Users Guide to the Magnetospheric Multiscale Mission – SMART Science:

Spin-plane Double Probe instrument / Axial Double Probe instrument (SDP/ADP) Data Products Guide

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Document Status Sheet

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Draft 0.1	August 28, 2013	Khotyaintsev	Initial Version
Draft 0.2	October 21, 2014	Khotyaintsev	Updated file definitions for QL, Level 2 E
Draft 0.3	December 5, 2014	Khotyaintsev	Brought back GSE for L2 products, fixed typos
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1.3	18 March 2017	Lindqvist Khotyaintsev	Minor corrections Added Appendix E with gain and phase calibrations

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1 Scope of document

This document describes the data processing and data products of the Magnetospheric Multiscale mission (MMS) Spin-plane Double Probe (SDP) and Axial Double Probe (ADP) electric field instruments, collectively known as EDP (Electric field Double Probe).

2 Acronyms

ADC	Analog to Digital Converter
ADP	Axial Double Probe electric field instrument
AFG	Analog Fluxgate magnetometer instrument
ASPOC	Active Spacecraft POtential Control instrument
BCS	Body Coordinate System
BEB	Boom Electronics Board
CDF	Common Data Format
CEB	Central Electronics Box
DCE	3D DC E-field
DCE2D	2D DC E-field
DEFATT	Definitive Attitude data
DEFEPH	Definitive Ephemeris data
DFG	Digital Fluxgate magnetometer instrument
DSL	Despun Spacecraft L-axis (coordinate system)
DSP	Digital Signal Processor
EDI	Electron Drift Instrument
EDP	Electric field Double Probe (SDP+ADP) instrument
EFW	Electric Fields and Waves (Cluster instrument)
FAC	Field-Aligned Coordinates
FPI	Fast Plasma Instrument
GSE	Geocentric Solar Ecliptic (coordinate system)
GSFC	Goddard Space Flight Center
IRFU	Swedish Institute of Space Physics, Uppsala
KTH	Royal Institute of Technology, Stockholm
L1	Level 1 data (raw data)
L2	Level 2 data (scientific data)
MMS	Magnetospheric Multiscale
QL	Quicklook data
ROI	Region Of Interest
SDC	Science Data Center
SDP	Spin-plane Double Probe electric field instrument
SITL	Scientist In The Loop
SPDF	Space Physics Data Facility
SwRI	Southwest Research Institute, San Antonio
TBW	To be written
UNH	University of New Hampshire, Durham

3 Introduction

The Spin-plane Double Probe (SDP) and the Axial Double Probe (ADP) instruments are part of the FIELDS instrument suite of the Magnetospheric Multiscale mission (MMS). The combination of SDP and ADP is referred to as the Electric field Double Probe (EDP) instrument. EDP measures the 3-D electric field with an accuracy of 0.5 mV/m over the frequency range from DC to 100 kHz. SDP consists of 4 biased spherical probes extended on 60 m long wire booms 90° apart in the spin plane, giving a 120 m baseline for each of the two spin-plane electric field components. ADP consists of 2 biased cylindrical probes extended on ~12 m long stiff booms along the spacecraft axis, giving a 29.2 m baseline for the axial electric field component.

4 Instrument Overview

The detector of the SDP instrument consists of four orthogonal spherical sensors deployed from 60-meter cables in the spin plane of the spacecraft, four mechanical deployment units, each containing 3 boom electronic boards (BEBs). The detector of ADP consists of two cylindrical sensors deployed on ~12 m long stiff booms along the spacecraft spin axis, each containing 2 booms each containing 2 BEBs. The analog-to-digital conversion of the signals is done by the DSP (Digital Signal Processor) located in the FIELDS CEB (Central Electronics Box). The potential drop between two opposing spherical or cylindrical sensors is measured to provide an electric field measurement. The average value of the SDP probe-to-spacecraft potentials provides information on the spacecraft potential. The instrument can also perform current sweeps to provide the current-voltage curve and, thus, the electron temperature and density. The potentials of each spherical and cylindrical sensor and nearby conductors are controlled in order to minimize errors associated with photoemission from the spheres and impact of plasma electrons and ions on the spheres. For more details on SDP, ADP and DSP, refer to the instrument descriptions in (Lindqvist et al., 2016) and (Ergun et al., 2016).

4.1 Science Background

Measurement of the DC and AC electric fields are crucial to characterize the magnetic reconnection process. Measurements of the DC electric field provide information on convective plasma flows (**E**x**B** drifts), reconnection electric field, parallel electric fields, and are important for understanding particle acceleration. With the AC electric field measurements we can study electromagnetic and electrostatic waves, which scatter particles, among others, providing anomalous resistivity in the reconnection diffusion region. Interferometric measurements with long wire booms can be used to characterize the phase speeds of the waves.

4.2 Level 2 Science Requirements

SDP and ADP should measure the spin-plane electric field with accuracy 0.5 mV/m (with a goal of 0.3 mV/m), and the spin-axis electric field with accuracy of 1 mV/m (with a goal of 0.5 mV/m). The time resolution is 1 ms with a goal of 0.1 ms.

4.3 Instrument Characteristics

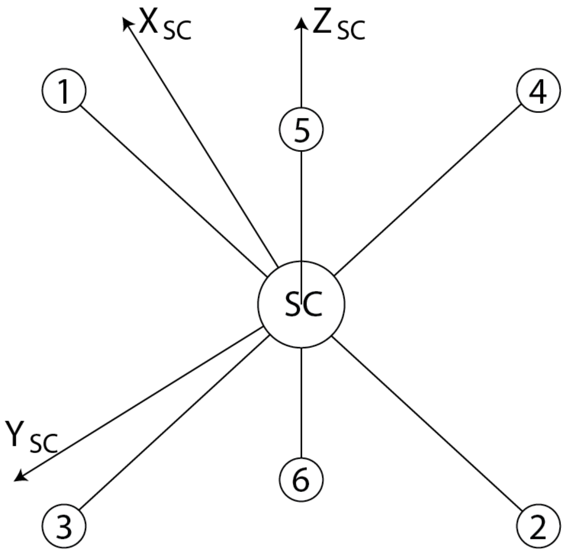

Figure 1. Schematic of SDP and ADP probes.

The SDP has four probes configured in two orthogonal probe pairs in the spin plane on each spacecraft, and ADP has two probes approximately along the spacecraft spin axis as shown in Figure 1. The angle between the probe pair 12 and X_{SC} is approximately 30 degrees.

The instrument sends a negative bias current to the probes. The total of the plasma and photoelectron currents must then equal the bias current (instead of zero), so the probe potential adjusts to the operating point shown in Figure 2 (assuming a bias current of 140 nA).

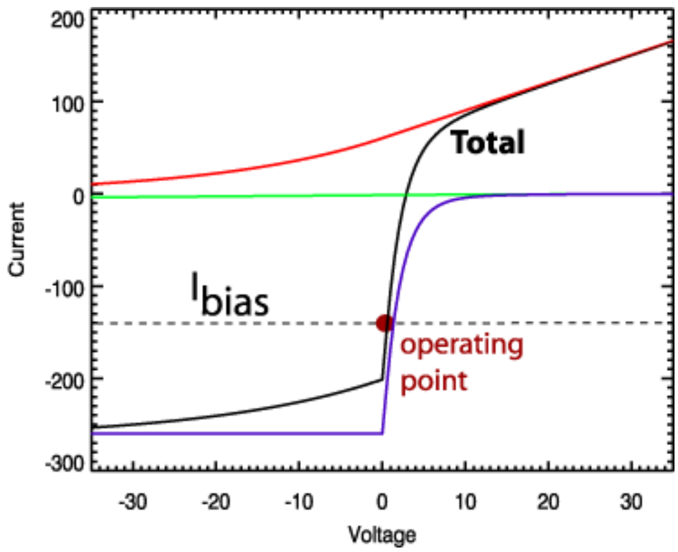

Figure 2. Idealized current-voltage curve of a biased probe in a low density (1 cc) plasma. The total current to the probe is sum of electron current (red), ion current (green) and photocurrent (purple).

This has the advantage of putting the instrument on the steep part of the curve (i.e. the low-resistance part), even in low-density environments. Small fluctuations in the currents (whether caused by actual changes in the plasma or simply stray currents) then do not significantly affect the probe voltage. The probe pairs remain stably grounded (with a small offset) to their local plasma environment. Stray currents and plasma density fluctuations do not show up as an electric potential drop between the probes.

The optimal value of the bias current is determined to large extent by the photocurrent, which in turn depends on the solar UV flux as well as on the proto-emissive properties of the probe surfaces. Therefore, the bias current needs to be adjusted over the course of the mission to account for changing solar UV flux and probe surface characteristics. The bias currents used during the mission are given in Appendix C.

Since the current biasing "grounds" each probe to the local plasma potential, the difference between the probe potentials divided by the length between the probes gives the electric field (see Figure 3). Normally, the full spin plane electric field is computed using the orthogonal signals P12 and P34 (see Figure 1). The average value of the probe-to-spacecraft potentials provides the spacecraft potential.

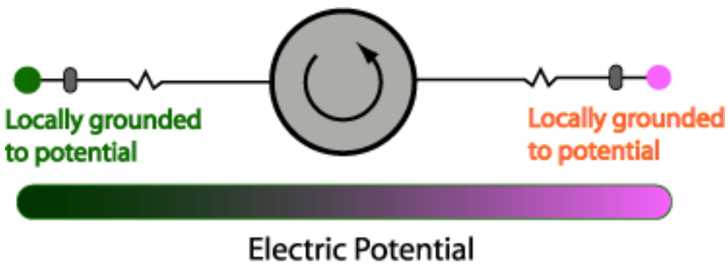

Figure 3. Electric field mode (biased probes).

The instrument can also be switched to the sweep mode and perform current sweeps to provide the current-voltage (IV) curves, like the ones shown in Figure 4. This curve contains information about the density, the ion and electron temperatures and the maximum photocurrent. In principle, all of these parameters can be found by fitting a curve to the data, but in practice, it is difficult to find the ion temperature.

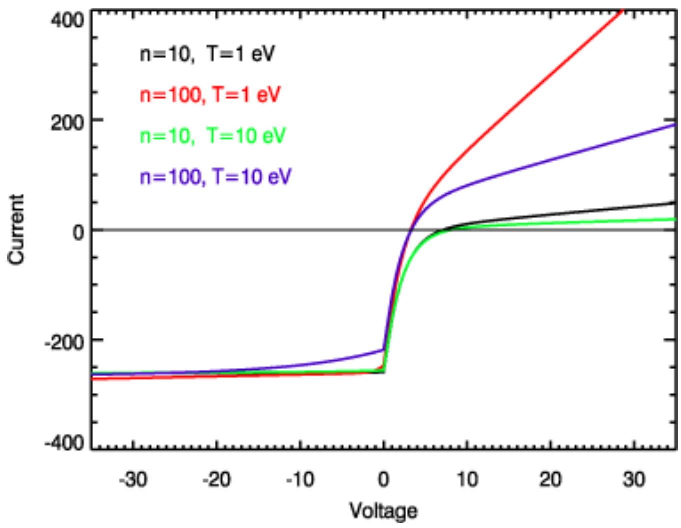

Figure 4. Current-voltage curves obtained in the sweep mode can be compared to theoretical curves to determine plasma density, electron temperature and the maximum photocurrent.

4.4 Heritage

Double-probe electric field experiments have been flown on a number of spacecraft (see review by

Pedersen et al., 1998) including Cluster (Gustafsson et al., 1997, Gustafsson et al., 2001). The EFW instrument on Cluster has been operating since 2000. MMS data analysis software will leverage the work done for Cluster (Khotyaintsev et al., 2010).

5 Data Products

5.1 Overview

The EDP instrument runs in several modes: **Fast** survey (normally run in the scientific Region of Interest, ROI), **Slow** survey (normally used outside the ROI), and **Burst** (for selected intervals within the ROI). The EDP data products can be broadly divided in **Level 1** (raw data) and **Level 2** (science data). In addition, there are **Quicklook** and **SITL** data, intended for quick production. The following table lists the possible combinations and their corresponding folder names in the hierarchical mms data file structure:

Table 1. EDP operating modes and data levels.

Level	Mode			
	Fast	**Slow**	**Burst**	**Survey**
Level 1	l1b	l1b	l1b	l1b
Level 2	l2a, l2pre, l2	l2a, l2pre, l2	l2pre, l2	l2
Quicklook	ql	ql	ql	
SITL	sitl	sitl		

As seen, there is a collective name **Survey**, which encompasses both **Fast** and **Slow** survey. The designations l2a and l2pre are used for intermediate and preliminary Level 2 data. For each of the entries in the table above, there are a number of possible available datatypes:

Table 2. EDP datatypes and brief descriptions.

Mode_Level	Data-type	Access	Brief description
Level 1 (raw data)			
{fast,slow,brst}_l1b	dce	EDP internal	Raw electric field, Individual probe potentials
brst_l1b	ace	EDP internal	(ONLY DURING COMMISSIONING)
brst_l1b	hmfe	EDP internal	Raw electric field, 65536 s^{-1}, 10% duty cycle (adjustable)
srvy_l1b	ace	EDP internal	AC electric field, 131072 s^{-1}, .1% duty cycle (16ms/16s)
srvy_l1b	dce	EDP internal	Raw electric field, Individual probe potentials (DO NOT USE)
srvy_l1b	sweeps	EDP internal	Current-voltage sweeps
Level 2			
{fast,slow}_l2a	dce2d	EDP internal	Raw electric field, Spin fit results and offsets
{fast,slow,brst}_l2pre	dce2d	EDP internal	Despun electric field in DSL, Ez calculated using E.B=0
{fast,slow,brst}_l2pre	dce	EDP internal	Despun electric field in DSL after preliminary calibrations
{fast,slow,brst}_l2	dce	Public	Despun electric field in DSL and GSE
brst_l2	hmfe	Public	Despun electric field in DSL, 65536 s^{-1}, 10% duty cycle

brst_l2	hmfe	Public	Despun electric field in DSL, 65536 s^{-1}, 10% duty cycle (adjustable)
srvy_l2	hfesp	Public	Electric field spectra 592 - 65536 Hz
{fast,slow,brst}_l2	scpot	Public	Spacecraft potential, Individual probe potentials
Quicklook			
{fast,slow,brst}_ql	dce2d	MMS/Public	Despun electric field in DSL
{fast,slow,brst}_ql	dce	MMS/Public	Despun electric field in DSL and FAC
SITL			
{fast,slow}_sitl	dce	SITL	Despun electric field in DSL

In the table above, the third column indicates whether the data are intended for internal or public use. The Quicklook data CDF files are for use by the MMS team, while the Quicklook plots are for public use.

Sections 5.2-5.3 below give descriptions of the processing and calibration of SDP and ADP raw data to obtain the final electric field data. Sections 5.4-5.7 describe briefly each datatype. Detailed contents of each datatype and corresponding CDF files are given in Appendix A. Appendix B contains flow diagrams of how data are processed in steps from the raw data to the final scientific data.

5.2 The SDP (spin-plane) calibration process

There is no on-board processing performed on SDP/ADP data which will be included in the science products. Ground processing includes decommutation and calibration into physical units of raw data. An example of SDP raw data is shown in Figure 5. Further scientific processing includes spin fitting of probe-probe difference signals, determination of offsets in the raw data, determination of DC offsets in the despun data (sunward and duskward offsets), amplitude correction, and despinning the full resolution data.

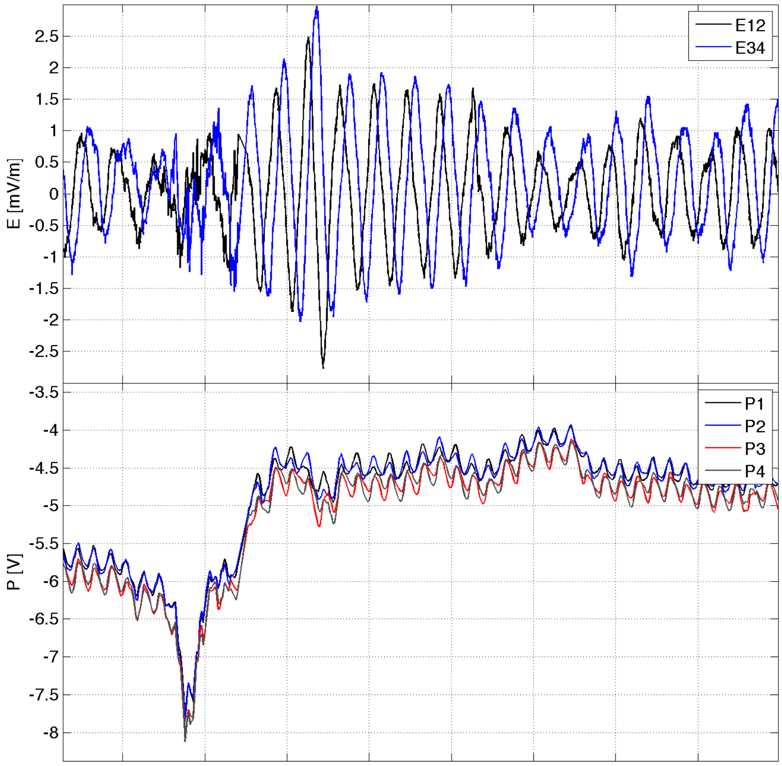

Figure 5. Time-series of raw data of the electric field (E12, E34) and of the probe-to-spacecraft potential (P1, P2, P3, P4). These sample data are from Cluster with a spin period of 4 sec: MMS has a 20 sec spin period.

As the first stage of calibration it is necessary to perform initial cleaning of the data at which we remove intervals with: bad data due to issues with electronics, probe saturations due to low plasma density in the magnetospheric lobes (when ASPOC is not operating), and saturations due to non-optimal bias current settings occurring in dense plasmas such as magnetosheath. If the spacecraft is in the solar wind we apply a correction for the wakes usually present in the raw data (Eriksson et al., 2007). All the possible problems with the data are recorded in the bitmask supplied with the data.

Spin fits. After initial cleaning of the data a spin fitting procedure is performed; the output of this procedure provides basic parameters, which are used later in the calibration procedure. In the presence of a constant ambient electric field, the raw data signal (probe potential difference) is a sine wave (see Figure 5) where the amplitude and phase give the electric field magnitude and direction. A least-squares fit to the raw data of the form

$$y = A + B \cos(\omega t) + C \sin(\omega t) + D \cos(2\omega t) + E \sin(2\omega t) + \ldots \qquad (1)$$

is done on 20 seconds of data once every 5 seconds (the spacecraft spin period is about 20 seconds). The fit is done individually on E12 and E34 to obtain a set of terms for each of the raw data signals.

The standard deviation of the raw data from the fitted sine wave can be used as indication of high frequency variations in the data. Higher order terms, D, E, ..., may be used for diagnostics of data quality: normally the higher order terms are much smaller than B and C, and the opposite situation would indicate problems with the measurements.

Offsets. The sine and cosine terms, B and C after correction for DSL offsets provide the 5-sec resolution electric field in DSL:

$$E_{x5s} = \alpha B - \Delta E_x \, , \quad (2)$$
$$E_{y5s} = \alpha C - \Delta E_y \, , \quad (3)$$

where α is the amplitude correction factor due to the ambient electric field is "short-circuited" by the presence of the spacecraft and wire booms, and ΔE_x and ΔE_y are the *DSL offsets*, which are determined from cross-calibration with EDI and particle instruments, as well as from the inter-spacecraft calibration.

As the spin fitting procedure would typically yield different values for the electric field from the two different probe pairs, it is useful to introduce additional offset which describes the difference between the two measurements, Δ_{p12p34}, which we call the *Delta offset*:

$$\Delta_{x\ p12p34} = E_{x5s}(E_{12}) - E_{x5s}(E_{34}) \, , \quad (4)$$
$$\Delta_{y\ p12p34} = E_{y5s}(E_{12}) - E_{y5s}(E_{34}) \, . \quad (5)$$

The delta offset is expected to vary relatively slowly, on a typical time-scale of several months and is therefore determined from statistical comparison of electric fields from the two probe pairs.

The despun full resolution electric field is obtained as follows:

$$E_x = \mathrm{Re}[\boldsymbol{\varepsilon}_{12}] - \Delta_{x\ p12p34} + \mathrm{Re}[\boldsymbol{\varepsilon}_{34}] \, , \quad (6)$$
$$E_y = \mathrm{Im}[\boldsymbol{\varepsilon}_{12}] - \Delta_{y\ p12p34} + \mathrm{Im}[\boldsymbol{\varepsilon}_{34}] \, , \quad (7)$$

where $\boldsymbol{\varepsilon}_{12} = (E_{12} - \Delta_{raw\ 12})e^{i\varphi 12}$, $\boldsymbol{\varepsilon}_{34} = (E_{34} - \Delta_{raw\ 34})e^{i\varphi 34}$, and $\varphi_{12} = \varphi_{34} + \pi/2$ is the spin phase of probe 1 with respect to the sun; *Raw data DC offset*, $\Delta_{raw} = \langle A \rangle$, is based on parameter *A* of the fit (Eq. 1). Ideally, the DC level of the raw data should be zero, however small differences between the probe surfaces and in the electronics create a DC offset in the raw data. If not corrected, it shows up as a signal at the spin frequency in the despun electric field. The 5-s resolution values of A are smoothed using 5 adjacent points according to the formula

$$\langle A \rangle = 0.1 * A_{i-2} + 0.25 * A_{i-1} + 0.3 * A_i + 0.25 * A_{i+1} + 0.1 * A_{i+2} \quad (8)$$

after which <A> is resampled to the full time resolution of the data using linear interpolation.

It may be noted that asymmetries due to the direction to the sun have the dominant contribution to the offsets, so that the following inequalities are typically satisfied:

$$\Delta E_x >> \Delta E_y, \quad (9)$$
$$\Delta_{x\ p12p34} >> \Delta_{y\ p12p34}. \quad (10)$$

5.3 The ADP (axial) calibration process (TBW)

TBW

5.4 Level 1 Products

L1b_dce: EDP raw data (for internal use by the EDP team). It contains the 3 probe-probe potential differences, used to calculate the vector electric field (E12, E34 and E56), and 3 of the individual probe-spacecraft potentials (V1, V3 and V5).

L1b_hmfe: EDP raw AC electric field data (for internal use by the EDP team). It contains AC-coupled burst data from the 3 probe-probe potential differences. Data are not sampled continuously but using a duty cycle.

L1b_ace: EDP raw AC E12 data (for internal use by the EDP team). It contains AC-coupled data from the E12 probe-probe potential difference. Data are not sampled continuously but using a duty cycle. Spectra are produced on ground.

L1b_sweeps: EDP current-voltage sweeps (for internal use by the EDP team). It contains current-voltage sweeps done on the probes for diagnostic purposes, normally at the start and at the end of each ROI.

5.5 Level 2 Products

L2a_dce2d: An intermediate E-field product (for internal use by the EDP team). It contains the electric field in the spinning frame, together with the computed spin fit coefficients, spin phase and various offsets. The L2a fast files are used as input to both the L2pre fast processing and the L2pre burst processing, ensuring consistency between the fast and burst data.

L2pre_dce2d: Preliminary 2D DC E-field in DSL coordinates (for internal use by the EDP team). The spin plane E-field (Exy) is computed from the SDP probes (E12 and E34), corrected for various offsets. The spin axis E-field (Ez) is obtained using the condition $\mathbf{E}\cdot\mathbf{B}=0$ when the magnetic field elevation above the spin plane is more than 10 degrees.

L2pre_dce: Preliminary 3D DC E-field in DSL coordinates (for internal use by the EDP team). The spin plane E-field (Exy) is unchanged from the preliminary 2D DC E-field, and the spin axis E-field (Ez) is computed from the ADP probes (E56).

L2_dce: Final 3D DC E-field in DSL and GSE coordinates. Both spin plane and spin axis E-field have been processed through elaborate calibration procedures involving comparisons with FPI and EDI data to obtain the best possible scientific data quality. The E-field data are given in both DSL and GSE coordinates.

L2_hmfe: EDP despun AC electric field data in DSL. It contains AC-coupled vector E-field burst data. Data are not sampled continuously but using a duty cycle.

L2_hfesp: EDP E12 electric field spectra. It contains power spectra of the E12 probe-probe potential difference. Data are not sampled continuously but using a duty cycle.

L2_scpot: Spacecraft potential. The spacecraft potential is calculated by averaging the four SDP probe-to-spacecraft potentials and correcting for the probe-plasma potential and the short-circuiting effect of the 60 m long booms. The product also contains the probe-spacecraft potential for all 6 EDP probes.

5.6 Quicklook products

QL_dce2d: Quicklook 2D DC E-field in DSL coordinates (for use by the MMS team). The spin plane E-field (Exy) is computed from the SDP probes (E12 and E34), calibrated for various offsets. The spin axis E-field (Ez) is computed from the ADP probes (E56) with no calibrations applied.

QL_dce: Quicklook **3D DC E-field in DSL coordinates (for use by the MMS team)**. The spin plane E-field (Exy) is unchanged from the Quicklook 2D DC E-field. The spin axis E-field (Ez) is computed from the ADP probes (E56) and calibrated as best possible without use of FPI or EDI data.

5.7 SITL products

SITL_dce: 3D DC E-field in DSL coordinates (for use by the SITL). This product is a simplified version of QL_dce which contains the electric field (Ex,Ey,Ez) only, omitting some error and quality indicators.

SITL_scpot: Spacecraft potential (for use by the SITL). This product is a simplified version of L2_scpot which contains the spacecraft potential only, omitting individual probe potentials.

5.8 Sample rates and timing

The basic EDP sample rates are 8 s^{-1} in slow survey, 32 s^{-1} in fast survey, and 8192 s^{-1} in burst mode. During the tail season (phase 1X), 21 April - 26 July 2016, the burst mode sample rate was increased to 16384 s^{-1}. During the dusk season (phase 1X-1B), 5 August - 13 October 2016, the slow survey sample rate was increased to 32 s^{-1}.

The sampling of the DC raw data signals (individual probe potentials and probe potential differences) are done by a single ADC running at 2^{18} = 262144 s^{-1}. This means that the data are not sampled simultaneously, but in the following order, with a delta time of 2^{-18} s or about 3.815 μs between each sample:

Table 3. Sampling sequence and delays of EDP DC raw data. (*) Sampled signals V2, V4 and V6 are not normally transmitted in telemetry to ground.

Sequence number	Signal sampled	Delay w r t first sample [μs]

0	V1	0
1	V2 (*)	3.815
2	V3	7.629
3	V4 (*)	11.444
4	V5	15.259
5	V6 (*)	19.073
6	-	22.888
7	E12	26.703
8	E34	30.518
9	E56	34.332

The data in the EDP CDF files have been time tagged to the sampling of V1, neglecting the time difference between the sampling of the different channels. For slow and fast survey data, with a time resolution of 31.25 ms, the sample time delay of up to 34 μs can be neglected. For detailed high time resolution studies using burst data, with a time resolution of 122 μs, the sample time delay of up to 34 μs may be significant. Users wishing to do, e.g., cross spectral analysis of burst data, are advised to correct the timing themselves, using the individual probe data in the Level 2 Spacecraft potential file (brst_l2_scpot). Information on how to do this is given in Appendix D.

5.9 Quality indicator and bitmask

Many of the data products include a quality indicator and a bitmask indicating specific issues with the data. The quality indicator is a value between 0 and 3, with the meaning given in Table 4.

Table 4. EDP Quality indicator.

Quality indicator	Meaning
0	Very bad data or no data available
1	Bad data, use with caution
2	OK data, use with some caution
3	Good data

The EDP bitmask is a 16-bit unsigned integer where each bit indicates a specific issue with the data, as listed in Table 5.

Table 5. EDP bitmask values and corresponding Quality indicator.

Bit position	Hex value	Decimal value	Meaning if bit is set (1)	Corresponding Quality ind.
0	0x0001	1	Probe(-s) are disabled	0
1	0x0002	2	Probe(-s) have bad bias settings	1
2	0x0004	4	Probe(-s) are saturated	0
3	0x0008	8	Probe(-s) are saturated due to low density	1
4	0x0010	16	Probe(-s) are sweeping bias current	1
5	0x0020	32	SDP probe(-s) are in shadow from the ADP booms	1
6	0x0040	64	ASPOC is emitting non-zero current	2
7	0x0080	128	TBW	TBW
8	0x0100	256	Asymmetric probe configuration (e.g. MMS4 after 2016-06-12)	2

9	0x0200	512	Maneuver is ongoing	1

5.10 CDF file naming

All data are stored in CDF files according to the MMS-wide data standards. For EDP data, the file naming convention is:

<observatory>_edp_<mode>_<level>_<datatype>_<datetime>_<version>.cdf

where

<observatory> = {mms1, mms2, mms3, mms4}
<mode> = {fast, slow, brst, srvy}
<level> = {l1b, l2a, l2pre, l2, ql, sitl}
<datatype> = {dce, ace, hmfe, hfesp, sweeps, dce2d, scpot}
<datetime> = {yyyymmdd, yyyymmddhhmmss}
<version> = vx.y.z where x, y, and z are the major version, minor version, and revision:
The major version changes when updates to productions software have been made to change file format and/or contents. The minor version changes with new calibrations and/or correction of errors which do not affect the file format. The revision is incremented each time a file is re-generated using the same software, e.g., due to more data becoming available.

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6.1 Publications

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6.2 MMS-related web sites

MMS Science Data Center: https://lasp.colorado.edu/mms/sdc/
MMS Mission at NASA: http://www.nasa.gov/mms
MMS Mission at GSFC: https://mms.gsfc.nasa.gov/
MMS Science Payload at SwRI: http://mms.space.swri.edu/
MMS Education and Public Outreach at Rice: http://mms.rice.edu/mms/
MMS Mission Archive at the SPDF: https://spdf.gsfc.nasa.gov/pub/data/mms/

The EDP Data Products guide (this document) is available from the MMS SDC at
https://lasp.colorado.edu/mms/sdc/public/datasets/fields/

Appendix A: Detailed contents of EDP CDF files

This Appendix lists the detailed contents of the EDP CDF data files. Only the most relevant variables are listed. For complete information including all Metadata and Global and Variable attributes, please consult the actual CDF files. Table 2 is repeated here for convenience.

Table 2 (repeated)*. EDP datatypes and brief descriptions.*

Mode_Level	Data-type	Access	Brief description
Level 1 (raw data)			
{fast,slow,brst}_l1b	dce	EDP internal	Raw electric field, Individual probe potentials
brst_l1b	ace	EDP internal	(ONLY DURING COMMISSIONING)
brst_l1b	hmfe	EDP internal	Raw electric field, 65536 s^{-1}, 10% duty cycle (adjustable)
srvy_l1b	ace	EDP internal	AC electric field, 131072 s^{-1}, .1% duty cycle (16ms/16s)
srvy_l1b	dce	EDP internal	Raw electric field, Individual probe potentials (DO NOT USE)
srvy_l1b	sweeps	EDP internal	Current-voltage sweeps
Level 2			
{fast,slow}_l2a	dce2d	EDP internal	Raw electric field, Spin fit results and offsets
{fast,slow,brst}_l2pre	dce2d	EDP internal	Despun electric field in DSL, Ez calculated using E.B=0
{fast,slow,brst}_l2pre	dce	EDP internal	Despun electric field in DSL after preliminary calibrations
{fast,slow,brst}_l2	dce	Public	Despun electric field in DSL and GSE
brst_l2	hmfe	Public	Despun electric field in DSL, 65536 s^{-1}, 10% duty cycle (adjustable)
srvy_l2	hfesp	Public	Electric field spectra 592 - 65536 Hz
{fast,slow,brst}_l2	scpot	Public	Spacecraft potential, Individual probe potentials
Quicklook			
{fast,slow,brst}_ql	dce2d	MMS/Public	Despun electric field in DSL
{fast,slow,brst}_ql	dce	MMS/Public	Despun electric field in DSL and FAC
SITL			
{fast,slow}_sitl	dce	SITL	Despun electric field in DSL
{fast,slow}_sitl	scpot	SITL	Spacecraft potential

A.1 Level 1 (raw data)

A.1.1 Level 1: {fast,slow,brst}_l1b_dce

Brief description: Raw electric field, Individual probe potentials
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_l1b_dce_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_sensor	float(3)	E12, E34, E56: Raw electric field
mms#_edp_dcv_sensor	float(3)	V1, V3, V5: Raw probe potential

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)

Timing: A raw data packet in telemetry is time stamped with the sampling time of V1. The onboard ADC converts samples in the following order: (V1, V2, V3, V4, V5, V6, nap, E12, E34, E56), with a time delay between each sample of 2^{-18} s ≈ 3.8 μs. V2, V4 and V6 are not normally transmitted in telemetry (except in commissioning). For convenience, the time tag of all quantities in the Level 1 CDF file has been set to the V1 time tag. For detailed high time resolution studies the user is advised to perform correct resampling of V3, V5, E12, E34 and E56 from their actual sampling times to the sampling time of V1 before further analysis. See also section 5.8 and Appendix D.
Predecessors: None

A.1.2 Level 1: brst_l1b_ace

(Available only during commissioning)

A.1.3 Level 1: brst_l1b_hmfe

Brief description: Raw AC electric field
File name: mms{1,2,3,4}_edp_brst_l1b_hmfe_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_hmfe_sensor	float(3)	E12, E34, E56: Raw AC electric field

Sample rates: 65536 s^{-1}
Duty cycle: 25%, 2 s data in each 8 s time interval (adjustable)
Predecessors: None

A.1.4 Level 1: srvy_l1b_ace

Brief description: Raw AC electric field
File name: mms{1,2,3,4}_edp_srvy_l1b_ace_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_ace_sensor	float(1)	Raw AC electric field, one component only

Sample rates: 131072 s^{-1}
Duty cycle: 0.1%, 16 ms data every 16 s
Predecessors: None

A.1.5 Level 1: srvy_l1b_dce

Brief description: Raw electric field, Individual probe potentials **(DO NOT USE)**
File name: mms{1,2,3,4}_edp_srvy_l1b_dce_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_sensor	float(3)	E12, E34, E56: Raw electric field
mms#_edp_dcv_sensor	float(3)	V1, V3, V5: Raw probe potential

Note: **This file should normally not be used**. It is only a temporary file which is later split into the fast and slow survey files mms{1,2,3,4}_edp_{fast,slow}_l1b_dce_<datetime>_v<x.y.z>.cdf. Refer to the description of these files instead.

A.1.6 Level 1: srvy_l1b_sweeps

Brief description: Current-voltage sweeps
File name: mms{1,2,3,4}_edp_srvy_l1b_sweeps_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_sweeps	float(6)	Individual probe potentials during sweep
...	...	...

Details: TBW
Predecessors: None

A.2 Level 2 (science data, including intermediate data products)

A.2.1 Level 2: {fast,slow}_l2a_dce2d

Brief description: Raw electric field, Spin fit results and offsets
File name: mms{1,2,3,4}_edp_{fast,slow}_l2a_dce2d_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_{fast,slow}_l2a	float(3)	E12, E34, Ez: Raw electric field
mms#_edp_phase_{fast,slow}_l2a	float(1)	Spacecraft spin phase
mms#_edp_espin_p12_{fast,slow}_l2a	float(2)	Spin fit coefficients B,C=Ex,Ey in DSL using E12
mms#_edp_sdevfit_p12_{fast,slow}_l2a	float(1)	Spin fit standard deviation using E12
mms#_edp_offsfit_p12_{fast,slow}_l2a	float(1)	Spin fit coefficients A using E12
mms#_edp_espin_p34_{fast,slow}_l2a	float(2)	Spin fit coefficients B,C=Ex,Ey in DSL using E34
mms#_edp_sdevfit_p34_{fast,slow}_l2a	float(1)	Spin fit standard deviation using E34
mms#_edp_offsfit_p34_{fast,slow}_l2a	float(1)	Spin fit coefficients A using E34
mms#_edp_adc_offset_{fast,slow}_l2a	float(2)	ADC offsets to be removed
mms#_edp_delta_offset_{fast,slow}_l2a	float(2)	Delta offset between E12 and E34
mms#_edp_bitmask_{fast,slow}_l2a	uint16(3)	Status bitmask (see separate description)
mms#_edp_quality_{fast,slow}_l2a	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 0.2 s^{-1} (Spin fit results)
Predecessors: Level 1 {fast,slow}_l1b_dce + FIELDS hk data, ASPOC srvy data, DEFATT
Details: E12,E34 computed from l1b_dce raw data by 1) multiplying by gain 1.25 and 2) removing ADP shadow spikes. Ez computed from raw data as -E56 to make right-handed coordinate system: E12 = E12(l1b_dce)*1.25, E34 = E34(l1b_dce)*1.25, Ez = -E56(l1b_dce).
Spin fits to E12 and E34 are done every 5 s to create A, B, C. Spin fit coefficients A are smoothed to give ADC offsets to be removed.

A.2.2 Level 2: {fast,slow,brst}_l2pre_dce2d

Brief description: Despun electric field in DSL
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_l2pre_dce2d_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_dsl_{fast,slow,brst}_l2pre	float(3)	Ex, Ey, Ez: Electric field in DSL using E.B=0
mms#_edp_adp_{fast,slow,brst}_l2pre	float(1)	Ez in DSL from ADP E56
mms#_edp_phase_{fast,slow,brst}_l2pre	float(1)	Spacecraft spin phase
mms#_edp_adc_offset_{fast,slow,brst}_l2pre	float(3)	ADC offsets which have been removed
mms#_edp_delta_offset_{fast,slow,brst}_l2pre	float(2)	Delta offsets which have been removed
mms#_edp_bitmask_{fast,slow,brst}_l2pre	uint16(1)	Status bitmask (see separate description)
mms#_edp_quality_{fast,slow,brst}_l2pre	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)
Predecessors for {fast,slow}_l2pre_dce2d: Level 2 {fast,slow}_l2a_dce2d + DFG srvy data
Predecessors for brst_l2pre_dce2d: Level 2 fast_l2a_dce2d, Level 1 brst_l1b_dce + FIELDS hk data, ASPOC srvy data, DEFATT, DFG srvy data
Details: Ex, Ey are despun electric field in DSL from SDP E12 and E34, Ez is computed using E.B=0. Ez from ADP (E56) is available as a separate parameter (_adp_).

A.2.3 Level 2: {fast,slow,brst}_l2pre_dce

Brief description: Despun electric field in DSL after preliminary calibrations
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_l2pre_dce_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_dsl_{fast,slow,brst}_l2pre	float(3)	Ex, Ey, Ez: Electric field in DSL
mms#_edp_dce_par_epar_{fast,slow,brst}_l2pre	float(2)	Eerr, Epar: Electric field error, Parallel electric field
mms#_edp_dce_dsl_res_{fast,slow,brst}_l2pre	float(3)	Ex, Ey, Ez: Electric field residue
mms#_edp_dce_err_{fast,slow}_l2pre	float(3)	Ex, Ey, Ez: Electric field error (not in brst)
mms#_edp_phase_{fast,slow}_l2pre	float(1)	Spacecraft spin phase (not in brst)
mms#_edp_adc_offset_{fast,slow,brst}_l2pre	float(3)	ADC offsets which have been removed
mms#_edp_delta_offset_{fast,slow,brst}_l2pre	float(2)	Delta offsets which have been removed
mms#_edp_bitmask_{fast,slow,brst}_l2pre	uint16(1)	Status bitmask (see separate description)
mms#_edp_quality_{fast,slow,brst}_l2pre	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)
Predecessors for {fast,slow}_l2pre_dce: Level 2 {fast,slow}_l2pre_dce2d, {fast,slow}_l1b_dce + FIELDS hk data, FIELDS sweep data, AFG srvy data
Predecessors for brst_l2pre_dce: Level 2 brst_l2pre_dce2d, fast_l2pre_dce + AFG srvy data
Details: Ex and Ey are unchanged from l2pre_dce2d. Ez has been corrected as best possible without using FPI and/or EDI data.

A.2.4 Level 2: {fast,slow,brst}_l2_dce

Brief description: Despun electric field in DSL and GSE
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_l2_dce_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_gse_{fast,slow,brst}_l2	float(3)	Ex, Ey, Ez: Electric field in GSE
mms#_edp_dce_dsl_{fast,slow,brst}_l2	float(3)	Ex, Ey, Ez: Electric field in DSL
mms#_edp_dce_par_epar_{fast,slow,brst}_l2	float(2)	Eerr, Epar: Parallel electric field error and value
mms#_edp_dce_dsl_res_{fast,slow}_l2	float(3)	Ex, Ey, Ez: Electric field residue (not in brst)
mms#_edp_dce_err_{fast,slow}_l2	float(3)	Ex, Ey, Ez: Electric field error (not in brst)
mms#_edp_bitmask_{fast,slow,brst}_l2	uint16(1)	Status bitmask (see separate description)
mms#_edp_quality_{fast,slow,brst}_l2	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)
Predecessors for {fast,slow}_l2_dce: Level 2 {fast,slow}_l2pre_dce, {fast,slow}_l2_scpot + AFG srvy data + DEFATT + DEFEPH
Predecessors for brst_l2_dce Level 2 fast_l2_dce, fast_l2pre_dce, brst_l2pre_dce + AFG srvy data
Details: Electric field after possible correction using FPI and/or EDI data (more details TBW).

A.2.5 Level 2: brst_l2_hmfe

Brief description: Despun AC electric field
File name: mms{1,2,3,4}_edp_brst_l2_hmfe_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_hmfe_dsl_brst	float(3)	Despun AC electric field in DSL
mms#_edp_hmfe_par_epar_brst	float(1)	Parallel electric field

Sample rates: 65536 s^{-1}
Duty cycle: 2 s data in each 8 s time interval (adjustable)
Predecessors: Level 1 brst_l1b_hmfe + AFG srvy data

A.2.6 Level 2: srvy_l2_hfesp

Brief description: Electric field spectra 592 - 65536 Hz
File name: mms{1,2,3,4}_edp_srvy_l2_hfesp_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_hfesp_srvy_l2	float(322)	Electric field spectra 592-65536 Hz

Sample rates: 1 spectrum every 16 s, based on 131072 s^{-1} raw data
Predecessors: Level 1 srvy_l1b_ace
Details: The spectra are based on raw data from one component of the electric field, E12, only.

A.2.7 Level 2: {fast,slow,brst}_l2_scpot

Brief description: Spacecraft potential, Individual probe potentials
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_l2_scpot_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_scpot_{fast,slow,brst}_l2	float(1)	Spacecraft potential wrt plasma
mms#_edp_psp_{fast,slow,brst}_l2	float(1)	Average probe to spacecraft potential
mms#_edp_dcv_{fast,slow,brst}_l2	float(6)	Individual probe potentials V1,V1,...,V6
mms#_edp_bitmask_{fast,slow,brst}_l2	uint16(1)	Status bitmask (see separate description)
mms#_edp_quality_{fast,slow,brst}_l2	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)
Timing: A raw data packet in telemetry is time stamped with the sampling time of V1. The onboard ADC converts samples in the following order: (V1, V2, V3, V4, V5, V6, nap, E12, E34, E56), with a time delay between each sample of 2^{-18} s ≈ 3.8 μs. V2, V4 and V6 are not normally transmitted in telemetry (except in commissioning), but are computed as V2 = V1-E12*LSDP, V4=V3-E34*LSDP, V6=V5-E56*LADP, where LSDP=120 m and LADP=29.2 m. For convenience, the time tag of all quantities in the Level 2 CDF file has been set to the V1 time tag. For detailed high time resolution studies the user is advised to perform correct resampling of V3, V5, E12, E34 and E56 from their actual sampling times to the sampling time of V1 before further analysis. This is further described in section 5.8 and Appendix D.
Predecessors: Level 1 {fast,slow,brst}_l1b_dce
Details: Average probe to spacecraft potential (psp) is calculated as (v1+v2+v3+v4)/4. Spacecraft potential wrt plasma (scpot) is calculated as *shorteningFactor**(-psp)+*probe2plasma*, where values of *shorteningFactor* and *probe2plasma* used during the mission are given in the calibration files mms#_edp_sdp_scpot_<datetime>_v<x.y.z>.txt. At present (2017-03-17) values used throughout the mission are: *shorteningFactor* = 1.2 and *probe2plasma* = {1.3, 1.5, 1.2, 0.0} V for {mms1, mms2, mms3, mms4}. (On MMS4 after probe 4 bias failure 2016-06-12 05:28:48, psp is instead calculated as (v1+v2)/2.)

A.3 Quicklook (quicklook science data)

A.3.1 Quicklook: {fast,slow,brst}_ql_dce2d

Brief description: Despun electric field in DSL
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_ql_dce2d_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_xyz_dsl	float(3)	Ex, Ey, Ez: Electric field in DSL
mms#_edp_bitmask	uint16(1)	Status bitmask (see separate description)
mms#_edp_quality	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)
Predecessors for {fast,slow}_ql_dce2d: Level 1 {fast,slow}_l1b_dce + FIELDS hk data, ASPOC srvy data
Predecessors for brst_ql_dce2d: brst_l1b_dce, fast_l2a_dce2d + FIELDS hk data, ASPOC srvy data

Details: Ex, Ey are despun electric field in DSL from SDP E12 and E34. Ez is from ADP E56.

A.3.2 Quicklook: {fast,slow,brst}_ql_dce

Brief description: Despun electric field in DSL and FAC
File name: mms{1,2,3,4}_edp_{fast,slow,brst}_ql_dce_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_xyz_dsl	float(3)	Ex, Ey, Ez: Electric field in DSL
mms#_edp_dce_xyz_fac	float(3)	Espin, Eperp, Eparr: Electric field in FAC
mms#_edp_dce_xyz_err	float(2)	Eerr, Epar: Electric field error, Parallel electric field (not in brst)
mms#_edp_dce_xyz_res_dsl	float(3)	Ex, Ey, Ez: Electric field residue (not in brst)
mms#_edp_bitmask	uint16(1)	Status bitmask (see separate description)
mms#_edp_quality	uint8(1)	Quality flag (0-4, 4=best)

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast), 8192 or 16384 s^{-1} (brst)
Predecessors: Quicklook {fast,slow,brst}_ql_dce2d + FIELDS hk data + AFG srvy data
Details: Ex and Ey are unchanged from ql_dce2d. Ez has been corrected as best possible without using FPI and/or EDI data.

A.4 SITL (quicklook science data for SITL use)

A.4.1 SITL: {fast,slow}_sitl_dce

Brief description: Despun electric field in DSL
File name: mms{1,2,3,4}_edp_{fast,slow}_sitl_dce_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_dce_dsl_{fast,slow}_sitl	float(3)	Ex, Ey, Ez: Electric field in DSL

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast)
Note: This file is created for SITL purposes from the Quicklook DCE file, reducing file size by omitting all variables except one.
Predecessors: Level 2 {fast,slow}_ql_dce

A.4.2 SITL: {fast,slow}_sitl_scpot

Brief description: Spacecraft potential
File name: mms{1,2,3,4}_edp_{fast,slow}_sitl_scpot_<datetime>_v<x.y.z>.cdf
File contents:

Variable name	Type	Description
mms#_edp_scpot_{fast,slow}_l2	float(1)	Spacecraft potential wrt plasma

Sample rates: 8 or 32 s^{-1} (slow), 32 s^{-1} (fast)
Note: This file is created for SITL purposes from the Level 2 SCPOT file, reducing file size by omitting all variables except one.
Predecessors: Level 2 {fast,slow}_l2_scpot

Appendix B. Flow diagrams

B.1 Flow diagram of EDP Level 2 E-field processing

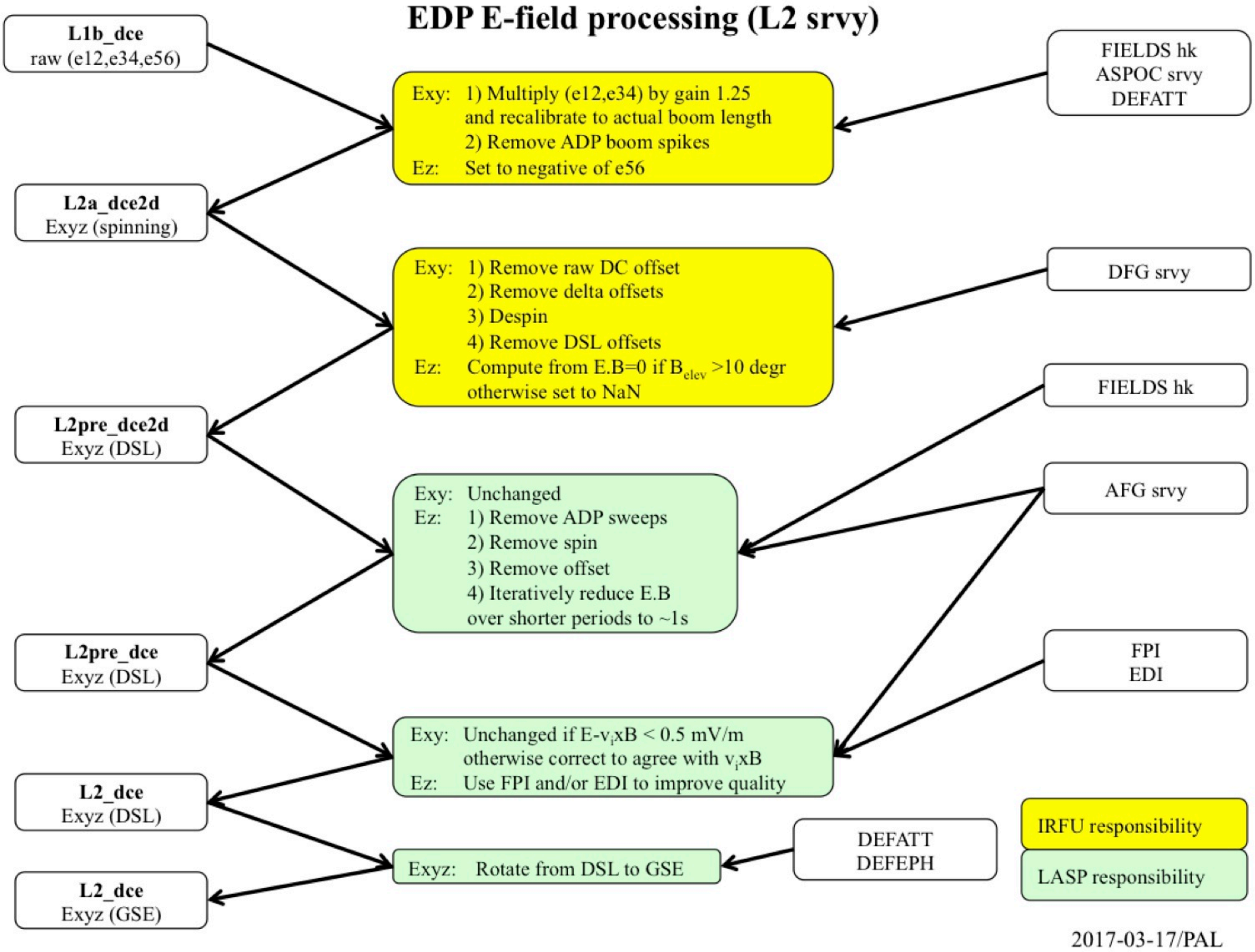

Figure 6. Flow diagram of EDP Level 2 survey data E-field processing. A corresponding diagram for burst data is TBW.

B.2 Flow diagram of EDP Quicklook and SITL E-field processing

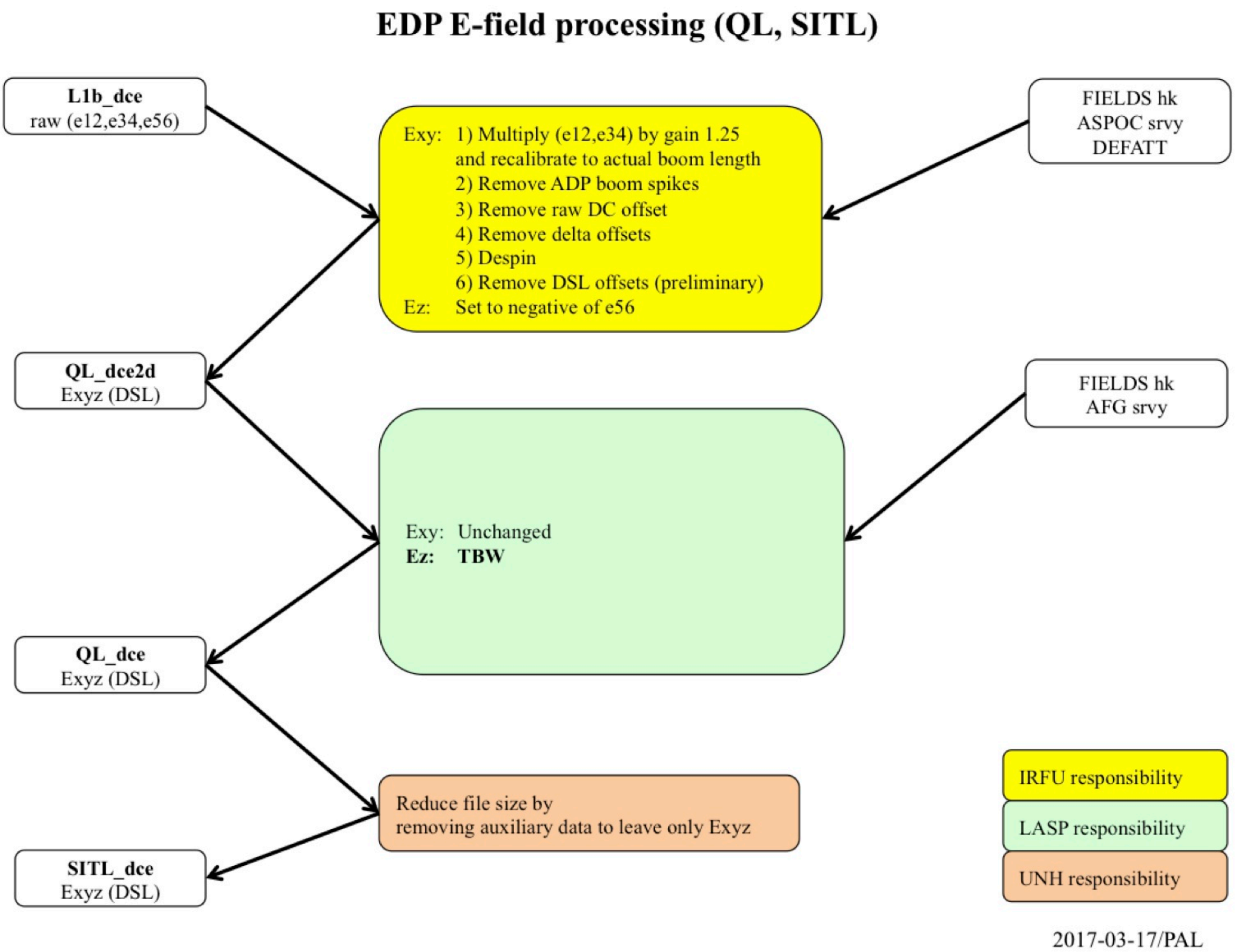

Figure 7. Flow diagram of EDP Quicklook and SITL E-field processing.

B.3 Flow diagram of EDP Level 2 and SITL Spacecraft potential processing

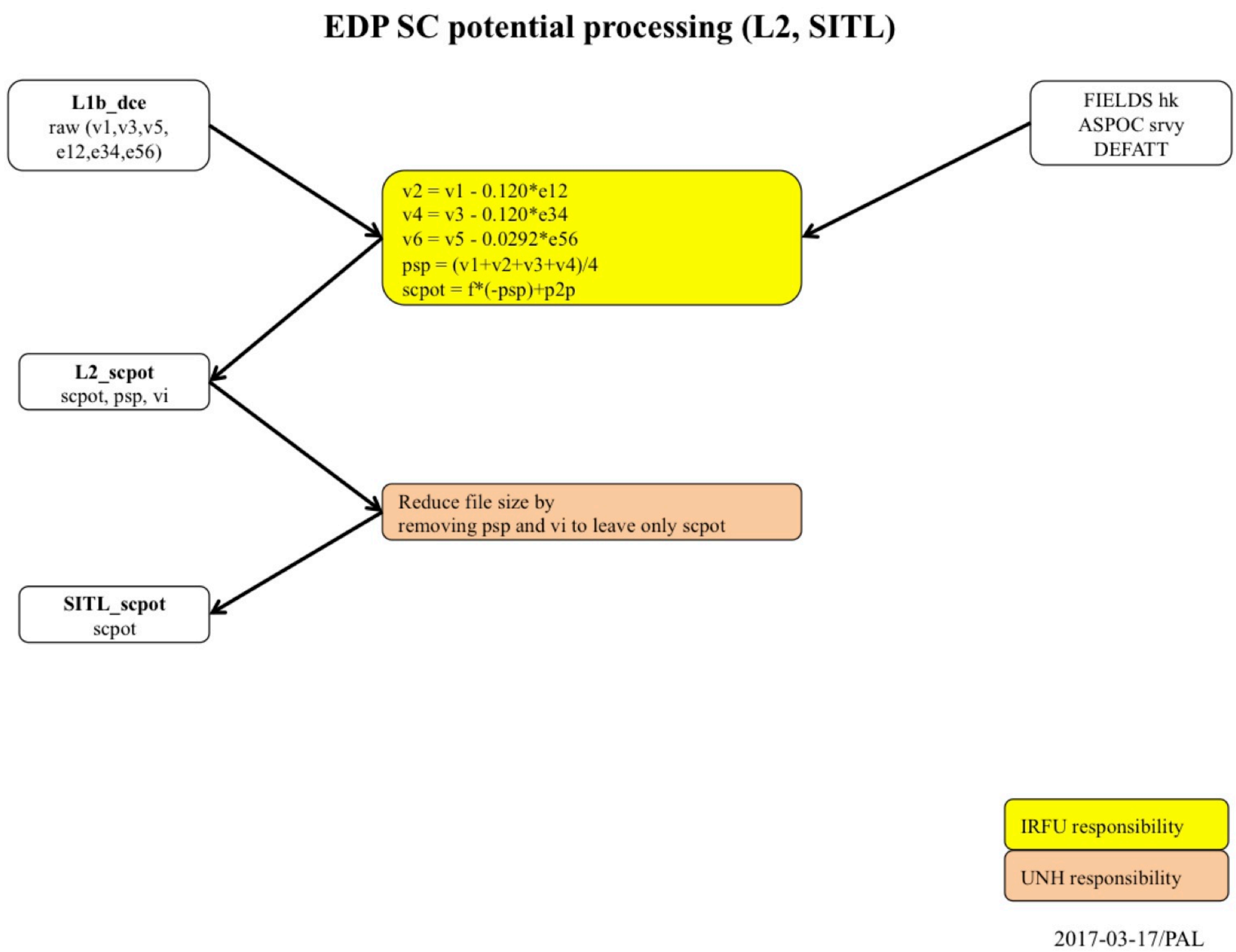

Figure 8. Flow diagram of EDP Level 2 and SITL Spacecraft potential processing.

Appendix C. SDP and ADP probe bias currents

The bias current to the SDP and ADP probes are normally kept at constant values for long periods. They have been changed a few times during the mission to accommodate for changes in the photoemission of the probes. The bias currents used will affect the spacecraft potential, since the spacecraft will need to go more positive to collect more ambient electrons for larger bias currents, so any analysis of spacecraft potential versus plasma parameters will need to take the bias current values into account. The following tables list the bias current values used [nA] on the different probes in sunlight during the mission. During eclipses the bias currents are set to zero.

Table 6. MMS1 probe bias currents.

MMS1						
Start time	**SDP p1**	**SDP p2**	**SDP p3**	**SDP p4**	**ADP p5**	**ADP p6**
150501	-160	-160	-160	-160	-100	-100
150626 20:04	-120	-120	-120	-120	-100	-100
150723 15:10:41	-110	-110	-110	-110	-100	-100
150803 16:05:48	-90	-90	-90	-90	-100	-100
160126 18:55:16	-110	-110	-110	-110	-125	-125
160203 17:24:11	-110	-110	-110	-110	-175	-175
160907 16:19:09	-90	-90	-90	-90	-175	-175
161018 14:48:08	-90	-90	-80	-90	-175	-175

Table 7. MMS2 probe bias currents.

MMS2						
Start time	**SDP p1**	**SDP p2**	**SDP p3**	**SDP p4**	**ADP p5**	**ADP p6**
150501	-160	-160	-160	-160	-100	-100
150625 01:58	-100	-100	-100	-100	-100	-100
150723 16:24:53	-90	-90	-90	-90	-100	-100
150803 20:04:29	-70	-70	-70	-70	-100	-100
160126 20:55:36	-90	-90	-90	-90	-125	-125
160203 18:39:11	-90	-90	-90	-90	-175	-175
160907 17:34:25	-90	-70	-70	-70	-175	-175

Table 8. MMS3 probe bias currents.

MMS3						
Start time	**SDP p1**	**SDP p2**	**SDP p3**	**SDP p4**	**ADP p5**	**ADP p6**
150501	-160	-160	-160	-160	-100	-100
150626 15:53	-120	-120	-120	-120	-100	-100
150724 15:09:26	-110	-110	-110	-110	-100	-100
150804 02:05:29	-90	-90	-90	-90	-100	-100
160126 14:48:17	-110	-110	-110	-110	-125	-125

160203 14:14:55	-110	-110	-110	-110	-175	-175
160907 18:51:40	-90	-110	-110	-110	-175	-175

Table 9. MMS4 probe bias currents.

MMS4						
Start time	**SDP p1**	**SDP p2**	**SDP p3**	**SDP p4**	**ADP p5**	**ADP p6**
150501	-160	-160	-160	-160	-100	-100
150723 21:42:48	-160	-160	-160	-160	-100	-100
150803 15:07:51	-140	-140	-140	-140	-100	-100
160126 16:39:44	-160	-160	-160	-160	-125	-125
160203 15:49:27	-160	-160	-160	-160	-175	-175
160612 05:28:48 (*)	-160	-160	-160	0	-175	-175
160907 20:04:56	-140	-140	-140	0	-175	-175

(*) Failure of bias to probe 4 due to dust impact

Appendix D. How to improve burst data timing

As explained in section 5.8, the sampling of DC raw data (individual probe potentials and probe potential differences) is not simultaneous. Users wishing to use high time resolution (burst data) individual probe potentials as given in the Level 2 Spacecraft potential file (brst_l2_scpot) for detailed timing analysis are advised to correct the timing in the following manner.

1. Recompute the originally sampled data (E12, E34, E56) [mV/m] from the data available in the scpot file (V1, V2, V3, V4, V5, V6) [V]:

   E12 = (V1 - V2) / 0.120
   E34 = (V3 - V4) / 0.120
   E56 = (V5 - V6) / 0.0292

2. Correct the time tags of the data:

   Add $2*2^{-18}$ s or approximately 7.629 μs to the time tags of V3
   Add $4*2^{-18}$ s or approximately 15.259 μs to the time tags of V5
   Add $7*2^{-18}$ s or approximately 26.703 μs to the time tags of E12
   Add $8*2^{-18}$ s or approximately 30.518 μs to the time tags of E34
   Add $9*2^{-18}$ s or approximately 34.332 μs to the time tags of E56

3. Resample all data to the time tags of V1.

4. Recompute the individual probe potentials (V2, V4, V6):

   V2 = V1 – E12 * 0.120
   V4 = V3 – E34 * 0.120
   V6 = V5 – E56 * 0.0292

Now (V1, V2, V3, V4, V5, V6) can be used for detailed timing analysis, such as cross spectral analysis. However, be aware that the data were not originally sampled simultaneously, but that all quantities except V1 have been interpolated in the resampling process. This might introduce systematic differences between the probe potentials (for example, the noise level of the resampled data will be lower due to the interpolation).

Sample MATLAB code to do the above correction is given here, using the IRFU MATLAB library (https://sites.google.com/site/irfumatlab/) to create, manipulate, and plot data objects and time series:

```
% Create data object from file
object = dataobj('mms2_edp_brst_l2_scpot_20161201052448_v2.2.0.cdf');;
% Create time series containing individual probe potentials
Vorig = mms.variable2ts(get_variable(object,'mms2_edp_dcv_brst_l2'));
% Recompute original E12, E34 and E56
E12 = TSeries(Vorig.time,(Vorig.data(:,1)-Vorig.data(:,2))/0.120);
E34 = TSeries(Vorig.time,(Vorig.data(:,3)-Vorig.data(:,4))/0.120);
E56 = TSeries(Vorig.time,(Vorig.data(:,5)-Vorig.data(:,6))/0.0292);
% Correct the time tags to create individual time series
V1 = TSeries(Vorig.time          , Vorig.data(:,1));
```

```
V3 = TSeries(Vorig.time+ 7.629e-6, Vorig.data(:,3));
V5 = TSeries(Vorig.time+15.259e-6, Vorig.data(:,5));
E12.time = E12.time + 26.703e-6;
E34.time = E34.time + 30.518e-6;
E56.time = E56.time + 34.332e-6;
% Resample all data to time tags of V1
V3 = resample(V3, V1.time);
V5 = resample(V5, V1.time);
E12 = resample(E12, V1.time);
E34 = resample(E34, V1.time);
E56 = resample(E56, V1.time);
% Recompute individual probe potentials V2, V4, V6
V2 = V1 - E12 * 0.120;
V4 = V3 - E34 * 0.120;
V6 = V5 - E56 * 0.0292;
% Now (V1, V2, V3, V4, V5, V6) can be further analyzed
% Plot new values
figure;
irf_plot({V1,V2,V3,V4,V5,V6});
% Plot both old and new values
figure;
h = irf_plot({TSeries(V1.time,[V1.data Vorig.data(:,1)]), ...
  TSeries(V2.time,[V2.data Vorig.data(:,2)]), ...
  TSeries(V3.time,[V3.data Vorig.data(:,3)]), ...
  TSeries(V4.time,[V4.data Vorig.data(:,4)]), ...
  TSeries(V5.time,[V5.data Vorig.data(:,5)]), ...
  TSeries(V6.time,[V6.data Vorig.data(:,6)])},'.-');
title(h(1),'mms2');
legend(h(1),'V1new','V1old');
legend(h(2),'V2new','V2old');
legend(h(3),'V3new','V3old');
legend(h(4),'V4new','V4old');
legend(h(5),'V5new','V5old');
legend(h(6),'V6new','V6old');
```

A sample plot of 4 ms of data is shown in Figure 9. It is clearly seen that the difference between old and new potential values is largest for V2, V4 and V6, which are not transmitted in telemetry but are calculated using E12, E34 and E56, which are sampled later in the sampling sequence.

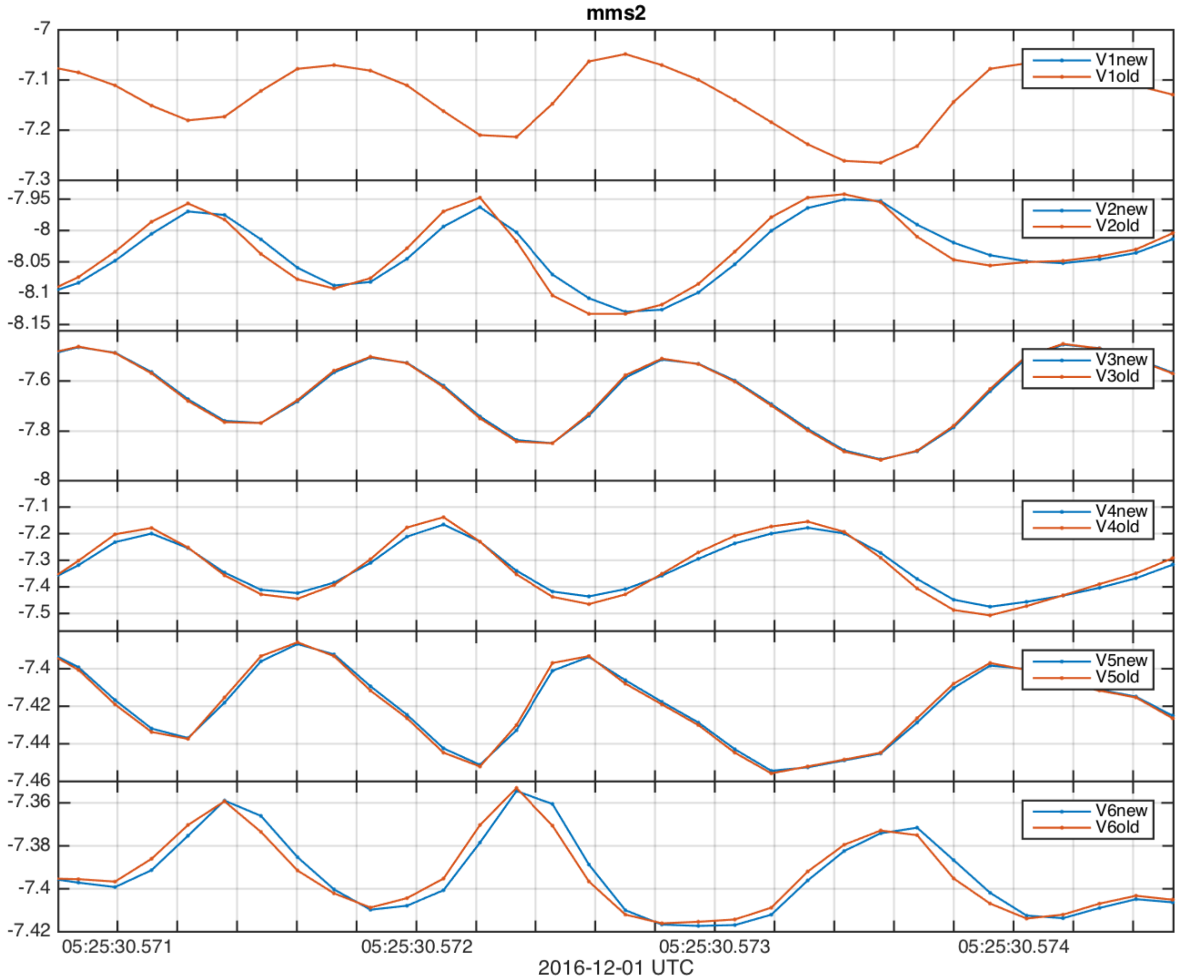

Figure 9. Plot of individual probe potentials before and after time correction.

Sample IDL code to do the above correction is given here:

TBW

Appendix E. Phase and gain calibrations

The burst data are corrected using transfer functions shown in Figure 10 and Figure 11. These are related to:

1. The DSP analog filters (5-pole low-pass Bessel filters for DC and AC, 1-pole high pass filter for AC),
2. The ADP/SDP plasma-preamp-BEB response (20 Mohm sheath resistance assumed for ADP, 10 Mohm for SDP).

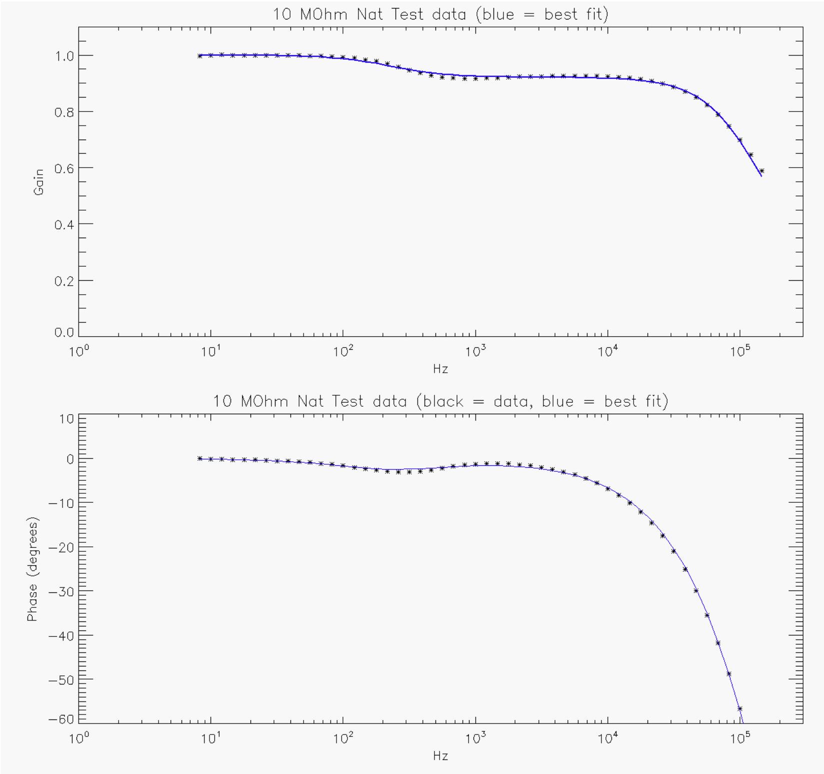

Figure 10. Gain and phase correction applied to SDP.

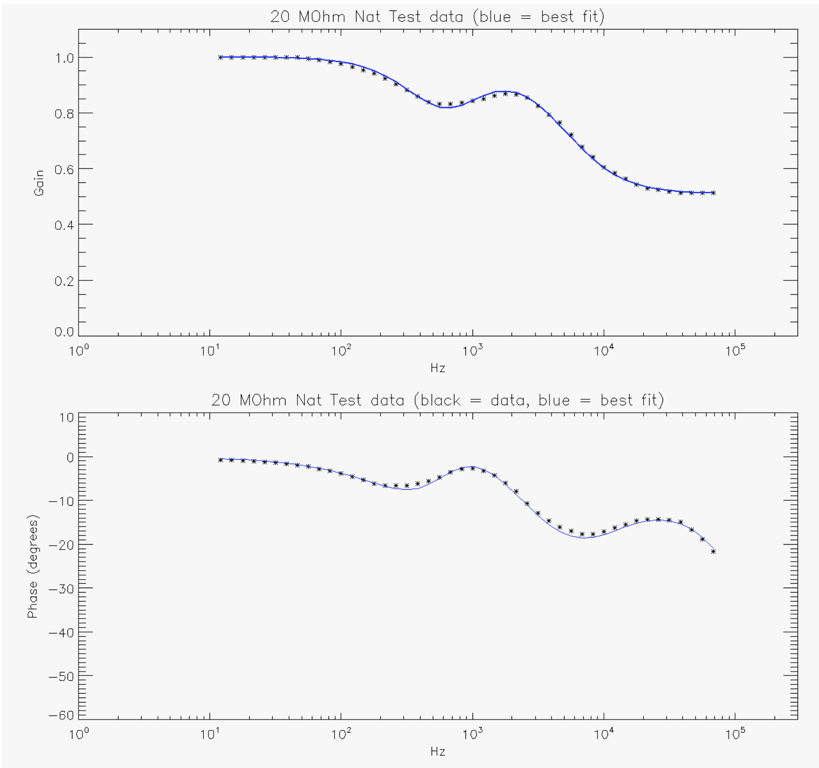

Figure 11. Gain and phase correction applied to ADP.