nautical miles. Our antenna correlates well with this assumption.

POLARIZATION REQUIREMENTS

Polarization of the antenna was not specified, but like the TM antenna there was an expressed preference for vertical polarization to reduce multipath. As explained previously[1], tracking will be done at near grazing angles resulting in no real advantage for vertical polarization. Unlike the TM case where data corruption through fading is important, we are more concerned with signal loss. Mr. Law accounted for this by including a 10 dB fade margin in his analysis. He also included a 3 dB polarization loss, since most FTS transmitting antennas use circular polarization. In view of the above it was concluded that we could arbitrarily select the antenna polarization. However the geometry of the problem indicated a preference for horizontal polarization, since most conceivable antennas fit this category, and indeed the antenna selected is horizontally polarized.

ANTENNA SELECTION

Early in the AMRAAM program at the conceptual design review, Jan 85, candidates for both the TM and FTS antennas were considered. At this meeting the microstrip patch was offered as a candidate for both the TM and FTS antennas, while a second candidate for the FTA was the asymmetrical flat folded dipole as described by Dubost[3]. Later in the year at the preliminary design review, Jun 85, measured data on patch antennas for both requirements was presented. Also presented was data on the parasitically loaded antenna described earlier[1]. This antenna demonstrated better pattern coverage and improved bandwidth compared to the single mode patch and was the antenna of choice for the TM. The FTS patch antenna demonstrated reasonable patterns, but had a 2 to 1 VSWR bandwidth of only 2.0 MHZ. Additionally, as it turned out, this antenna exceeded the allowed height by 0.1 inches. Consequently the antenna would have ended up with even less bandwidth. There were other problems related to feed location and questionable temperature stability that suggested the need to pursue a better design. It was felt that the flat or printed folded dipole (PFD) was just such a design.

DESIGN THEORY

In figure 1 is shown a picture of the printed circuit board which constitutes the active element of the antenna. As can be seen, it takes the form of a classical three element folded dipole wherein the center element is driven. Dubost[3] analyzes the PFD antenna by use of transmission line theory. He assumes a sinusoidal excitation at the feed point from which he deduces the current distribution on the antenna as well as the input impedance. This current distribution is then used to calculate the far field radiation pattern. In his analysis the input impedance is purely reactive since the analyzed structure is lossless and non-radiating. A resonance condition is determined by demanding that the input reactance equal zero, however Dubost makes no attempt to predict the driving point radiation resistance.

Although the Dubost analysis was enlightening and aroused our initial interest in the antenna, we felt alternative methods might provide more insight into the design. An alternative method having merit centered on investigation of the folded dipole; first in free space, then in the presence of a nearby ground plane. The objective was to arrive at a value for the radiation resistance plus a prediction of the antenna bandwidth.

In a paper by Harrison and King[4], the following exact expression for the free space admittance of a three-wire coplanar folded dipole is derived.

$$Y_{in} = \frac{1}{Z_d}\left[\frac{\alpha_3}{\alpha_1}\right]^2 - jB_h\frac{2}{\alpha_1} \tag{1}$$

where

$$\alpha_0 = 2\ln\frac{b}{a}$$
$$\alpha_1 = 3\alpha_0 - 2\ln 2$$
$$\alpha_3 = 2\ln\frac{b}{2a}$$
$$B_h = \frac{\cot\beta h}{60}$$

In this equation, β is the wave number and Z_d is the impedance of a dipole whose effective radius (d) is defined the following:

$$d = (2ab^2)^{\frac{1}{3}}e^{-q} \qquad (2)$$

where

$$q = \frac{\ln 4 \ln\frac{b}{2a}}{6\ln\frac{b^3}{2a^3}}$$

The half length (h) along with the spacing (b) and diameter (2a) of the antenna are as shown in figure 2. Note the negative susceptance term in the expression for antenna admittance. This is typical of all folded dipoles. This term, which tends to cancel the positive susceptance of the effective dipole, is attributed to the non-radiating transmission line modes of the structure. It is this self compensating property that is primarily responsible for the broad band characteristic of this class of antenna.

In order to evaluate Y_{in}, some consideration must be given to the fact that our elements are flat. Wolff(5) treats elements of arbitrary cylindrical cross section including the flat strip. He derives an effective radius for the flat strip which is 0.25 times the strip width. Our FTA uses three equal width elements 0.500 inches wide separated by 0.050 inch gaps. Three equal width elements were chosen in order to provide a free space radiation resistance as high as possible together with meeting the microstrip feed considerations.

Applying the above to the FTA gives a three element coplanar array with effective element radii (a_e) of 0.125 inches and effective separations (b_e) of 0.550 inches. Using these parameters in (1), the input susceptance to the antenna becomes:

$$Y_{in} = \frac{1}{Z_d(22.64)} - j\frac{\cot\beta h}{225.1} \qquad (3)$$

Note that when cot(βh) becomes zero, near dipole resonance, the input impedance becomes that of the effective dipole multiplied by 22.64. The effective dipole impedance will have a value influenced by its effective radius and its environment. Even for thick dipoles, the real part of this impedance does not depart markedly from 73 ohms. Thus the resulting free space input impedance to the antenna will approximate 1653 ohms. This is an exceptionally high input impedance but is exactly what is desired since the impedance will fall drastically when the antenna is brought near ground.

The effective radius (d) of the equivalent dipole using (2) becomes 0.403 inches. This radius results in a value of 7.08 for the expansion parameter of Hallén defined by the following:

$$\Omega = 2\ln\frac{2h}{a} \qquad (4)$$

The problem now is to determine the input impedance when the antenna is placed close to ground. For our case the spacing is 0.16 inches since the antenna board is inverted in the cavity for tuning convenience. If we use image theory, this problem is identical to that of the end fire array composed of two half wave elements driven 180 degrees out of phase. King[(6)] treats this case extensively. He shows in his figure 7.4 that dipole elements spaced 0.010 wavelengths, which corresponds to our case, would have an input resistance of 0.25 ohms for an $\Omega = 10$. Our effective dipole with $\Omega = 7.08$ would increase this value to possibly 0.30 ohms. Thus our antenna should have an input impedance of 22.64 times this value or 6.79 ohms. This figure does not include losses which King indicates can be significant for very close spacing. Additionally our physical geometry violates the infinite ground plane assumption. We also have taken the liberty of using the center lines of the strips as our effective spacing which is questionable. These taken together could have a significant effect on the input impedance.

Exact calculations using King's equations is a formidable undertaking even for an ideal geometry. For this reason it was decided to terminate the theoretical analysis at this point, including bandwidth predictions, and proceed with modeling the antenna. It was felt that the analysis served well to describe the operation of the antenna and predict a finite impedance amenable to matching. Development of the antenna is described in the next section.

ANTENNA DEVELOPMENT

In figure 3 is shown an impedance plot taken on the antenna when driven from a 50 ohm microstrip line. Before we discuss this plot, a physical description of the antenna is in order.

In figure 4 is shown the harness cover cavity that accepts the antenna circuit board along with the completed antenna. The circuit board is mounted with the feed line down against the harness cover so that the capacitive tuning blocks do not affect the feed lines. Because of this arrangement the microstrip line is top loaded by the harness cover which has a dielectric constant of 5.10. Design of the top loaded feed lines is handled through use of a program written by Peter Simon from Raytheon, Goleta based on a paper by Bahl and Stuchly(7). There is not sufficient space to described the program in this paper. The harness cover also presents a distributed loading to the antenna which accounts for its foreshortening to 10.0 inches without top loading.

Also in figure 4 note that the tuning blocks with their locking screws are quite visible through the slots in the ground plane. The tuning blocks are made by bonding 0.032 inch thick teflon fiberglass to a 0.090 inch thick aluminum base. The antenna is tuned by sliding the blocks equally from the ends toward the center of the antenna until the correct frequency is reached.

Returning to the impedance plot of figure 3 note that the input resistance of the antenna at resonance is 8.13 ohms. This along with the other data points was plotted on a more detailed Smith chart to determine the Q of the antenna which turned out to be 92.8. This value of Q was used to predict an optimum match for the antenna over the required operating bandwidth of approximately 20 MHZ. For an n = 4 design the optimum transmission loss was 1.7 dB with a 0.24 dB ripple(8). This corresponds to a return loss of 4.9 dB which was considered excessive so it was decided to match the antenna on a narrow band basis and provide tuning. Matching was accomplished through use of a three step maximally flat transformer, since the antenna was known to be quite narrow.

The transformer has impedance values of 12.80 and 31.75 ohms which give line widths of 0.150 and 0.045 inches respectively. The width for a 50 ohm line is a narrow 0.021 inches so it was decided to shift the transformer toward the input location to keep line widths as wide as possible. This necessitated introducing a short section of 8.13 ohm line at the feed point which is 0.260 inches wide. The feed point is not directly connected, instead the feed line continues into a very low impedance open circuited stub that provides a virtual short at the feed point. This allows for no direct connection of the feed lines. When the input impedance was measured, the virtual short was tested by directly connecting the feed line. There was no significant difference in the two impedance plots.

This structure always promotes questions concerning the unbalanced feeding of a balanced antenna. This is possible because the input line enters at a virtual ground point where the electric field is zero and does not disturb the antenna.

MEASURED ANTENNA PARAMETERS

Figure 5 shows a return loss plot of the antenna taken at the top of the tuning range. The antenna exhibits a bandwidth of 4.5 MHZ at a return loss of 9.54 dB which corresponds to a VSWR of 2. As configured the antenna has a tuning range of 28.75 MHZ. The return loss at the center of the band is a bit low indicating some problem with the transformer. We suspect that our impedance measurement was done with insufficient grounding and that the impedance is actually lower than 8.13 ohms. This conclusion was based on the fact that the return loss improves when the antenna is operated unmounted.

A cursory test of the temperature properties was conducted in the laboratory by heating the harness cover with a heat gun to simulate in flight heating. We found the antenna to have a short term positive temperature coefficient of approximately 0.02 MHZ per degree Celsius.

In figures 6, 7, and 8 are shown the principal plane patterns of the antenna mounted on an AMRAAM missile mock-up. It should be observed that the missile was mounted upside down on the pedestal to reduce reflections since the AMRAAM normally flies with the harness cover down. The patterns demonstrate that the antenna meets the -12 dBi value used by Eugene Law in his link analysis at all required angles but as expected falls short of the 0 dBi figure which we considered unrealistic.

CONCLUSIONS

Design of antennas for missile application always present unique and stringent requirements. At lower frequencies these can become even more severe. The FTA design presented here is a solution to one of these problems. It demonstrates extended bandwidth over the popular patch antenna in the same application but falls way short of the intrinsic bandwidth attributable to the folded dipole. It demonstrates conclusively the difficulty of acquiring bandwidth for antennas very close to ground.

ACKNOWLEDGEMENTS

We acknowledge with pleasure the useful discussions with E. L. Law of PMTC and Dr. E. S. Gillespie of California State University, Northridge on the AMRAAM FTA development.

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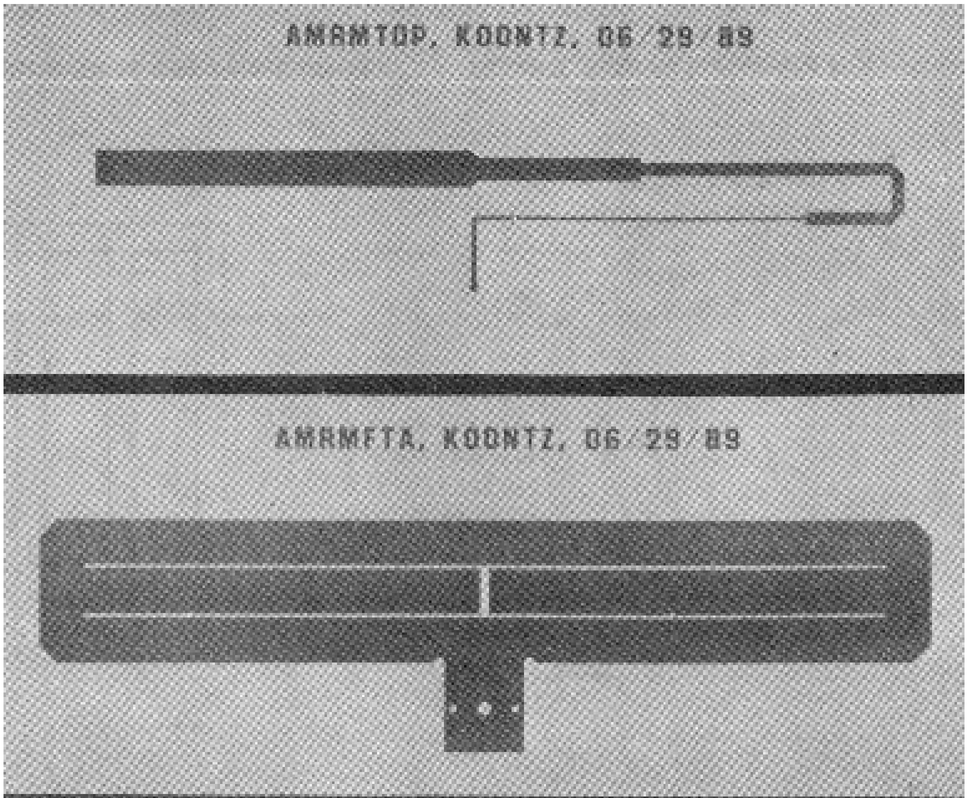

Figure 1. Antenna Printed Circuit Board.

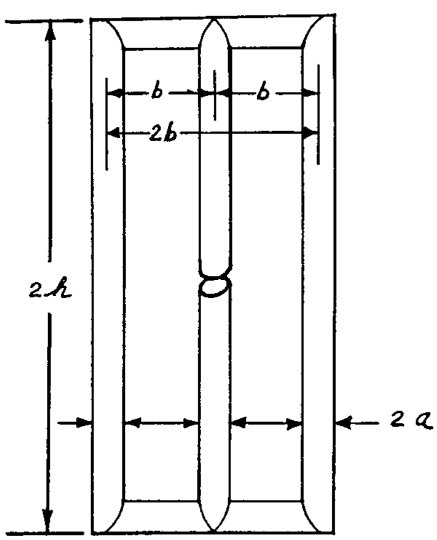

Figure 2. Coplanar Three-Wire Folded Dipole.

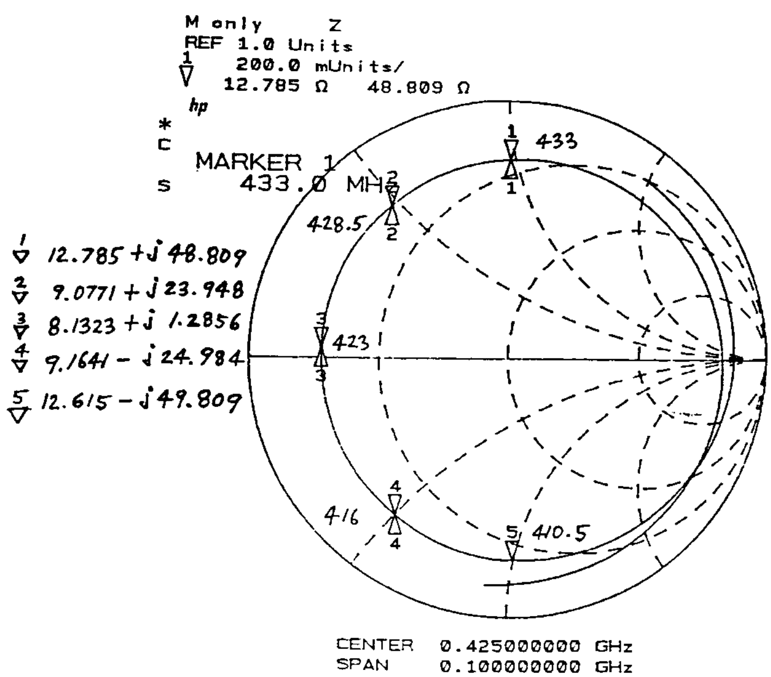

Figure 3. Antenna Impedance Plot.

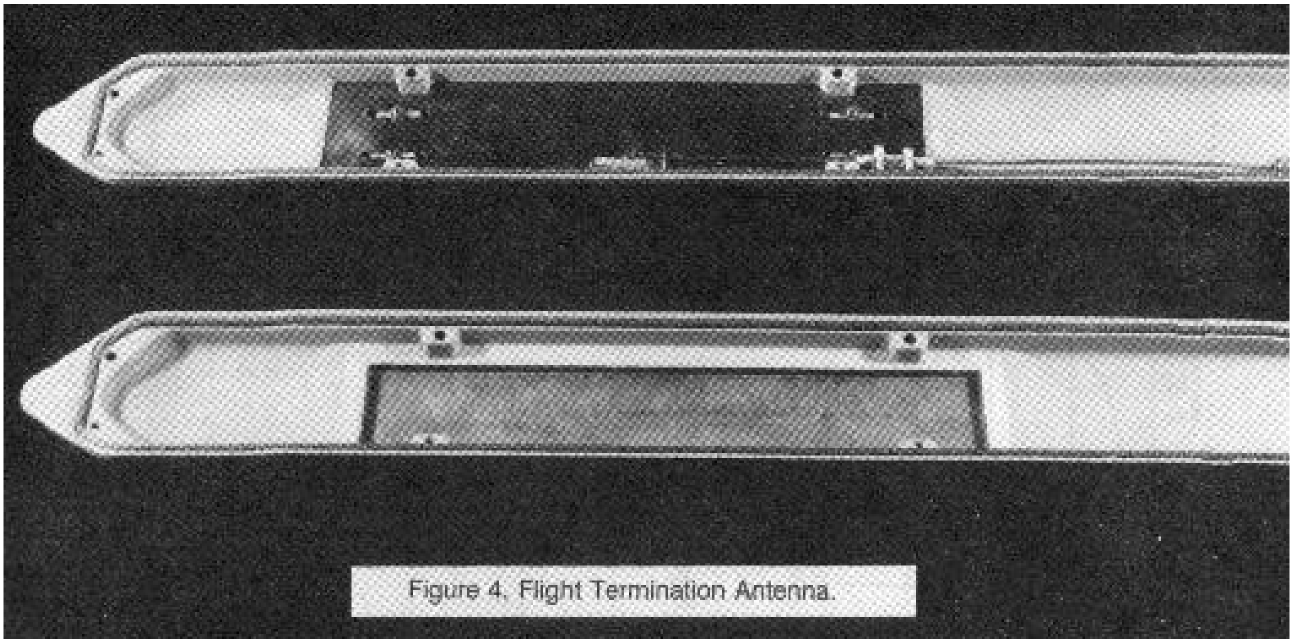

Figure 4. Flight Termination Antenna.

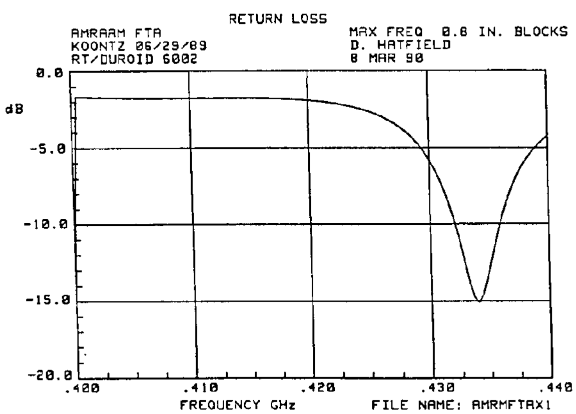

Figure 5. Return Loss.

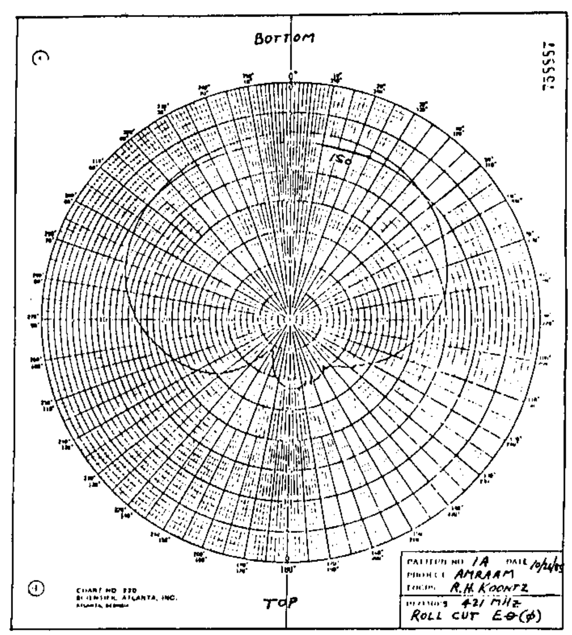

Figure 6. Roll Plane Cut.

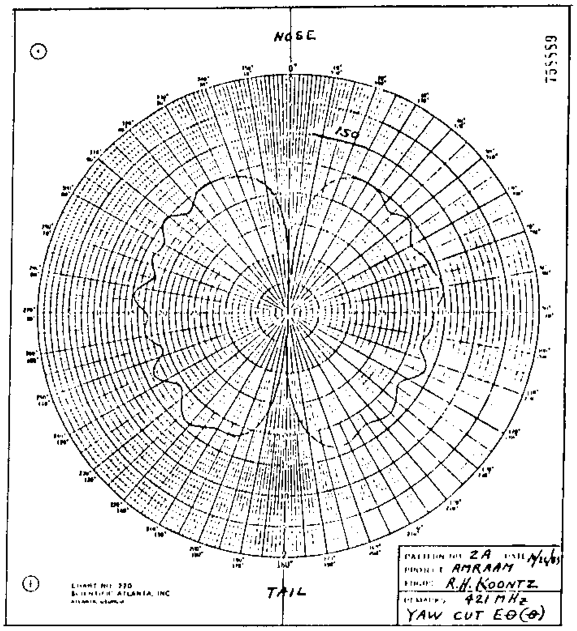

Figure 7. Yaw Plane Cut.

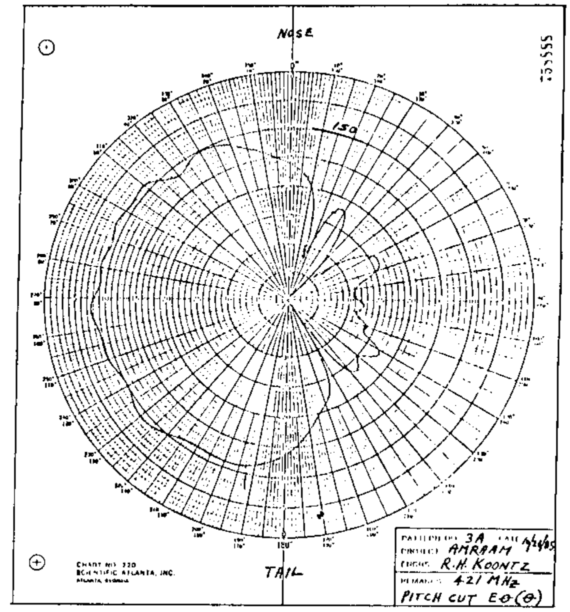

Figure 8. Pitch Plane Cut.