
Summary of the waves calibration method used for GEOS ULF data

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This method has been used to calibrate the ULF (0.1-11.5 Hz) GEOS data (1977-1983), but can be used for any other mission/experiment which provides waveform data having a non linear frequency transfer function. This is the case for the search coils of STAFF-SC experiment of the CLUSTER mission, so this summary will be useful.

The calibration method works on a series of consecutive data window, each of it having no data gap. To calibrate a waveform data window, the N points taken must be as $N=2*m$, with m integer, because we use a Fast Fourier Transform (FFT). Having a window data of N points, the following steps are required :

1) Production of "clean" raw waveforms in the spinning Sensor Coordinate System (SCS)

This preliminary step is required because the spacecraft rotation in the local high DC magnetic field make a high level signal (more that 100 time the usefull AC field) at the spin frequency in the wave TM data. Sample frequency F_e and spin frequency F_s are required.

Telemetry data In TM counts $i=1,N$	<i>conversion to volts and step amplificator factors</i>	Raw waveforms in Volts	<i>subtract sinusoidal wave at spin frequency by 'desinus' soft</i>	Clean raw waveforms without big spin frequency in Volts
$x_o(t_i)$ $y_o(t_i)$ $z_o(t_i)$	→	$x_1(t_i)$ $y_1(t_i)$ $z_1(t_i)$	→	$x_2(t_i)$ $y_2(t_i)$ $z_2(t_i)$

2) Calibration of each component and conversion in nT in frequency domain

Calibration table (complex values, modulus and phase, inVolt/nT, versus frequency), possible sample delay (between x, y, z components) and low cut-off frequency (low significant value of the calibration tables) are required.

Clean raw waveforms without big spin frequency in Volts	<i>Transformation of time serie in frequency serie By FFT</i>	Spectrum in Volts	<i>(i) Correction of tranfert function by $*1/G(f_i)$ (ii) correction of possible sample delays between x,y,z (iii) cut-off at low frequency</i>	Calibrated spectrum, Sensor Coordinate System, in nT
$x_2(t_i)$ $y_2(t_i)$ $z_2(t_i)$	→	$X_2(f_i)$ $Y_2(f_i)$ $Z_2(f_i)$	→	$X_3(f_i)$ $Y_3(f_i)$ $Z_3(f_i)$

3) Getting calibrated time series data in nT, in the spinning Sensor Coordinate System (SCS)

Return to time domain by a simple inverse FFT :

Calibrated spectrum, sensor spinning system, in nT	<i>Transformation of frequency serie in time serie By FFT⁻¹</i>	Calibrated waveform, Sensor Coordinate System, in nT
$X_3(f_i)$ $Y_3(f_i)$ $Z_3(f_i)$	→	$x_3(t_i)$ $y_3(t_i)$ $z_3(t_i)$

4) Waveform transformation from SCS to GSE System

Data are calibrated in the spinning Sensor Coordinate System, characteristic to each experiment. For a scientific use of the data, it must be converted into a known and convenient system, such as the Geocentric Solar Equatorial system (GSE). This operation require the knowledge of a suit of matrix :

a) Sensor Coordinate System to Orthogonal Sensor System(OSS)

The original sensor system can be a non orthogonal system, the first step is to transform the data vector in an orthogonal coordinate system; Z axis being the reference of the new Orthogonal Sensor System. The corresponding matrix, close to an unit matrix, is required; values are supposed to be constant.

Calibrated waveform, Sensor Coordinate System SCS	Constant matrix [A] SCS_to_OSS	Orthogonal Sensor System OSS
$x_3(t_i)$ $y_3(t_i)$ $z_3(t_i)$	→	$x_{3A}(t_i)$ $y_{3A}(t_i)$ $z_{3A}(t_i)$

b) Orthogonal Sensor System to Body Build System (BBS)

The Body Build System (BBS) is a system fixed to the geometry of the spacecraft, and is used as the spacecraft system reference for all the experiments. Generally, the Z axis is close to the maximum principal inertia axis, also called the spin axis. The Z axis of the Orthogonal Sensor System is generally close to the Z axis of the BBS axis, but the 2 others axis may be rotated by an important angle. The corresponding matrix is required; values are supposed to be constant.

Orthogonal Sensor System OSS	Constant matrix [B] OSS_to_BBS	Body Build System BBS
$x_{3A}(t_i)$ $y_{3A}(t_i)$ $z_{3A}(t_i)$	→	$x_{3B}(t_i)$ $y_{3B}(t_i)$ $z_{3B}(t_i)$

c) Body Build System to Spin Reference System (SRS)

The Spin reference system has its Z axis parallel to the spin axis ; This is a spinning system, rotating at the spin frequency. It can be exist a small angle between the Z axis of the BBS and the spin axis. This angle could be constant, but can have also small variation during operation the spacecraft (trajectory modifications, etc.). The corresponding matrix is required.

Body Build System BBS	Constant matrix [C] BBS_to_SRS	Spin Reference System SRS
$x_{3B}(t_i)$ $y_{3B}(t_i)$ $z_{3B}(t_i)$	→	$x_{3C}(t_i)$ $y_{3C}(t_i)$ $z_{3C}(t_i)$

d) Spin Reference System to Spacecraft-SUN System (SSS)

The SSS system is derived from the SRS system by a despun operation; The spinning Spacecraft is “stopped” just at the time where the X axis is in the plane containing the Z spin axis and the direction of the Sun. The rotation angle require the Sun pulse or any other quantity to compute the spin phase angle, which can be provided at least one time per spin period. This angle, and the corresponding time measurement, is required to build the corresponding matrix. Terms of this matrix are fastly varying with time.

Spin Reference System SRS	Fast varying matrix [D] SRS_to_SSS	Spacecraft SUN System SSS
$x3_C(t_i)$ $y3_C(t_i)$ $z3_C(t_i)$	→	$x3_D(t_i)$ $y3_D(t_i)$ $z3_D(t_i)$

e) Spacecraft-SUN System to Geocentric Solar Ecliptic System (GSE)

The GSE system is a well known system, with the Z axis perpendicular to the Ecliptic plane, and the X axis toward the Sun. To do the transformation of the SSS to the GSE, the direction of the spin axis in the GSE system is required. Due to the gyroscopic effect of a spinning spacecraft, the spin axis is constant in an inertial system, and so have a yearly variation in the GSE system, excepted during spacecraft operations. The two angles, and the corresponding time measurement, is required to build the corresponding matrix.

Spacecraft SUN System SSS	Low varying matrix [E] SSS_to_GSE	Geocentric Solar Ecliptic System GSE
$x3_D(t_i)$ $y3_D(t_i)$ $z3_D(t_i)$	→	$x3_E(t_i)$ $y3_E(t_i)$ $z3_E(t_i)$

4) Transformation from GSE to another Geocentric System

The GSE system being a well known system, any other transformation to Geocentric Solar Magnetospheric system (GSM), Geocentric Equatorial Inertial system (GEI), Solar Magnetic system (SM), Geographic system (GEO), Geomagnetic system (MAG), Dipole Meridian system (DM), and Vertical Dusk Horizontal system (VDH), can be done by the ROCOTLIB coordinate library transformation written for CLUSTER mission where all this systems are defined, with the corresponding matrix to pass from one to another. For details, see “CLUSTER SOFTWARE TOOLS, Part I, COORDINATE TRANSFORMATION LIBRARY”, by Patrick ROBERT, RPE/TID, DT/CRPE/1231, Centre de Recherche en Physique de l’Environnement Terrestre et Planétaire, CNET-CNRS, July 1993. Corresponding Fortran 77 source code can be provided.