

ADAPTIVE CROSSED DIPOLE ANTENNAS

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ABSTRACT

Crossed dipoles generate circular polarization at broadside. Moving away from broadside causes the polarization to become elliptical and the antenna gain to go down. By adaptively changing the amplitude and phase of one of the dipoles, the gain and polarization may be optimized to maximize power transfer between the transmit and receive crossed dipoles. A genetic algorithm maximizes the power transfer between the transmit and receive dipoles in a short period of time and increases the link budget by several dB.

INTRODUCTION

As a spacecraft maneuvers in space, the antennas in the communications system no longer align for optimum power transfer. Antenna engineers design the antennas for maximum gain and a polarization match when the antennas point at each other. If one or both antennas do not point at each other, then the Friis transmission formula shows a reduction in the antenna gain and a polarization mismatch. Thus, the power transfer goes down.

An obvious solution is to keep the antennas pointing at each other. Often times, maneuvering the spacecraft or the ground antenna is out of the question. Even if the antenna is a phased array, the gain can be steered, but the polarization mismatch cannot be improved. One way to improve the link budget is to adaptively change the antenna polarization and gain to maximize the power transfer. The polarization and gain of the receive and/or transmit antennas can be adaptively changed to improve the link budget.

The polarization and gain of a crossed dipole antenna are easy to control. A crossed dipole consists of two or three orthogonal dipoles. Each dipole is fed by its own source. Controlling the amplitude and phase of the signal at a dipole modifies the radiation pattern and the polarization of the crossed dipole. Previous adaptive antenna work emphasized steering the beam of an array antenna [1] or altering the axial ratio of the antennas to adjust for depolarization of signals passing through rain [2]. This paper uses a genetic algorithm to control the currents from a single receive crossed dipole to optimize the power transferred in the communications link.

CROSSED DIPOLES

A crossed dipole is used for both the transmit and receive antennas, so the gain and polarization of both antennas can be controlled. The receive antenna is located at an angle of (θ_r, φ_r) from the transmit antenna. Similarly, the transmit antenna is located at an angle of (θ_t, φ_t) from the receive antenna. In order to determine the gain and polarization of the antennas, the electric fields must be found.

The crossed dipole current is the sum of the constant currents on each short dipole.

$$I(r') = I_x \hat{x} + I_y \hat{y} \quad (1)$$

Substituting this current into the equation for the magnetic vector potential for a short dipole yields

$$A = \frac{\mu e^{-jkr}}{4\pi r} (I_x L_x + I_y L_y) \quad (2)$$

where

r = distance from the origin to the field point at (x, y, z) ,

- L = dipole length
- ω = radial frequency
- k = wave number,
- μ = permeability,
- $I_{x,y}$ = constant current in x or y direction.

The electric field in rectangular coordinates is found from the magnetic vector potential by

$$E = \frac{-j\omega}{k^2} (k^2 A + \nabla \nabla \cdot A) \quad (3)$$

The model consists of two orthogonal short dipoles as shown in Figure 1. The transmitted electric field is

$$E_x = \frac{-j\omega\mu e^{-jkr}}{4\pi k^2 r^5} \left\{ \begin{aligned} & \left[r^4 k^2 + 3x^2 - r^2 - k^2 x^2 r^2 + jkr(3x^2 - r^2) \right] I_x L_x \\ & + (-k^2 r^2 + 3 + 3jkr) xy I_y L_y \end{aligned} \right\} \quad (4)$$

$$E_y = \frac{-j\omega\mu e^{-jkr}}{4\pi k^2 r^5} \left\{ \begin{aligned} & \left[r^4 k^2 + 3y^2 - r^2 - k^2 y^2 r^2 + jkr(3y^2 - r^2) \right] I_y L_y \\ & + (-k^2 r^2 + 3 + 3jkr) xy I_x L_x \end{aligned} \right\} \quad (5)$$

$$E_z = \frac{-j\omega\mu e^{-jkr}}{4\pi k^2 r^5} \left\{ (-k^2 r^2 + 3 + 3jkr) (yz I_y L_y + xz I_x L_x) \right\} \quad (6)$$

Converting the rectangular form of the electric field into spherical coordinates produces

$$E_r = E_x \sin \theta \cos \varphi + E_y \sin \theta \sin \varphi + E_z \cos \theta \quad (7)$$

$$E_\theta = E_x \cos \theta \cos \varphi + E_y \cos \theta \sin \varphi - E_z \quad (8)$$

$$E_\varphi = -E_x \sin \varphi + E_y \cos \varphi \quad (9)$$

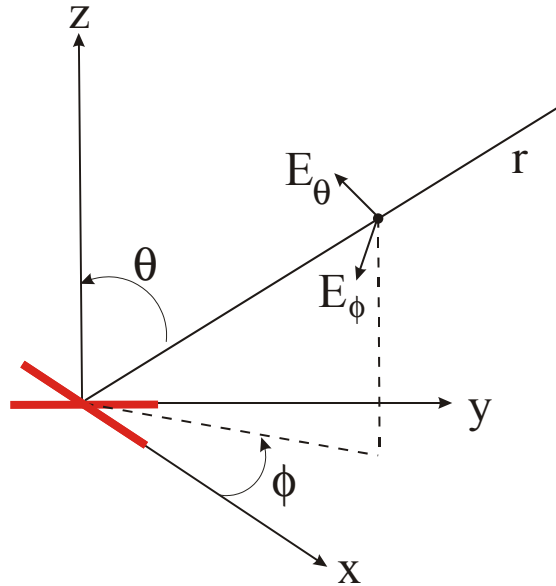


Figure 1. Crossed dipole layout.

The directivity is given by

$$D(\theta, \varphi) = 4\pi \frac{|E_\theta(\theta, \varphi)|^2 + |E_\varphi(\theta, \varphi)|^2}{\int_0^{2\pi} \int_0^\pi \left[|E_\theta(\theta, \varphi)|^2 + |E_\varphi(\theta, \varphi)|^2 \right] \sin\theta d\theta d\varphi} \quad (10)$$

and the polarization loss factor is given by

$$PLF = \frac{E_{\theta_t}}{\sqrt{E_{\theta_t}^2 + E_{\varphi_t}^2}} \frac{E_{\theta_r}}{\sqrt{E_{\theta_r}^2 + E_{\varphi_r}^2}} + \frac{E_{\varphi_t}}{\sqrt{E_{\theta_t}^2 + E_{\varphi_t}^2}} \frac{E_{\varphi_r}}{\sqrt{E_{\theta_r}^2 + E_{\varphi_r}^2}} \quad (11)$$

where $0 \leq PLF \leq 1$ with $PLF = 1$ a perfect match.

ADAPTATION

The following objective function returns the portion of the link budget relating to polarization and gain:

$$O(I_x, I_y) = -D_t \times D_r \times PLF \quad (12)$$

where D_t is the directivity of the transmit crossed dipoles in the direction of the receive crossed dipoles, and D_r is the directivity of the receive crossed dipoles in the direction of the transmit crossed dipoles. The negative sign makes this a minimization problem. A continuous parameter genetic algorithm was used to find the values of the amplitude and phase of the receive dipole currents that minimize (12). The GA has a population size of 8, mutation rate of .2, single point crossover, and 50% replacement. This small population size and high mutation rate results in a very fast convergence as will be shown in the following section.

Consider the example where both the transmit and receive antennas are crossed dipoles in only the x and y directions. The transmit antenna is right-hand circularly polarized. The receive antenna is located at $(\theta_t, \varphi_t) = (\pi/3, \pi/3)$ in transmit coordinates and the transmit antenna is located at $(\theta_r, \varphi_r) = (\pi/3, \pi/4)$ in receive antenna coordinates. The received power increased by 5.7 dB in about 30 power measurements. The adapted receive dipole had $I_x = 1$ and $I_y = -0.77 - j0.38$ which results in a directivity of 1.43 and an inverse axial ratio of 0.12. The directivity of the transmit antenna in the receive antenna direction has a directivity of 0.93 and inverse axial ratio of 0.5. Figures 2 and 3 are plots of the inverse axial ratio and directivity of the transmit and unadapted receive antennas. Figures 4 and 5 are plots of the inverse axial ratio and directivity of the adapted receive antenna.

CONCLUSIONS

The received signal in a mobile communications system loses strength due to a decrease in antenna gain and polarization mismatch. The current fed to a set of crossed dipoles can be modified to increase the gain and polarization match between the transmit and receive antennas.

REFERENCES

- [1] R.T. Compton, Jr., *Adaptive Antennas Concepts and Performance*, Englewood Cliffs, NJ: Prentice Hall, 1988.
- [2] R. E. Marshall and C. W. Bostian, "An adaptive polarization correction scheme using circular polarization," *IEEE International Antennas and Propagation Society Symposium, Atlanta, GA*, pp. 395-397, June 1974.

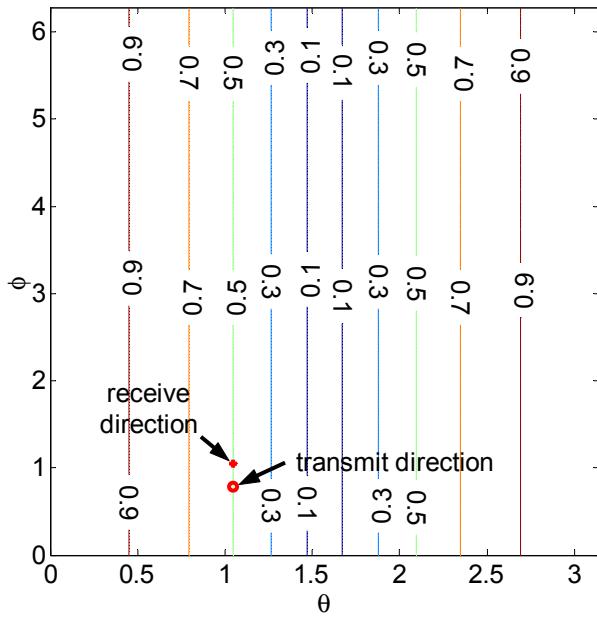


Figure 2. Plot of the inverse axial ratio as a function of angle for the transmit antenna and unadapted receive antenna.

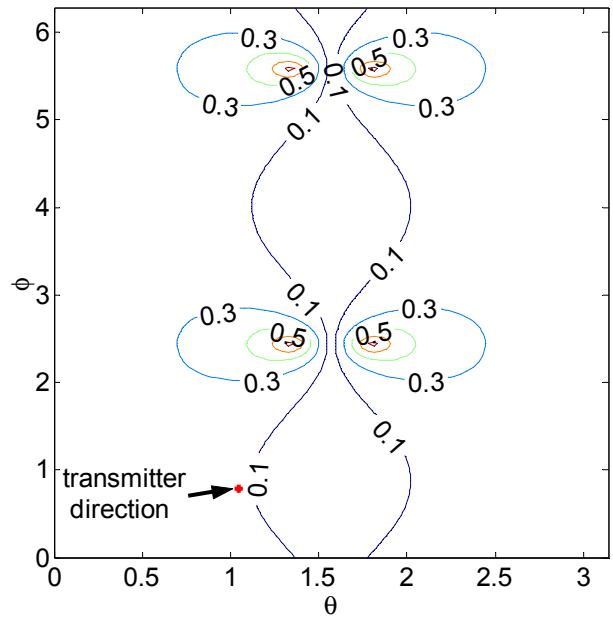


Figure 4. Plot of the inverse axial ratio as a function of angle for adapted receive antenna.

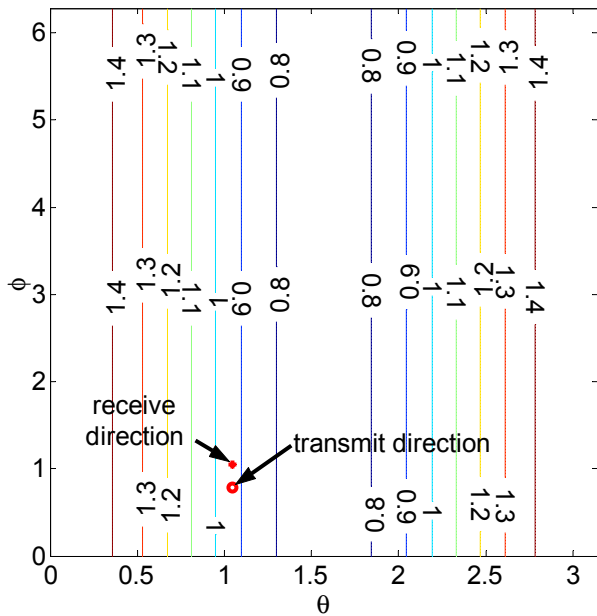


Figure 3. Plot of the directivity as a function of angle for the transmit antenna and unadapted receive antenna.

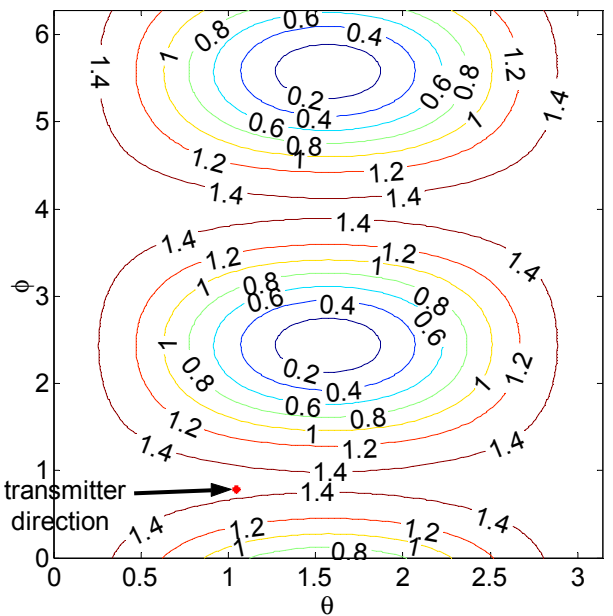


Figure 5. Plot of the directivity as a function of angle for adapted receive antenna.