Definition of Variables and Directions
Data flow from Raw to processed delta E-field data.

(Version 1.0 by Gao-Peng Lu / February 2005)
(Version 2.0 modified by Richard Sonnenfeld / March 2005)

1. Raw Data and Corrections thereto

The actual raw data values are A/D counts on the 16-bit A/D used by the Diamond Prometheus sonde mainboard. The board and driver have several settings. The settings selected for the Esonde project have the board/driver (Prometheus/DSCUD) provide integers directly into system memory on each data acquisition cycle. The integers (-9999 to 9999) represent –9.999 to 9.999 volts. We represent these integers by N_0 - N_3. Different settings of the board and driver could result in a different range of N, but we assume the board setup remains consistent., and thus it is accurate to refer to the N's as "raw-data". The actual raw-data (16 bit A/D counts) are never seen at any stage of our program.

The Balloon_TX program begins each data acquisition run by acquiring a set of offsets. It obtains these by cycling through all 16 channels of the board and recording the A/D value. The only sense in which these "offsets" are accurate is if one can assume that all the analog sensors are reading 0. This assumption in invalid for all the sensors but E-field. (For example, the Earth's B-field is certainly present at power on, and the temperature outside is likely not 0 C, nor is the pressure 0 torr.). In the future, we might obtain accurate offsets for some purposes by grounding all inputs of the A/D board before running the offset acquisition program. However, for the purpose of calculating E-fields, the offsets have some value. Because the delta-E board returns to baseline several seconds after a field change, and because the ambient field is likely to be constant when the sonde is first powered on, the offsets measured capture a combination of actual A/D offset and (the dominant factor) the DC offset shifts of the A/D board itself. Because of the circuit design, these shifts can be as large as 0.2 V (200 A/D counts). Balloon_TX creates a NNNNNNN_HH_MM.cal file. The cal file contains the offsets ($o_0 - o_{15}$) as decimal volts. There is (as yet) no gain calibration file, but one can imagine gain factors for the E-field board ($g_0 - g_3$). The gain factors are predicted to be in the range 0.98-1.02 based on the accuracy specifications of the components used in the E-field circuit and some bench testing of the response of several boards to sine-wave charge inputs.

Finally then, we calculate the V's in terms of the N's as follows.

$$V_I = g_I \times \left(\frac{N_I}{10000} - o_I \right)$$

2. Multiple sets of variables for same quantity

Table 1 shows 4 sets of variables for E-field. This is for clarity and consistency in data processing. The first 2 sets refer to the raw signals measured at individual sense plates. Sets 3 and 4 are both obtained by processing the raw data. The goal is ultimately to get

vector E-field information relative to the fixed Earth reference frame, but the first information is always sonde referenced (thus SE_X, SE_Y, SE_Z).
After calculating the sonde referenced values, we correct for the absolute sonde orientation (using the B-field information) to yield Earth referenced data.

3. Definition of positive direction for E-fields

Our individual amplifier channels were designed to be consistent with the 'lightning' or 'charge' convention, in that the sign of the output is the same as the size of the dominant charge in the neighborhood of the electrode. Thus, buffed Teflon (negatively charged) creates a negative voltage out of the amplifier when brought near. This is a useful fact to know. However, we have elected to represent electric fields using the "physics convention" rather than the old atmospheric-electric or charge convention. Thus, since a the presence of negative charge above the electrode induces positive charge on the electrode and has the same effect as a positive electric field (that is a field vector emanating from the electrode and pointing away from it), we wish to flip the sign of our outputs in additional calculations.

This can only be completely clear if you look at the definitions in the table.
Defining:

$SE_X = (V_1 - V_0) \cdot \frac{\Gamma_{IP}}{p \cdot G_{xcal}}$ We see that if the E-field (physics convention) points along the arrow labeled SE_X in figure 1, then the function $SE_X(V_1, V_0) > 0$. Similarly $SE_Y(V_3, V_2) > 0$ if the E-field vector points as specified under SE_Y. Finally, if the E-field vector points up (fair weather field), $SE_Z(V_0, V_1, V_2, V_3) > 0$. Note that this is a right-handed coordinate system, as it should be.

To unify the variable definition in later data processing, we define the variables associated with electric field as listed in Table 1. With the definition of the positive direction for electric fields in the Sonde frame, for example, if we have a positive SE_x, then the dominant charge nearby Sensor 0 is negative, which leads to a negative output for channel 0, while the channel 1 output is positive. Thus, to assure that the positive electric field corresponds with a positive value, the formula to get the electric field with the combination of channel data should be as shown below.

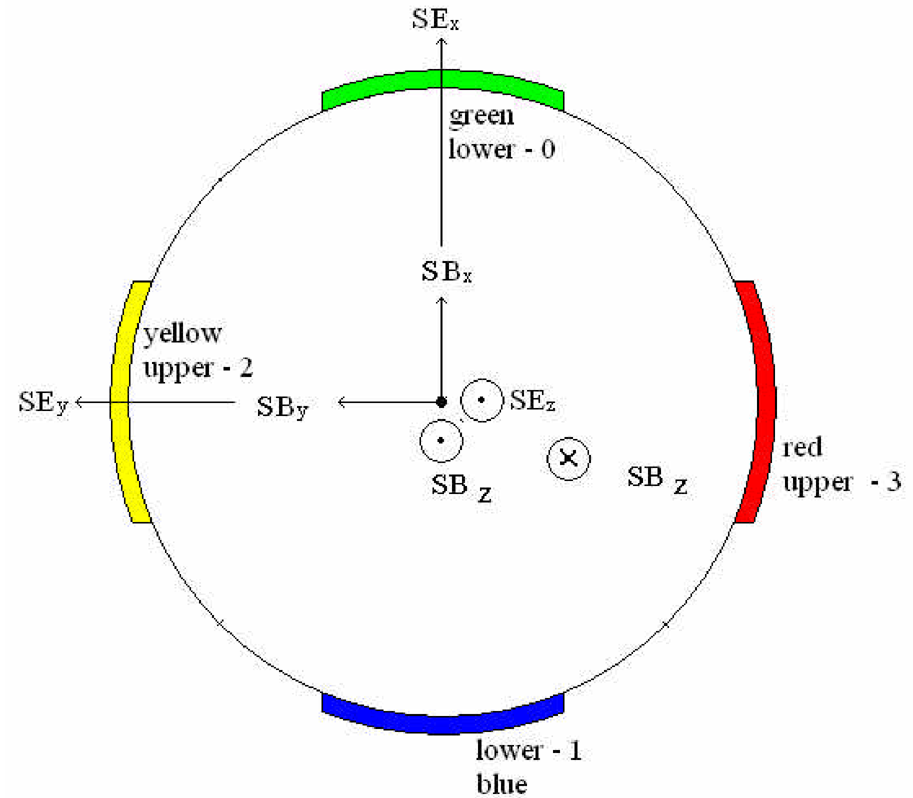

Figure 1. The top view of Sonde.

Set No.	Variable	Physical meaning
0	N_0	Integer value (-9999-9999) A/D channel 0
	N_1	Integer value (-9999-9999) A/D channel 1
	N_2	Integer value (-9999-9999) A/D channel 2
	N_3	Integer value (-9999-9999) A/D channel 3
1	V_0	Corrected Output voltage on ch 0
	V_1	Corrected Output voltage on ch 1
	V_2	Corrected Output voltage on ch 2
	V_3	Corrected Output voltage on ch 3
2	SE_x	x component in Sonde reference frame
	SE_y	y component in Sonde reference frame
	SE_z	z component in Sonde reference frame
	$SE_\perp$	$\sqrt{SE_X^2 + SE_Y^2}$
	Sf_E	The sonde-referenced angle the E-field vector makes w.r.t. x in Sonde x-y plane

	Sq_E	The sonde-referenced angle the E-field vector makes w.r.t. z in Sonde x-z plane
3	E_x	x component in Earth reference frame
	E_y	y component in Earth reference frame
	E_z	z component in Earth reference frame

Table 1. Definition of variables (E).

For single plate in the ideal buried guarded plate geometry, there is a simple relation (Γ_{IP}, for "ideal-plate gain") between the output voltage and the ambient electric field as follows,

$$V_{out} = e_0 EA \frac{G_2}{C_1} = \Gamma_{IP} \times E \Rightarrow E / V_{out} = \Gamma_{IP} = 24.8 \times 10^3 \mathrm{m}^{-1} .$$

What should be noted is that when using the combination of several plates to determine the ambient electric field, the transformation factor should be modified by the number (p) of the plates included, that is

$$SE_x = (V_1 - V_0) \cdot \frac{\Gamma_{IP}}{p \cdot G_{xcal}} = (V_1 - V_0) \cdot \frac{24.8\ \mathrm{kV/m}}{2 \cdot 1} \text{; and}$$

$$SE_y = (V_3 - V_2) \cdot \frac{\Gamma_{IP}}{p \cdot G_{ycal}} = (V_3 - V_2) \cdot \frac{24.8\ \mathrm{kV/m}}{2 \cdot 1} = (V_3 - V_2) \cdot 12.4\ \mathrm{kV/m} \text{; and}$$

$$SE_z = (V_0 + V_1 - V_2 - V_3) \cdot \frac{\Gamma_{IP}}{p \cdot G_{zcal}} = (V_0 + V_1 - V_2 - V_3) \cdot \frac{24.8\ \mathrm{kV/m}}{4 \cdot 1} = (V_0 + V_1 - V_2 - V_3) \cdot 6.2\ \mathrm{kV/m}$$

where G_{xcal}, G_{ycal} and G_{zcal} are correction factors due to distortion by the configuration of Sonde.

In the above calculations, $G_{xcal} = G_{ycal} = G_{zcal}$ =1. In actual fact, these gain factors aren't 1. They are probably closer to 2, and $G_{xcal} \neq G_{zcal}$

4. Definition of Positive Direction for B-fields

The 3-axis B-field board is installed into the sonde with sensors aligned as shown. It is installed such that V5-V7>0 if Earth's B-field is as shown in Fig. 1. Because Earth's B-field has a declination below the horizontal, generally V7 should be <0. For Sonde3 and earlier sondes, the B-field board was mounted upside down, thus making V7>0, but giving the board a left-handed coordinate system.

Set No.	**Variable**	**Physical meaning**
0	N_5	Integer value (-9999-9999) A/D channel 5
	N_6	Integer value (-9999-9999) A/D channel 6
	N_7	Integer value (-9999-9999) A/D channel 7
1	V_5	Corrected Output voltage on ch 5

	V_6	Corrected Output voltage on ch 6
	V_7	Corrected Output voltage on ch 7
2	SB_x	x-comp of B_{EARTH} in Sonde reference frame
	SB_y	y-comp of B_{EARTH} in Sonde reference frame
	SB_z	z-comp of B_{EARTH} in Sonde reference frame
3	B_x	x component of B in Earth reference frame
	B_y	y component in Earth reference frame
	B_z	z component in Earth reference frame

When SB_x is maximum and SB_y=0, we define the x direction of the sonde to be pointing north. Thus, if the field vector for E was along SE_x at this time, we would say the E-field was North in Earth based coordinates. When SB_y is maximum and SB_x=0, we define the y direction of the sonde to be pointing north, and the x-direction to point East. Thus, if the field vector for E was along SE_x at this time, we would say the E-field was East in Earth based coordinates.

The NASA earth Model says that Bz= …. By= …., Bx=….

5. Cartesian to Spherical Coords

The reason for all this work is to easily understand the E-field vector in spherical coordinates where it is useful. We use the coordinate definitions common in most physics texts, with theta as angle from North pole and Phi as positive CCW from X-axis. Since much data analysis will be done with MATLAB, we reference the "ATAN2" function which does an unambiguous 4-quadrant decoding of X and Y components of a vector.

With these preliminaries. Sf_E =atan2(SE_y, SE_x)

Sq_E =atan2(SE_Z, $SE_\perp$)

f_B = atan2(SB_y, SB_x), q_B = atan2(SB_Z, $SB_\perp$)

$$f_E = Sf_E + f_B$$