Technical Description

of the LET spectrometer Liulin-4S with GPS receiver

designed by
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Introduction

The LET spectrometer Liulin-4S main purpose is to monitor the doses and flux at the place of measurements. It is a miniature spectrometer-dosimeter containing: one semiconductor detector, one charge-sensitive preamplifier, 3 microcontrollers and 1 MB flash memory. Pulse analysis technique is used for the measurement of the deposited energy in the detector, which is proportional to the deposited dose. The unit is managed by the microcontrollers through specially developed firmware. Plug-in links provide the transmission of the stored on the flash memory data toward the standard PC. The spectrometer is designed for multi-session use with the same initialization parameters as the first one. Each measurement session begins with the switching of the instrument ON and finished when the instrument is switched OFF. The data sets of each session are defined by the automatically created names of the ASCII files, which are produced by the Liulin-4S.exe program during the selection of the sessions. PC provides to spectrometer standard parallel communication port (printer port). Rockwell's Zodiac Global Positioning System receiver is used in Liulin-4S for processing the signals from all visible GPS satellites for 3D geographical and time positioning of the measurements. The Zodiac receiver provides an output timing pulse that is synchronized to one second with UTC (Universal Time Coordinated) boundaries. (http://dtelunix.dtcc.edu/rocket/99launch/downloads/Zodiac.pdf).

Description of the spectrometer

The Liulin-4S is designed for continuous monitoring of the radiation environment on board of aircrafts.

After switching on, Liulin-4S starts to accumulate in 256 channels the spectrum used to calculate the dose and the flux of events in the silicon detector. The exposition time of one spectrum is variable in the interval 5 sec - 3539 sec. After finishing the first measurement cycle the spectra, accumulated dose, flux and GPS data are stored in the flash memory. This continues till the aircraft power is available. The instrument stops to operate when the aircraft power is switched off. The clock calendar, which is powered by internal Li battery continue to work only. When power appears again the normal operation is restored. After connection of the instrument with PC all accumulated data are transmitted to PC and organized in a separate binary file.

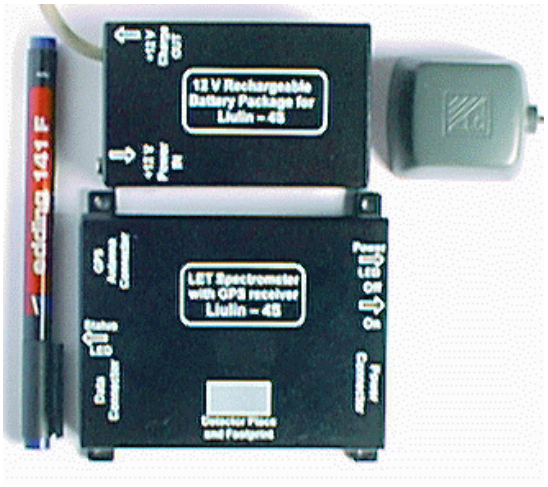

Figure 1. External view of the Liulin-4S components. Liulin-4 Spectrometer is in the middle. Rechargeable battery package is at the top of figure. Gray box in the upper right part of the figure is the GPS active antenna.

Inside of Liulin-4S is mounted single-board standard Rockwell's Zodiac Global Positioning System (GPS) Jupiter receiver. The GPS antenna is outside of Liulin-4S on a 5 m long cable. The power supply of Liulin-4S is performed with a DC/DC converter, which is electrically insulated from the internal signal ground and from Liulin-4S external box. For validation of the GPS data it is required at least 4 satellites to be observed, that is why the

GPS antenna is required to be situated at the front edge of the front window of the aircraft or outside of it.

Liulin-4S contains: one semiconductor detector; one low noise, hybrid, charge-sensitive preamplifier A225 type of AMPTEK inc.; a fast 12 channel ADC; 3 microcontrollers, flash memory (1.024 Mbytes). Pulse high analysis technique is used for measurement of the energy losses in the detector. The unit is managed by 2 microcontrollers through specially developed software. A block schema of portable spectrometer-dosimeter is presented in Figure 2.

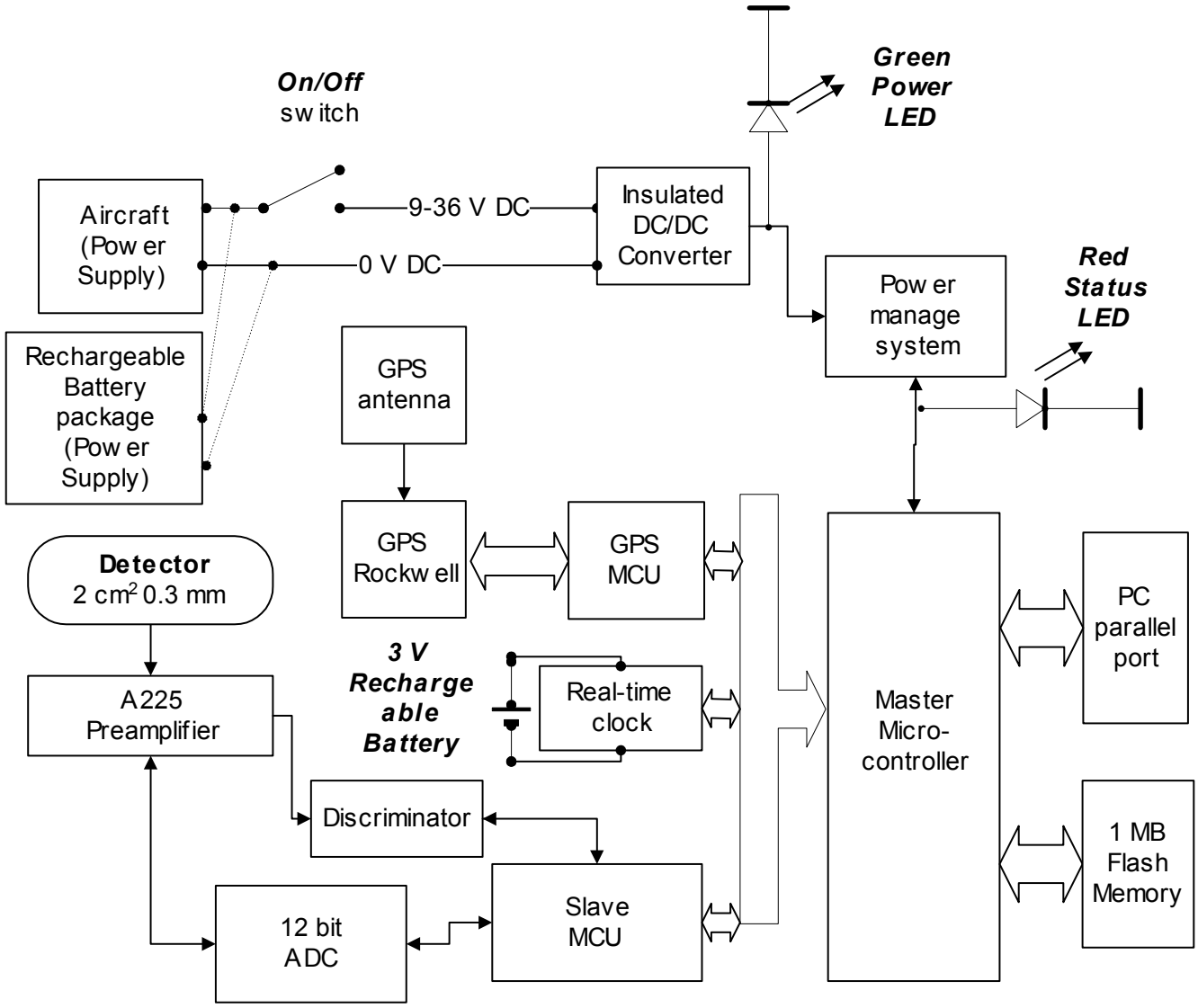

Figure 2. Block-scheme of Liulin-4S

The ON/OFF switch on the right side operate the spectrometer. After initialization with the Liulin-4S.exe software the spectrometer has to be switched OFF and is ready for the first working session. It starts to operate with switching ON. In a case of normal operation the green LED next to the ON/OFF switch shine continuously till the end of session when either the ON/OFF switch is switched OFF or the airplane power supply is disconnected. The red "Status" LED on the left side of the spectrometer after switching ON shines continuously till the first GPS connection. When correct GPS solution is obtained the LED starts to blink for about 0.5 sec at the end of each exposition interval. There are 3 possible cases of red LED continuous shine: 20-150 sec when the GPS is at the same place at which the spectrometer was switched OFF; 10-12 minutes at a completely new place; 15 minutes when no GPS solution was found. In this case the spectrometer starts to work without GPS from the internal clock-calendar.

Description of the 12 V Rechargeable battery package

The Rechargeable Battery Package (RBP) is seen at the top of Figure 1. It is an aluminum box, which contains 10 Rechargeable Nikel-Metalhidride Batteries with 1800 mAh capacity and specially developed for it electronic schema on a printed board, which controls the recharge and discharge voltage and current. Usually the recharge time with the available AC/DC converter is about 20 hours. Special test was performed in STIL-BAS, which proof that the Liulin-4S spectrometer and the active antenna worked from fully charged battery package for 37 hours according the following conditions: GPS sleep mode enabled and exposition time 300 sec.

The table below gives the estimated operation times from RBP in different modes of operation and the accuracy of the GPS data.

Mode of operation	**Operation time from fully recharged battery package**	**Accuracy of the GPS data**
Without (Disable) GPS	30 days	No GPS data available
With GPS with enable sleep of it	24 hours	The GPS data obtained are not very accurate
With GPS with disable sleep of it	10 hours	The GPS data obtained are most accurate

"Liulin-4S.exe" software manage the modes of operation.

Results of the GPS operation

Usually the first switch ON in a new place of the GPS takes about 12-15 minutes to be connected with the GPS satellite net and to be found an accurate GPS solution. Last GPS solution is stored in the memory and when the instrument is switched ON again this allows connection for about 25 seconds.

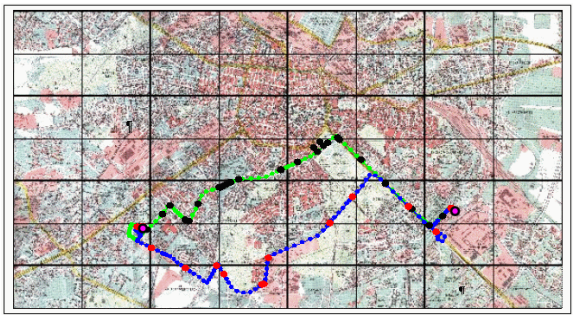

Fig. 3. Different car routes in Sofia obtained with the GPS receiver and processed by Liulin-4S

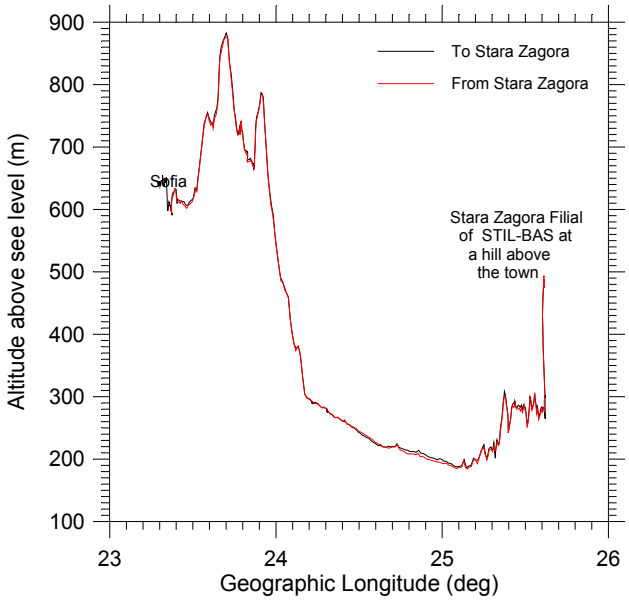

Fig. 4. Altitudinal profiles of the car routes from Sofia to Stara Zagora town and back obtained with the GPS receiver and processed by Liulin-4S

On Figure 3 are shown 4 different routes in Sofia obtained with the GPS receiver and processed by Liulin-4S. The green one is with 10 s measurement period. The GPS was enabled; the sleep of GPS was disabled. The antenna of the GPS was on the roof of the car. Blue route are in same condition with antenna situated inside of the car below the front edge of the front window. Black route is with 1 min resolution with disable sleep of the GPS; antenna on the roof, while the red one is with same condition with 2 min resolution. Relative large errors in the GPS solution are seen on the black route when the view of the GPS antenna was narrowed toward Nord-West direction by high buildings. On Figure 4 are presented 2 altitudinal profiles, obtained with Liulin-4S. The statistics of the measured altitudes from Sofia to Stara Zagora shows the following: 402 measured

points; 2.7 m average altitude error; 1.5 m standard deviation; 1.8 m minimum error; 26.6 m maximum error, obtained when a road tunnel was crossed.

Spectrometer data organization

The main measurement unit in Lilin-4S is the amplitude of the pulse after the preamplifier, which is proportional by a factor of 240 mV/MeV to the energy loss in the detector and respectively to the dose and LET. By the 12 bit ADC these amplitudes are digitized and organized in a 256-channel spectrum. The spectrum together with information from GPS is saved in the flash memory of the instrument. The capacity of the memory is 1.024 MB, which is enough for storage of data from the spectrometer and from GPS for 7.3 days non-stop measurements with 30 sec exposition time ore 34 days non-stop measurements with 600 sec exposition time. When GPS is switched OFF the capacity of the memory only for the spectrometric data is about twice of the mentioned above.

The following method for calculations of the dose is used: The dose D [Gy] by definition is one Joule deposited in 1kg or:

$D = K.Sum(EL_I*i)_{30\ sec}/MD,$

where MD is the mass of the detector in [kg] and EL_i is the energy loss in Joules in channel i. Energy loss in channel i is proportional to the number of events A_i in it multiplied by i. K is a coefficient.

The Liulin-4S operate in 3 modes: Working mode, Mode of Transferring the data from the flash memory to PC and Mode of initialization of the unit:

- In the Working mode the instrument is operating under the software in the microcontrollers. The operational time of the instrument depends on the rate of the memory fills up. The working mode is switched OFF automatically when the memory is totally filled up or the voltage of the RBP fals below 9 V;
- In the mode of data transferring the instrument is switched ON when it is connected to PC parallel interface after the end of the experiments before the reading of data. It is indicated with continuous shine of the red “Status” LED. The mode allows the transfer of the accumulated in the flash memory data to the PC;
- In the mode of initialization is switched on by special command when it is connected to PC parallel interface before the experiments. The mode allows the user to select the necessary exposition time of the instrument. In this mode the transfer of the real time data from the PC toward the Liulin-5S is performed.

Data accumulated in the flash memory of the instrument are transmitted to the PC by the parallel interface connection using a specially developed protocol and interface. The Liulin software product (Liulin-4S.exe) is developed in "WIN/98/NT/XP" environment. At the PC it creates automatically the subdirectory "Data" in the directory in which "Liulin-4S.exe" is located. In the subdirectory "Data" 1 binary file and four types of ASCII files are automatically created. The binary file of Liulin-4S is named automatically and contains in the name YYMMDDhhmm. The extension of the binary file means L01 for the first spectrometer and L02 for the second spectrometer. "YYMMDDhhmm" is the date and time of the moment when the first session begin. This file contains the rough binary data from all sessions and is for permanent storage of data from the instrument, because of the minimal volume of it. Four ASCII files for each instrument session of work are created automatically from the binary file. The names of first session ASCII files set contain same "YYMMDDhhmm" string as the binary file. The names of the next session files are created automatically and the date-time strings reflect the times of the first measurements in the new sessions. The files with extensions of type "D01", "S01", "Y01" and “G01” contains the "D"ose, "S"pectrum, "Y" (pure spectrum) and “G”PS data from the instrument. Same type of files but with extensions “02” are created by the second Liulin-4S spectrometer.

The first 3 rows of the dose (*.D01) file looks as follows:

```
MDU-01  EXPOSITION = 300[sec]
DD/MM/YY hh:mm:ss  DOSE = x.xx[uGy/h]  FLUX = x.xx[p/cm2.sec]
29/04/03 12:50:00 0.129812    0.065 116   39    0.0108176   42.6748     23.372
      601.79
```

where the meaning of the columns is: Date (DD/MM/YY), Universal Time (hh:mm:ss), Dose in (uGy/hour), Flux in (cm^{-2} s^{-1}), Sum(eventN*ChanellN), Sum of events in all channels, Total accumulated dose since the beginning of the measurements (μGy), Geographic Latitude in (degree), Geographic Longitude in (degree) and Altitude above the see level in (meters).

The first 4 rows of the full spectrum (*.S01) file looks as follows:

```
MDU-01  EXPOSITION = 300[sec]
DD/MM/YY hh:mm:ss  DOSE = x.xx[uGy/h]  FLUX = x.xx[p/cm2.sec]
0 10 12 9 4 2 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0
29/04/03 12:50:00 DOSE = 0.129812 FLUX = 0.065 116 39 0.0108176
```

where the 256 columns contains the number of event in each channel. The fourth row contains the same information as in dose file without the GPS data.

The first 2 rows of the spectrum (*.Y01) file looks as follows:

```
MDU-01  EXPOSITION = 300[sec]
0 10 12 9 4 2 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0
```

where the 256 columns contains the number of event in each channel.

The first 2 rows of the GPS (*.G01) file in the case GPS is connected with the set of satellites looks as follows:

```
MDU-01  EXPOSITION = 300[sec]
29/04/03 12:50:00 0 0 6 0 29 04 03 12 50 01 42.6748 23.372 601.79 2.62 4.86
```

where the meaning of the columns is given in the table below.

Remark: The differences in the UTC in columns 1 and 2 and 7-12 are seen usually in the seconds. This difference show how much later than the internal clock the GPS solution is taken. The spectrometer data for the whole exposition time are related to the point of the start of the exposition interval.

Column No	***Table ID***	***Word number***	***Word description; Units; range; Remark***
1	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	19/20/21	UTC DD/MM/YY
2	Table 5-5. Message 1000:	22:23:24	UTC hh:mm:ss

	Geodetic Position Status Output Message (2 of 3)		
3	Table 5-5. Message 1000: Geodetic Position Status Output Message (1 of 3)	10.0-10.15	Navigation Solution Validity (10.0-10.15) (this number needs to be 0 to be a valid solution)
4	Table 5-5. Message 1000: Geodetic Position Status Output Message (1 of 3)	11.0-11.15	Navigation Solution Type (11.0-11.15) (this number needs to be 0 to be a valid solution)
5	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	12	Number of Measurements Used in Solution (as larger this number is as accurate the solution is)
6	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	13	Polar Navigation (this number is 1 in a case of polar navigation)
7	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	19	UTC DD (day of the of last GPS connection with the satellite set)
8	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	20	UTC MM (month of the of last GPS connection with the satellite set)
9	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	21	UTC YY (year of the of last GPS connection with the satellite set)
10	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	22	UTC hh (hour of the of last GPS connection with the satellite set)
11	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	23	UTC mm (minute of the of last GPS connection with the satellite set)
12	Table 5-5. Message 1000: Geodetic Position Status Output	24	UTC ss (seconds of the of last GPS connection with the satellite set)

	Message (2 of 3)		
13	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	27-28	Latitude Degree.
14	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	29-30	Longitude Degree.
15	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	31-32	Height Meters.
16	Table 5-5. Message 1000: Geodetic Position Status Output Message (3 of 3)	40-41	Expected Horizontal Position Error (Note 7); Meters; 0-320000000
17	Table 5-5. Message 1000: Geodetic Position Status Output Message (2 of 3)	42-43	Expected Vertical Position Error (Note 7); Meters; 0-250000

In the case when GPS is not connected with the set of the satellites the UTC date and time in the first 2 columns are substituted with the date and time, which the spectrometer obtain during the initialization from the PC.

Remark: We recommend the instrument to be set under UTC before the initialization.

SPECIFICATIONS OF Liulin-4S

- *Dose range: 0.093 nGy – 1.56 mGy;*
- *Flux range: - 0.01 – 1250 part/cm^{2}s;*
- *Energy loss range: - 0.0407 – 20.83 MeV;*
- *Pulse height analysis range: - 9.25 mV – 5.0 V;*
- *LET range: 0.135 - 69.4 keV/μ;*
- *Temperature range: -20^{o}C - +40^{o}C;*
- *Power consumption at normal operation: not more than 150 mA from 28 V*
- *Spectrometer dimensions: 100x80x25 mm; weight 0.25 kg;*
- *Rechargeable battery package dimensions: 85x52x35 mm; weight 0.41 kg;*
- *Active antenna dimensions 50x40x20 mm; weight 0.06 kg.*