Direction Finding
Stereo

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Abstract

Direction Finding is the process of finding the 6 parameters that define an electromagnetic (EM) wave. It will be a vital part of the STEREO mission, conducted by NASA, to be launched in spring 2006. In this paper, I will outline the methods and equation systems available to date, in regard to the the STEREO mission.

1 Introduction

STEREO is a space mission, conducted by NASA, to be launched in spring 2006. The mission consists of two space probes which will enter a heliocentric orbit. One spacecraft will orbit sun ahead of the earth, the other behind.

The scientific goal of the mission is to increase our knowledge of the physics of our solar system, especially:

- Understanding the causes and mechanisms of CME initiation
- Characterize the propagation of CMEs through the heliosphere
- Discover the mechanism and sites of energetic particle acceleration in the low corona and the interplanetary medium
- Develop a 3D time dependent model of the magnetic topology, temperature, density and velocity structure of the ambient solar wind.

Among several other experiments, one particular important is STEREO WAVES (SWAVES). This experiment is designed to track interplanetary radio bursts and trace the generation and evolution of radio disturbances from the sun to earth orbit and beyond. Each spacecraft has three, nearly orthogonal, antennas. With this configuration, it is possible to perform direction finding (DF) to find the direction of the origin of the received radiation and information about its polarization. When both spacecraft receive radiation from the same source at the same time, the actual location of the source can be pinpointed by the method of triangulation.

SWAVES uses 3, nearly orthogonal, antennas to receive EM radiation in the frequency range of XXX. The output of the receiver is a combination of auto and cross correlation parameters, depending on the mode in use. All different combinations of correlation parameters can be obtained. The spacecraft will maintain a fixed orientation in space, a fact that has to be considered, when doing the analysis of possible methods of direction finding.

2 DF Basics

The following figure defines the symbols and coordinate system which will be used throughout this paper.

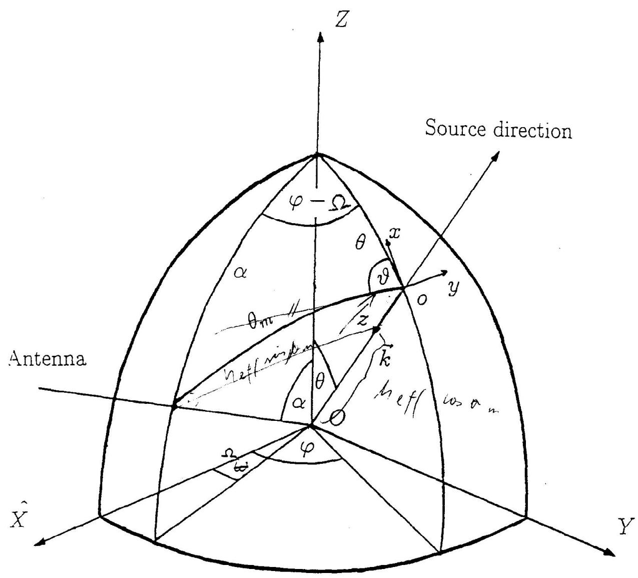

Figure 4 *Coordinate systems used throughout the text showing the antenna system (X,Y,Z) and the wave system (x,y,z).*

X, Y and Z define the spacecraft centered orthogonal cartesian coordinate system, while x,y and z define the coordinate system of the incident electromagnetic wave. The wave vector $\mathbf{k}$ is points in the positive z-axis, so the equation of the electric field of the wave is

$$\mathbf{E} = \mathbf{E}_0 e^{i(\mathbf{k}\cdot\mathbf{r}-\omega t)} \tag{1}$$

The electric field is the sum of the components in x and y direction. There is no component in the z direction.

$$\begin{aligned} \mathbf{E} &= E_x \mathbf{e}_x + E_y \mathbf{e}_y && (2) \\ E_x &= E_{0,x} e^{i(kz-\omega t)} && (3) \\ E_y &= E_{0,y} e^{i(kz-\omega t-\delta)} && (4) \end{aligned}$$

δ is the phase shift between the x and y components of the E-field. The direction of the incident wave is defined by the angles ϑ and φ, the effective height vector [Rucker et al. XXX] points to the direction that is defined by the angles α and Ω.

The 4 Stokes Parameter define the polarisation of the wave. They can be written in the following form:

$$S_0 = I = \langle E_x^2 \rangle + \langle E_y^2 \rangle \tag{5}$$

$$S_1 = q = \langle E_x^2 \rangle - \langle E_y^2 \rangle \tag{6}$$

$$S_2 = u = \langle 2 E_x E_y \cos\delta \rangle \tag{7}$$

$$S_3 = v = \langle 2 E_x E_y \sin\delta \rangle \tag{8}$$

The Stokes Parameters are more useful in normalized form.

$$\begin{aligned} \frac{S_0}{2Z} = \hat{I} &= \frac{\langle E_x^2 \rangle + \langle E_y^2 \rangle}{2Z} && (9) \\ \frac{S_1}{S_0} = \hat{q} &= \frac{\langle E_x^2 \rangle - \langle E_y^2 \rangle}{\langle E_x^2 \rangle + \langle E_y^2 \rangle} && (10) \\ \frac{S_2}{S_0} = \hat{u} &= \frac{\langle 2 E_x E_y \cos\delta \rangle}{\langle E_x^2 \rangle + \langle E_y^2 \rangle} && (11) \\ \frac{S_3}{S_0} = \hat{v} &= \frac{\langle 2 E_x E_y \sin\delta \rangle}{\langle E_x^2 \rangle + \langle E_y^2 \rangle} && (12) \end{aligned}$$

The output values of the measurements are the auto- and crosscorrelation parameters. For two antennas X and Z, they would be

$$\begin{gathered} \langle V_X V_X^* \rangle \\ \langle V_Z V_Z^* \rangle \\ Re\,\langle V_X V_Z^* \rangle \\ Im\,\langle V_X V_Z^* \rangle \end{gathered}$$

V_i is the voltage induced in antenna i and the star means the complex conjungate. The angular brackets mean the mean value. In general, for a complex function $C(t)$,

$$\langle CC^* \rangle = \frac{1}{T}\int_0^T CC^* dt \tag{13}$$

This equation gives only a good result, if T is large in relation to the periode of the EM wave. So the next step is to find a formula for V. The basic equation, upon which the method is built, is

$$V = \mathbf{h}_{eff} \cdot \mathbf{E} \tag{14}$$

$\mathbf{h}_{eff}$ is the effective length vector. The radiation pattern of the antenna is, as if it was a sole monopole that points in the direction of $\mathbf{h}_{eff}$ and with the same length. In general, the effective length vector depends on the frequency and direction of the incoming wave, fortunately, these dependencies can be neglected at the frequencies that are used by the SWAVES experiments. Also, at wavelength that are much larger than the antenna, the magnitude of the effective length vector can be taken half of the physical lenght of the antenna. [Macher, XXX]

When written in component form, one can write

$$V = h_{eff,x}E_x + h_{eff,y}E_y \tag{15}$$

After substituting equations (3) and (4)...

$$V = h_{eff,x}E_{0,x}e^{i(kz-\omega t)} + h_{eff,y}E_{0,y}e^{i(kz-\omega t-\delta)} \tag{16}$$

If the antenna is located at z=0 and short in relation to the wavelength, it can be simplified.

$$V = h_{eff,x}E_{0,x}e^{i(\omega t)} + h_{eff,y}E_{0,y}e^{i(\omega t-\delta)} \tag{17}$$

Hence, the next step is to find the x and y components of $\mathbf{h}_{eff}$.