<u>RTCA Special Committee 186, Working Group 5</u>

<u>ADS-B UAT MOPS</u>

<u>Meeting #6</u>

UAT
A Case for Gain Antennas

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SUMMARY

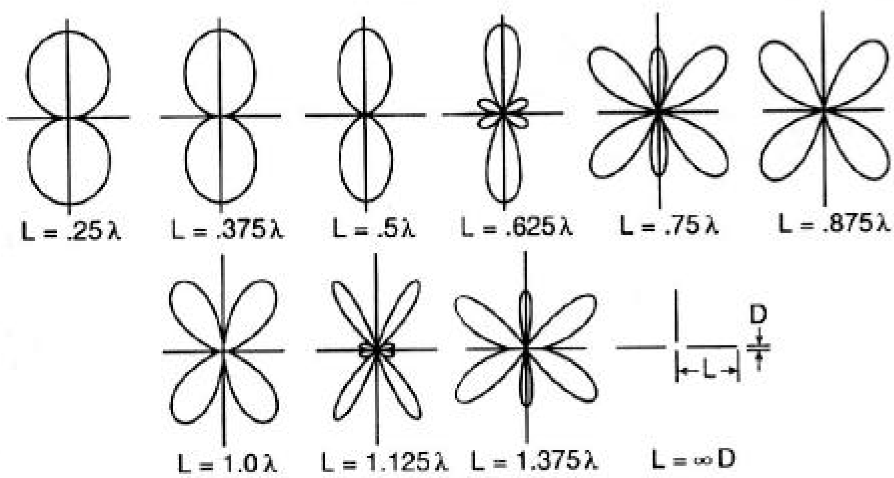
This paper examines the feasibility of using gain antennas to allow using lower power transmitters for UAT applications. Various types of gain antennas are presented then vertical and horizontal communication ranges are explored. Practical considerations are compared to theoretical calculations. Finally, existing ¼-wavelength antennas; as currently used on airborne transponders, DMEs and experimental UATs; are examined.

1. Introduction

Using antennas that provide uniform gain in the horizontal plane can achieve greater range requirements without incurring the exponential cost of added power amplifier stages. Gain in the vertical plane is somewhat reduced depending on the type of antenna.

2. Candidate Gain Antennas

Several candidate antennas are shown in figure 1 below. Since the antenna is shown horizontally, the pattern would be rotated 90 degrees when mounted on the top or bottom of and aircraft. The first four antennas provide gain in the aircraft's horizontal plane while providing reasonably uniform gain in the vertical plane. As expected, the vertical gain is somewhat reduced.



L/λ	Directivity (dBi)
0.25	2.151
0.375	2.746
0.5	3.822
0.625	5.162
0.75	3.474
0.875	3.748
1.0	4.026
1.125	4.867
1.375	4.914

Figure 1. Relative patterns of various wavelength antennas [2].

3. Range Requirements in the Aircraft's Vertical Plane

Reduced vertical antenna gain is not necessarily a bad thing, if we consider that the maximum vertical range that aircraft operate over is 55,000 feet. This translates into roughly 9 nautical miles. Practically vertical ranges required for separating aircraft are much smaller: on the order of 500 to 5000 feet, but let's just assume the 9 nautical miles as a worst case. At this range, even a 5-watt transmitter will produce an –91-dBm signal at the receiver using a pair of -6 dBi (-8dBd or 11 dB null on the 5/8 wave) gain antennas, as illustrated below.

Pr = (5 watts)*(0.25)*(0.25)*[(305.81E-3) / (4*PI*9*1.6093E3)]^2 = 8.82E-13 watts => -91 dBm

The 3/8, ½, and 5/8 wavelength antennas, shown in figure 1, will each yield more gain in the horizontal plane when compared to a ¼ antenna typically used for transponder and DME applications. Of these four uniform horizontal plane radiators, the 5/8-wavelength antenna has by far the greatest gain in the horizontal plane.

4. The 5/8 wavelength Antenna

The reason why a 5/8 wavelength antenna has a higher gain than that of a ¼ wavelength antenna is that its antenna aperture is larger, and the rise of the radiation beam due to the finite ground plane is less than that of a ¼ wave antenna. The current distributions are covered in antenna textbooks in greater detail to those interested. Unlike the 3/8 and ½ wavelength antennas, the 5/8 wavelength antenna's input impedance can be set to roughly 50 ohms if a series coil with an effective wavelength of 1/8 is placed between the 5/8 wave element and the ground plane. This typical 5/8-wave antenna structure is shown below.

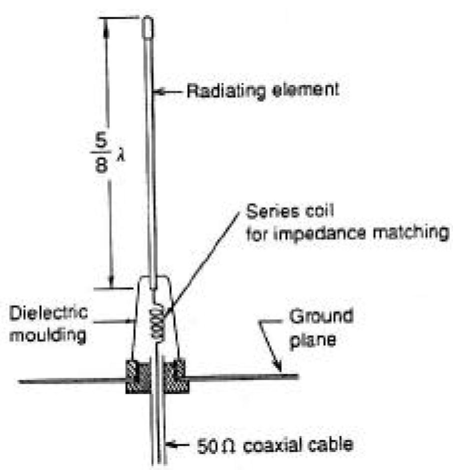


Figure 2. Structure of a typical 5/8-wavelength antenna over a ground plane [1].

So with a small sacrifice in gain in the vertical plane, a 5/8-wavelength antenna can provide 5.162 dBi gain versus the ¼ wave's 2.51 dBi gain. That's 2.65 dB gain over a ¼ wavelength antenna with the same 50-ohm antenna input impedance [1].

5. Horizontal range with a Gain Antenna

If we assume an antenna gain of 5.162 dBi (2.65 dBd) for the aircraft antenna and 8 dBi (6 dBd) for the ground surveillance antenna with a 5 watt power level at the aircraft's gain antenna, the 1^{st} mile received signal level is as follows:

Pr = (5watts) * (3.28) * (6.31) [(305.81E-3) / (4*PI*1.6093E3)]^2 = 23.66 nanoWatts => -47 dBm

Assuming a receiver sensitivity of –93 dBm, the surveillance station can hear a UAT signal out to186 nautical miles under line-of-sight conditions.

6. Theoretical vs. Practical patterns over a non-perfect ground plane

Waves radiated from an antenna into a ground plane are reflected back into the antenna pattern. The magnitude and phase of the resulting current from the voltage induced by the reflected waves depends on the height of the antenna above the reflecting surface. So the total current in the antenna pattern consists of two components: power from the transmitter as seen across the free space radiation resistance of the antenna and the induced power from the wave reflected from the ground plane (or any nearby surface or structure including other aircraft antennas). Changing the height of the antenna above the ground alters the radiation pattern as shown in figures 3 below [3].

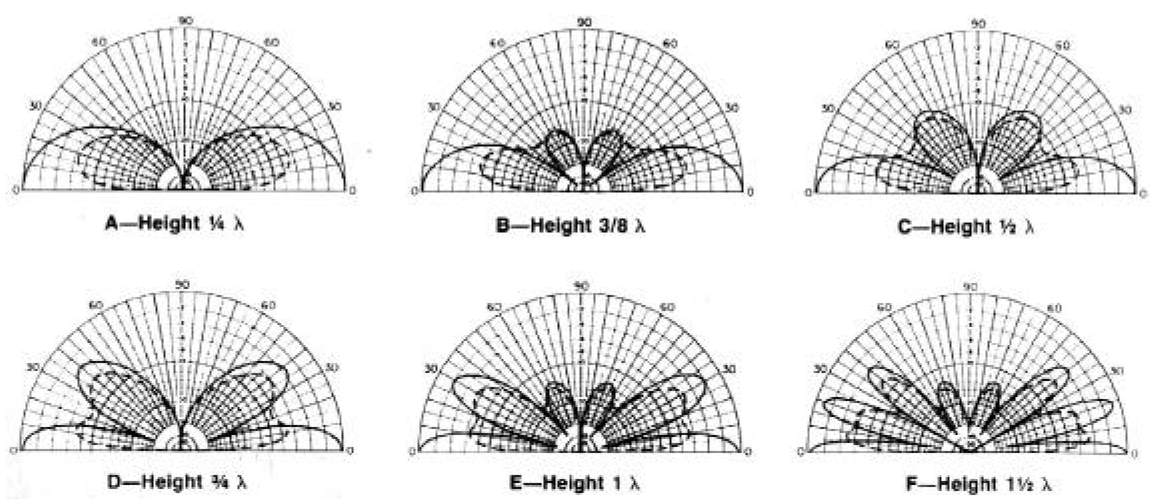


Figure 3. Radiation patterns of vertical ½ wave antennas at various heights above a ground plane [3].

It is interesting to note is that the nulls predicted in theory are not always realized in practice. The solid lines in figure 3 represents patterns predicted by theory assuming a perfectly conducting ground. The shaded patterns are actual measurements. Note that the shaded nulls are much softer and not as prominent as are those of the solid lines.

6. Measured Airframe effects on UHF and VHF Patterns

Deep nulls have been observed in aircraft using conventional ¼ wave antennas. For instance, even when this antenna is placed on the top on the aircraft's vertical stabilizer to give a relatively unobstructed view, nulls occur as depicted in figure 4 [4].

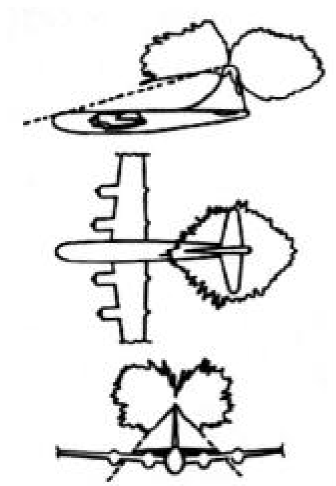


Figure 4. Measured radiation patterns of a 1000 MHz ¼ wave antenna on the tip a B-50 aircraft's vertical stabilizer [4].

Deep nulls can occur in the forward quadrants because of the destructive interference between the antenna's direct radiation and the radiation reflected from the aircraft's fuselage and wings. The effect becomes more important in smaller aircraft since the vertical stabilizer is closer to the reflecting surface of the fuselage and wings [4].

Most aircraft antennas are mounted on the top or bottom of the aircraft fuselage close to the centerline. Measurements on the radiation pattern of a ¼ wavelength 1000 MHz antenna mounted on the belly of a C-141 are shown in figure 5.

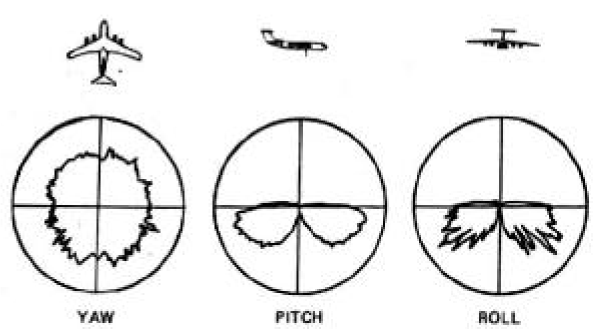


Figure 5. Measured radiation patterns of a 1000 MHz ¼ wave antenna on the bottom of a C-141 aircraft [4].

What's apparent is that the top antenna is confined to the upper hemisphere and the bottom antenna is limited to the hemisphere below the aircraft.

Not so apparent are the deep lobs present in the vertical (roll and pitch) plane of conventional ¼ wave antennas at 1000 MHz currently used in airborne transponders and DME equipment. "The deep lobing in the roll-plane pattern, " shown above in figure 4, "is due to reflections from the strongly illuminated engine nacelles. In some locations similar difficulties are encountered because of reflections from the wing flaps when they are extended. Shadows and lobing due to the landing gear, when extended, are frequently troublesome." [4].

"In many applications, as, for example, in scheduled-airline operations, these pattern limitations are acceptable, and fuselage locations are frequently used." [4]

7. Conclusions

We have shown that the range in the horizontal direction can be increased using gain antennas. Although a 5/8-wavelength antenna was used as an example, other designs that yield equivalent gains may be acceptable.

The maximum required vertical range is currently 55,000 feet, which translates to 9 nautical miles. At this worst case scenario, two UATs each equipped with –6 dBi gain antennas can communicate using 5 watts. Practical distances are smaller, as the majority of airlines operate between FL200 and FL350 (20,000 feet and 35,000 feet or 2.5 nautical miles). Most piston aircraft operate above 3,000 and below 18,000 feet on a typical cross-country flight (also 2.5 nautical miles). Compared to 9 nautical miles, operating at a vertical distance of 2.5 nautical miles will yield another 11 dB of margin.

Deep nulls already exist in current ¼ wave antennas in the vertical plane. Given real aircraft with metallic engines, wings, landing gear, flaps and other appendages, the situation is not likely to change.

Higher gain antennas will allow for lower powered transmitters. Lower power transmitters can keep costs down significantly in the equipage classes that are most sensitive to pricing.

8. References

[1] Fugimoto, K. and James, J.R., “Mobile Antenna Systems Handbook,” pp. 152-170, Boston: Artech House, 1994.

[2] Hahn, R.F. and Fikioris, J.G., “Impedance and Radiation Pattern of Antennas Above Flat Discs,” *IEEE Trans. Antennas and Propagation*, Vol. AP-21, No. 1, Jan. 1973, pp. 97-100.

[3] Hall, Gerald et al, “The ARRL Antenna Book,” pp. 3-7 through 3-7, Newington: American Radio Relay League, 1988.

[4] Johnson, Richard C. et al, “Antenna Engineering Handbook,” pp.37-25 through 37-29, New York: McGraw-Hill, 1961.