



## 22RPT02 True8DIGIT

### Deliverable D5:

Report on the development of an ultra-quiet and stable low noise power supply supplied from the mains supply, applicable for all voltage and current spans needed by the metrology grade ADC architectures. This includes the measured line interference noise and stability over the whole operating power range

Organisation name of the lead participant for the deliverable:

**NSAI**

Organisation name of the contributing participants for the deliverable:

**CMI, SIQ, FER, INRIM**

Due date of the deliverable: 30 April 2026

Actual submission date of the deliverable: 06 May 2026

---

**Confidentiality Status:** PU - Public, fully open (remember to deposit public deliverables in a trusted repository)

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

European Partnership  Co-funded by the European Union

Deliverable Cover Sheet

METROLOGY PARTNERSHIP 

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.



---

List of Authors

**Jan Kucera**  
*CMI, Cesky Metrologicky Institut*  
*Czechia*

**Bostjan Volic**  
*SIQ, Slovenski Institut za Kakovost in Meroslovje*  
*Slovenia*

**Bruno Trinchera**  
*INRIM, Istituto Nazionale di Ricerca Metrologica, Torino,*  
*Italy*

**Damir Ilic**  
*Sveuciliste U Zagrebu Fakultet Elektrotehnike I Racunarstva*  
*Croatia*

**Oliver Power**  
*NSAI, National Standards Authority of Ireland, Dublin,*  
*Ireland*



## Table of Contents

<b>1</b>	<b>Summary.....</b>	<b>4</b>
<b>2</b>	<b>Identification of power supply requirements and investigation of architectures .....</b>	<b>5</b>
	2.1 Power Supply Requirements .....	5
	2.2 Power Supply Architecture.....	6
<b>3</b>	<b>Design and Constructional Details of the Power Supply .....</b>	<b>6</b>
<b>4</b>	<b>Results of Power Supply Testing.....</b>	<b>11</b>
	4.1 Stability Test.....	11
	4.2 Loading Tests .....	24
	4.3 Isolation Test.....	29
	4.4 Noise Test.....	29
<b>5</b>	<b>Conclusion.....</b>	<b>31</b>



## 1 Summary

The quality of the power supply (PSU) used to provide power for a precision digitiser can have a significant effect on the performance of the digitiser. This report describes the design, development, construction and testing of an ultra-quiet and stable low-noise power supply with a continuous output, supplied from the mains but with negligible line interference noise. The output voltages provided by the PSU cater for all voltage and current spans needed by the metrology grade ADC architectures developed in other parts of the True8DIGIT project. The prototype PSU that was developed provides output voltages of  $\pm 18$  V (max  $+0.4$ ,  $-1$  A) and  $\pm 5$  V (max.  $\pm 0.5$  A) needed to power the analogue electronic parts of the digitiser as well as  $2 \times +5$  V (max. 5 A) and  $+3.3$ V (max. 1 A) outputs for the digital parts. A limited number of products with continuous output, lowered noise and enhanced isolation is available on the market. The authors have found only Metron Design's Double Regulated Ultra Low Isolation-Noise DC-DC Converter ISOP3 [1] and Stanford Research System's SIM928 Rechargeable isolated voltage source [2]. The first provides voltages in the ranges  $\pm 4$  to  $\pm 8$  V or  $\pm 9$  to  $\pm 19$  V separately only, with additional auxiliary non-isolated 5 V output (max. 0.1 A). The second has limited output current to  $\pm 10$  mA only,

The report content flow is as follows:

Chapter 2 gives the specifications of the PSU needed to satisfy the requirements of the various parts of the precision digitiser developed within the project, namely its input stage, integrator and timing platform. The voltage levels, current capacities, noise levels and mains isolation performance are given. Overall, the target was to meet or exceed the specifications of other power supplies available on the market.

In Chapter 3, the different approaches that were explored to satisfy the required specifications are described. Two main operating principles were considered: (1) a battery powered supply featuring two switchable battery packs so as to provide continuous power and (2) a mains powered supply using a very high isolation DC-DC converter. The battery powered option was chosen for development.

In Chapter 4, the design and development of the prototype PSU are described. The main components are the AC power block, battery packs and power management circuitry, high isolation switches, hot swap controller and low dropout regulator.

Chapter 5 describes the methods used to test the PSU and presents the results. The testing programme comprised stability, temperature and loading test as well as noise, isolation and leakage tests.

Chapter 6 presents the overall conclusions drawn from the research.

The authors wish to gratefully acknowledge the significant contribution of the project collaborator John Pickering (Metron Designs Ltd) who advised participants on principles of low noise DC/DC converter design and Jakub Kovac for his support in designing the battery based power supply.



## 2 Identification of power supply requirements and investigation of architectures

### 2.1 Power Supply Requirements

The power supply is intended to supply power for the key component parts of the digitiser, namely the composite operational amplifiers to be used in the input stage and the integrating ADC as well as the timing and synchronisation platform. Following consultation with the project partners responsible for researching and developing these components, the output voltage levels and current sourcing capacities of the power supply given the Table 1 were specified.

Voltage Levels	Current Levels	Noise Level	Stability	Required for
+18 V; -18 V	100 mA	Ultra quiet	High	Input COPA, Integrator COPA
+5 V; -5 V	200 mA	Quiet	High	integrator logic, additional analog circuits
3.3 V	0.3 A	5%	5%	Galvanic isolators for FPGA
+5 V; -5 V	4 A	5%	5%	Clock, FPGA

Table 1 Required power supply capabilities

Two key characteristics of the power supply are its noise level and its isolation from the mains supply. A survey of commercially available DC power supplies with state-of-the art capabilities found that the best available noise level was 10  $\mu$ V RMS (1 kHz bandwidth) and leakage current of the order of 10 nA. These were set as the target levels for the power supply prototype to be developed in this project.



## 2.2 Power Supply Architecture

Two main contending power supply architectures to achieve low noise and high isolation were investigated.

The first approach uses a special type of switched mode DC-DC adapter designed to achieve very high isolation [1]. The key element of this architecture is a specially designed transformer which has full, near perfect Faraday cage screening around each of the primary and secondary windings. The windings are magnetically coupled using a “shorted” turn winding that does not carry any induced voltage. The second important element is an adapted switching regulator which reduces the peak input voltage swing.

The second approach uses a battery as a power source for the power supply. For continuous operation, the battery must be kept in a charged condition and the challenge here to achieve this while maintaining high isolation from the mains. The solution is to use two battery packs, one of which is being charged while the other provides power to the supply [2]. Careful layout of the design is necessary to avoid any coupling between the battery packs and any glitch due to the switchover between the packs needs to be minimized.

## 3 Design and Constructional Details of the Power Supply

Since the special components required for the DC-DC converter approach were not commercially available, it was decided to pursue the switched-battery approach. Such an approach with modular design enables separated optimization of each PSU part.

The system architecture features four independent lithium-ion (Li-Ion) battery banks arranged to supply both positive and negative voltage rails, with two banks per rail forming a symmetric and fully isolated topology. Each battery bank comprises a dedicated charger, six Li-Ion cells, and an integrated battery management block (BMS). These management blocks monitor key operational parameters such as voltage, current, state-of-charge, and temperature, and provide protection from overvoltage, overcurrent, and overtemperature to enhance both safety and operational reliability.

To maintain galvanic isolation, the charging and discharging paths are separated: at any time, only one bank per rail delivers power to the load, while its companion bank is either charging or idle. This configuration prevents direct electrical connection between input and output, thereby eliminating common ground loops. A central power supply management block automates the switchover process between banks. It periodically reads the status of each bank via a galvanically isolated I2C bus, which further protects the control logic from noise coupling. To reduce inrush currents and suppress voltage transients during switchover, a hot-plug technique with slow voltage ramp-up is employed, preserving the integrity of sensitive equipment. The switch system is a simplified version of a high-isolation switch arrangement introduced in [3] for precise voltage and impedance metrology applications.

Since the battery bank's output voltage varies with state of charge, precise voltage regulation is achieved using high-performance, low-dropout regulators. The main  $\pm 20$  V rails are stabilized by TPS7A3301 (negative) and TPS7A4701 (positive) regulators. For ultra-low-noise applications, the



system provides silent  $\pm 18\text{ V}$  rails using LT3046 (positive) and LT3094 (negative) regulators, each capable of delivering up to 400 mA. Additionally, the LT3097 regulator delivers silent  $\pm 5\text{ V}$  rails, supporting up to 500 mA. This multi-stage regulation ensures all voltage outputs remain stable and ripple-free across battery states and load conditions. To supply power for digital circuits conventional supplies ( $2 \times 5\text{ V}$  and  $1 \times 3.3\text{ V}$ ) are also supplied. Note that these outputs do not feature any special isolation or noise reduction measures, The architecture of the PSU is depicted in Figure 1.

The PCB layout and output connectors are shown in Figure 2. Figure 3 shows the interface, developed on the LabView© platform, which allows the user to control the status of the relays and monitor the status of the batteries. The user can set the relays to the desired configuration for testing purposes. For normal operation the system is set to the Auto mode whereby the batteries are switched appropriately, depending on their state of charge. The status of battery (state of charge, capacity, voltage, current and temperature) are displayed.

The four battery packs are mounted underneath the PCB to allow easy connection and disconnection (Figures 4 and 5). Figure 6 shows a top view of the prototype power supply with the top cover removed.

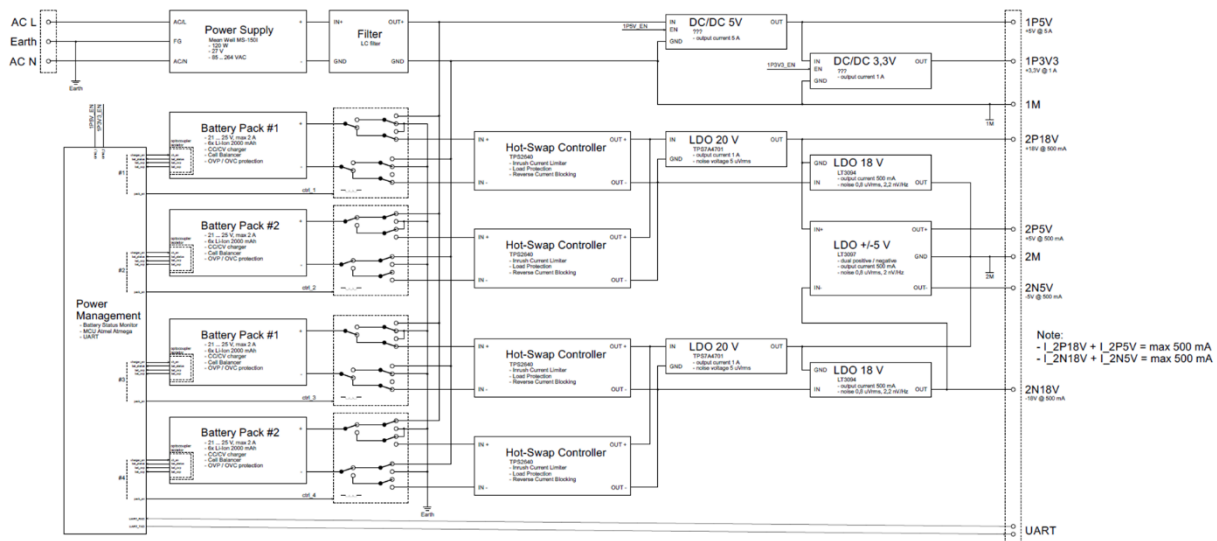
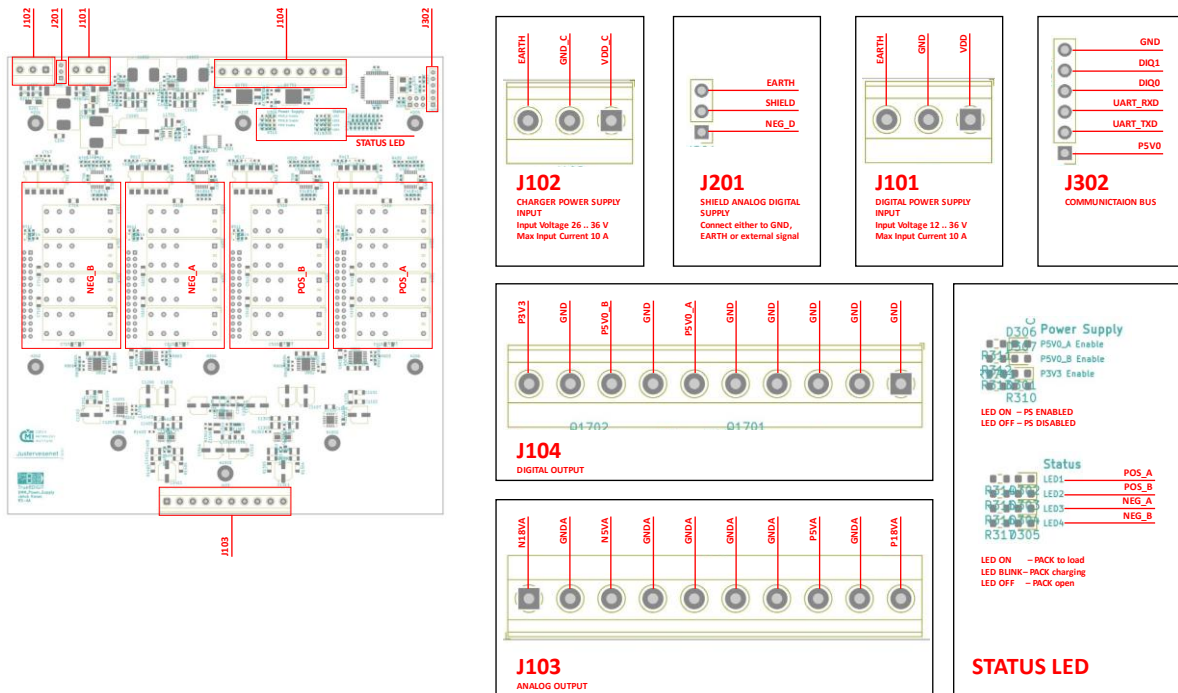


Figure 1

Block Diagram of the first revision of Power Supply



GUARDED

Figure 2 PCB Lay-out and output connectors

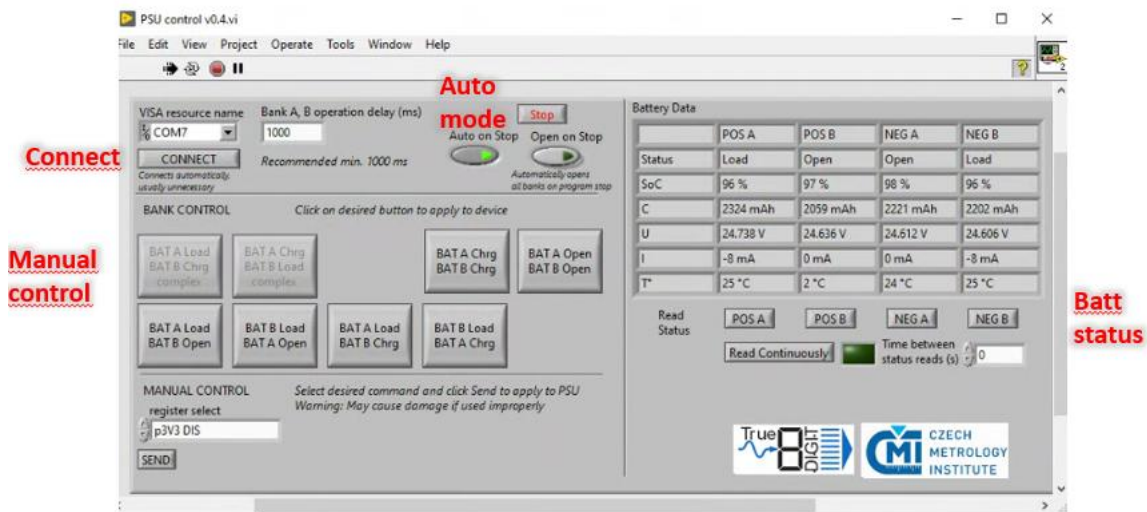


Figure 3 User Interface for battery monitoring and control

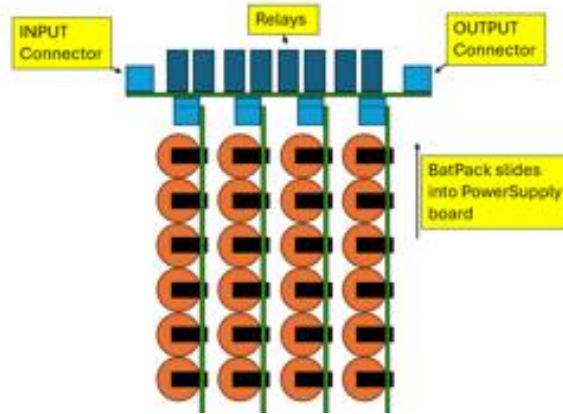


Figure 4 Physical layout of battery pack and PCB



Figure 5 Side view of the battery pack

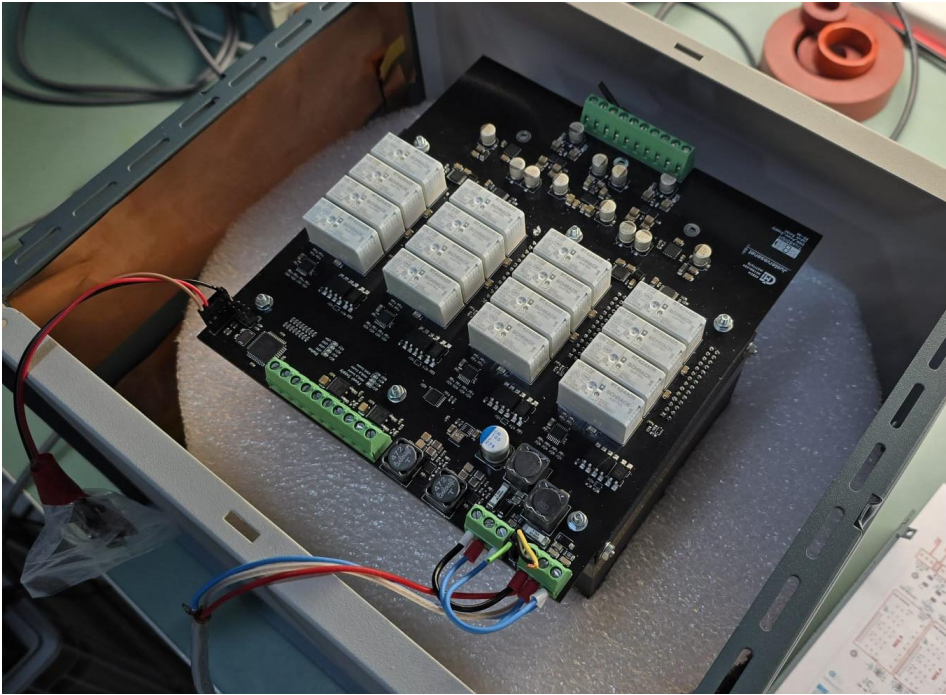


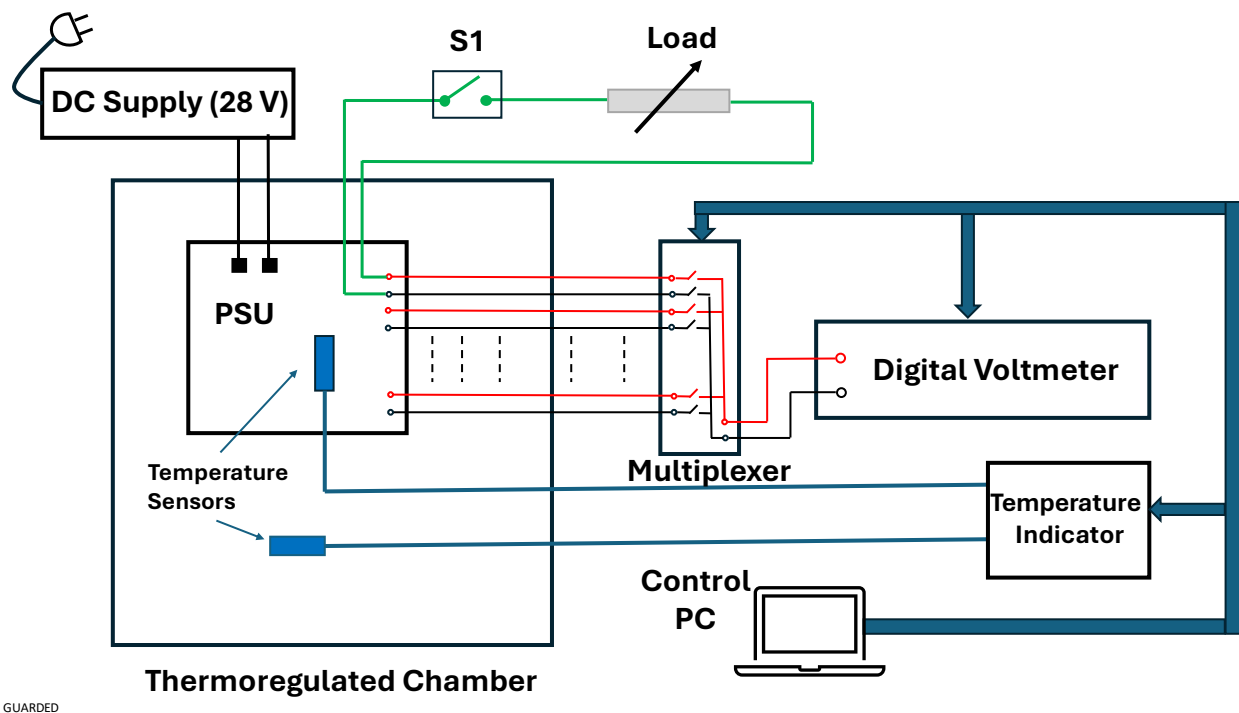
Figure 6 Top-view of the prototype power supply installed in the chassis

## 4 Results of Power Supply Testing

The demonstrator power supply was subjected to a number of performance tests to verify that it met its target specifications. The parameters tested were: stability, immunity to ambient temperature variations, load regulation, noise level, and mains isolation.

### 4.1 Stability Test

The test set-up used for stability testing is shown schematically in Figure 7.



GUARDED

Figure 7 Test Set-up for stability, temperature and load tests

The PSU, powered by a 28 V linear power supply (Agilent U8002A), was placed in a temperature controlled chamber (Kambic TK-190US) at  $(23 \pm 0.03) ^\circ\text{C}$  and allowed to stabilize for more than 48 hours. Its seven output voltages were connected to a multiplexer (Agilent 34970A) whose output was connected to a digital voltmeter (Keysight 3458A). One channel of the multiplexer was connected to a Zener diode-based 10 V voltage standard (Wavetek 7000, not shown in the figure) which provided a baseline for the stability measurements. The air temperature of the chamber was monitored by a Pt100 sensor placed adjacent to but not touching the PSU. The internal temperature of the PSU was monitored by a type N thermocouple placed in the air space inside the PSU case. The outputs of both sensors were measured by a temperature indicator (Fluke 1529).

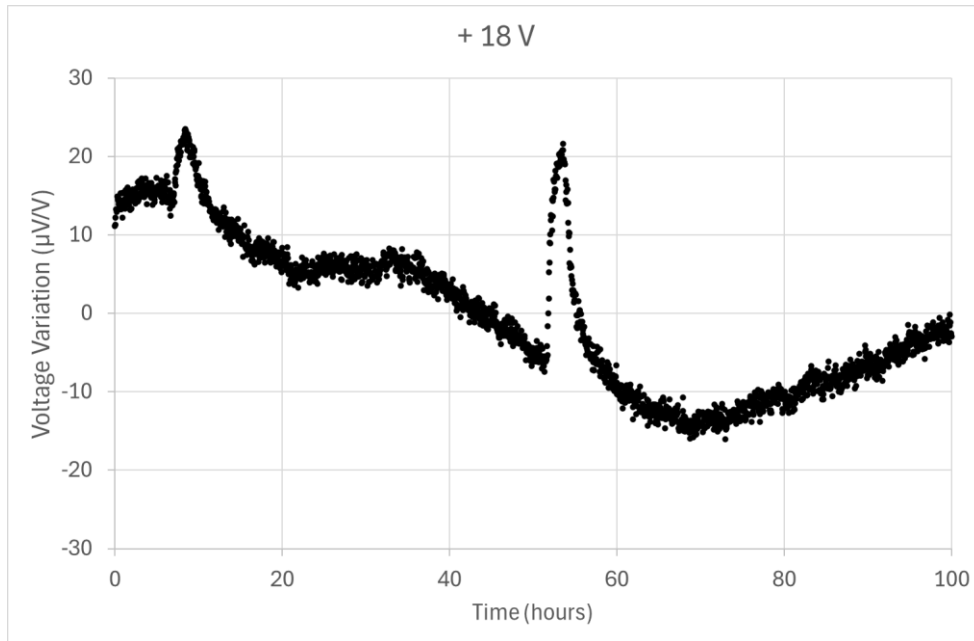


Fig 8(a) Stability of +18 V output

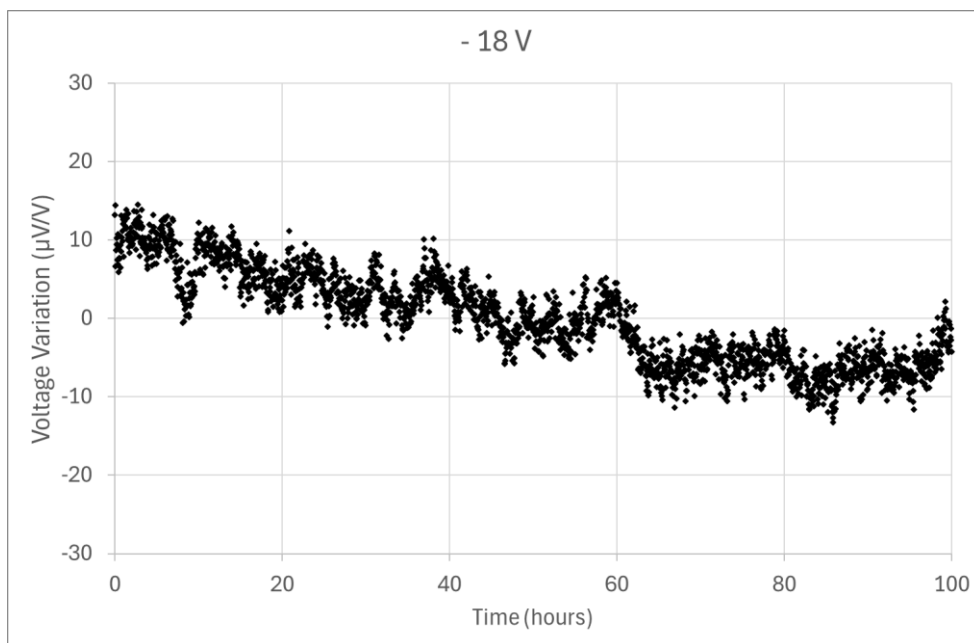


Fig 8(a) Stability of +18 V output

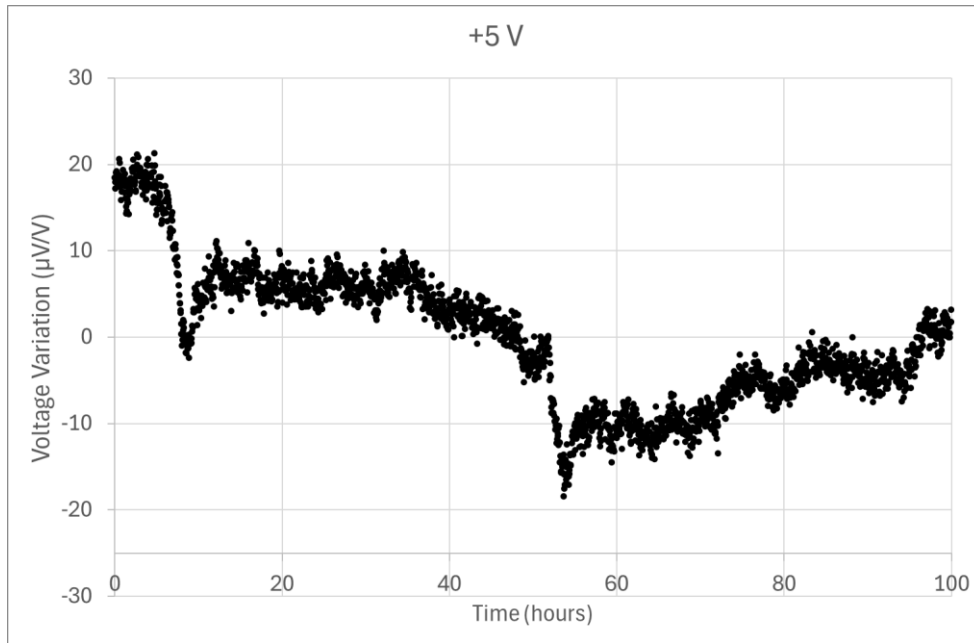


Fig 8(c) Stability of +5 V Output

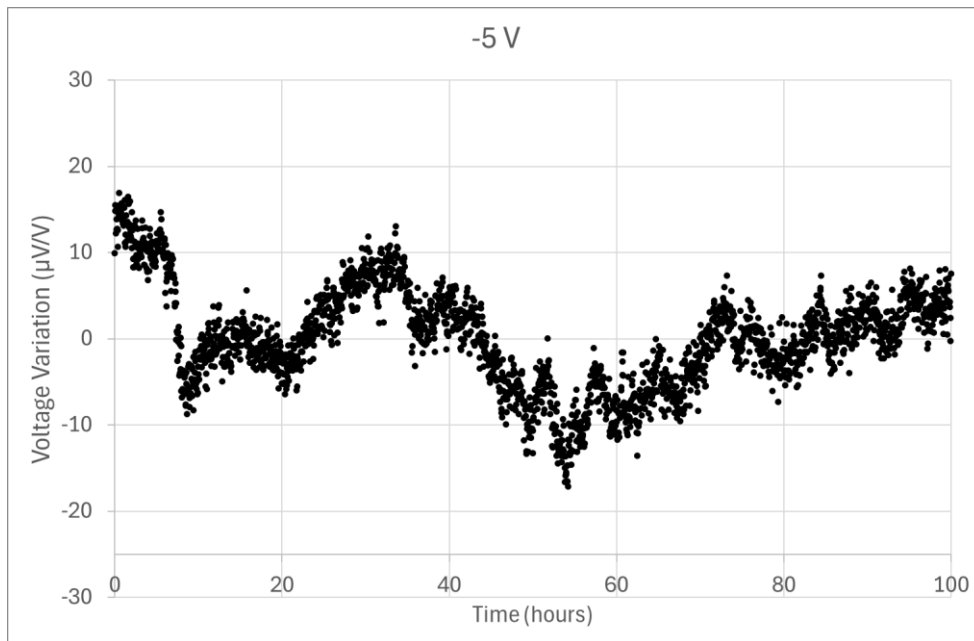


Fig 8(d) Stability of -5 V Output

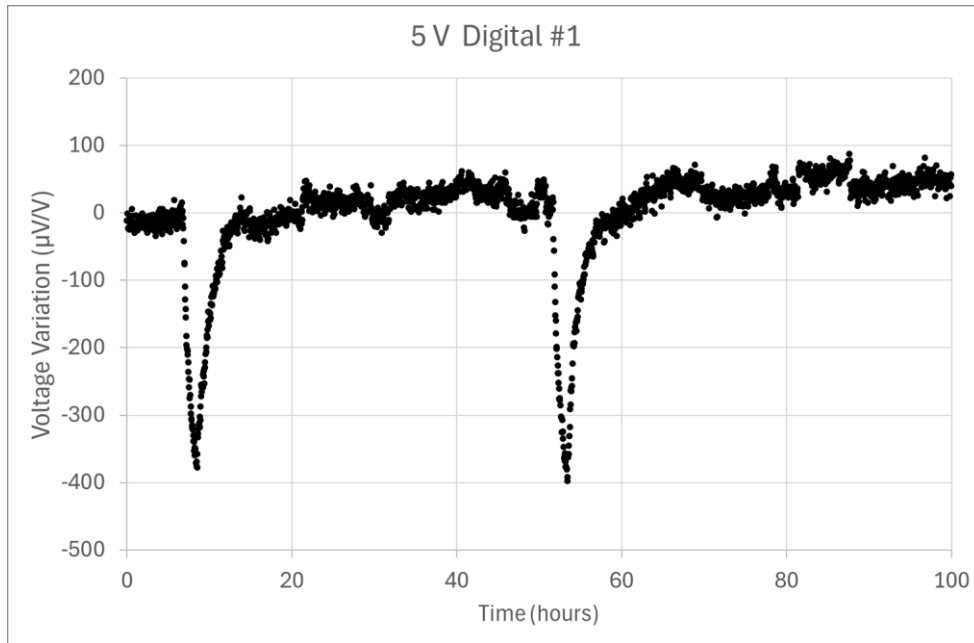


Fig 8(e) Stability of 5 V Digital Output #1

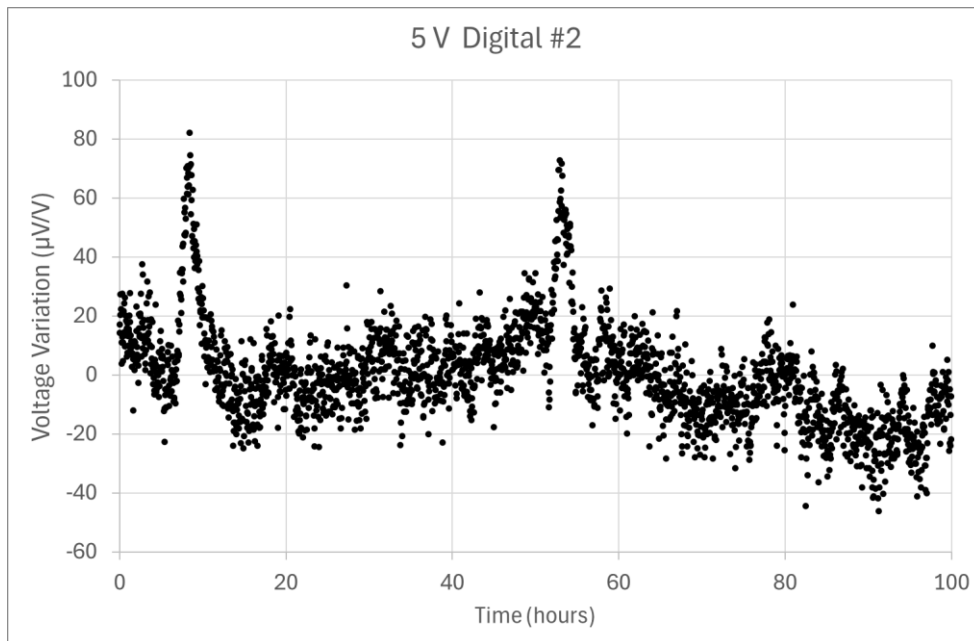


Fig 8(f) Stability of 5 V Digital Output #2

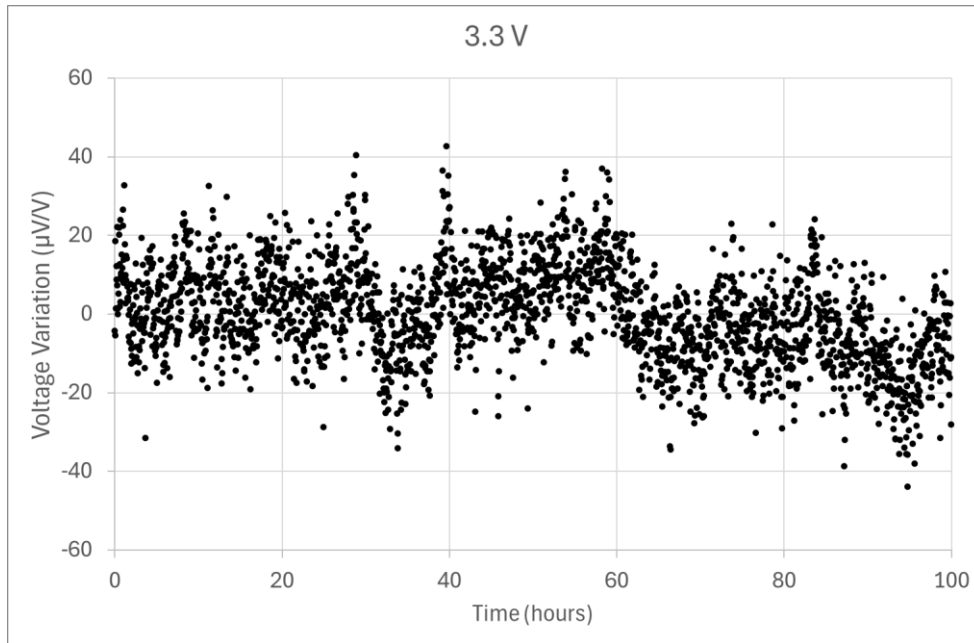


Fig 8(g) Stability of 3.3 V Output

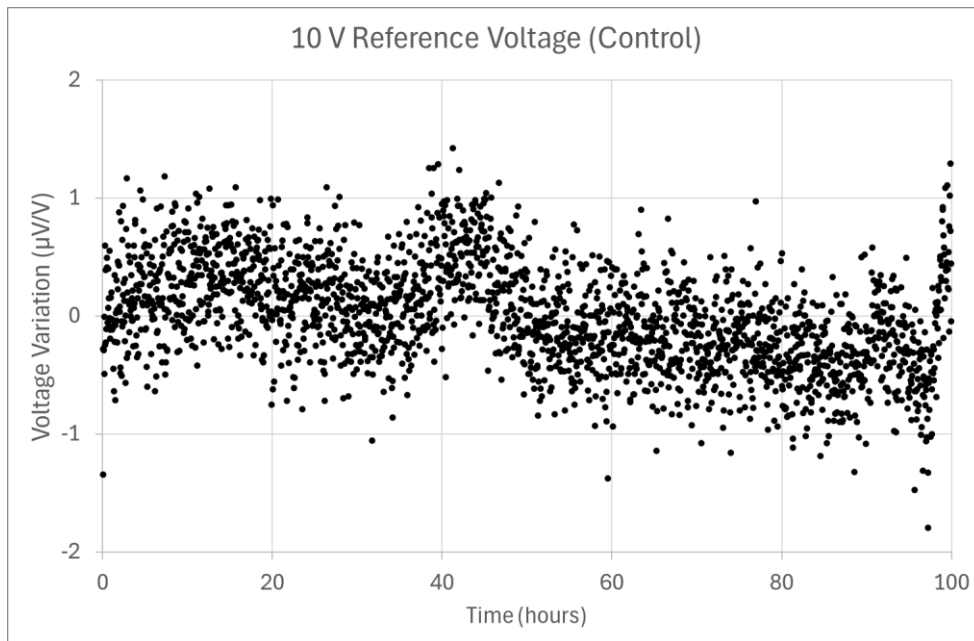


Fig (8h) Stability of 10 V Reference Voltage (|Control)



The unloaded output voltages (switch S in Figure 7 open) were measured with a sampling period of 156 seconds over a period of approximately 100 hours. The measured deviations of each output voltage from its mean value are shown in Figures 7 (a)-(g). Figure 7(h) shows the measured stability of the 10 V reference standard which varied by less than  $\pm 2 \mu\text{V/V}$  during the testing period.

The output voltages intended for use to power analogue circuits (+18 V, -18 V, +5 V and -5 V) varied by less than  $\pm 20 \mu\text{V/V}$ . In general, the voltage variations were smooth apart from the +18 V output which showed two short-term spikes which occurred approximately 45 hours apart. It is likely that these voltage spikes, lasting several minutes, are due to a thermal effect when the battery change-over occurs.

The output voltages intended for use to power digital circuits (2 x 5 V, 3.3 V) showed somewhat poorer stability and the voltage spikes on the 5 V outputs were more pronounced.

#### 4.2 Temperature Sensitivity Tests

The set up for the temperature sensitivity testing was identical to that used for the stability test (Figure 7). The supply voltages were unloaded during the test (switch S1 in figure 7 was open). The temperature of the chamber was varied in the sequence 23, 26, 20, 23 °C with a period of approximately 24 hours between temperature changes. The output voltages of the power supply outputs were monitored with a sampling period of 156 seconds.

The measured output voltage and temperature records are shown in Figures 9 (a)-(g). The continuous black line in the figures is the moving average (N = 32) of the measured voltages. Figures 10 (a)-(g) show plots of the mean voltages at each set temperature against temperature. The response of the voltages to temperature is substantially linear and the corresponding relative temperature coefficients are given in Table 2.

Intended Use	Nominal Voltage	Relative Temperature Coefficient ( $\mu\text{V/V}$ per °C)
Analog	+18 V	+12.8 (1.4)
Analog	-18 V	-3.1 (0.5)
Analog	+5 V	-10.8 (0.8)
Analog	-5 V	-7.3 (0.7)
Digital	+5 V (#1)	+16.4 (0.5)
Digital	+5 V (#2)	+33.6 (1.9)
Digital	+3.3 V	-178 (8)

Table 2 Measured relative temperature coefficients from linear fit to the data in figures 10(a)-(g) (figures in parentheses are type A standard uncertainties)

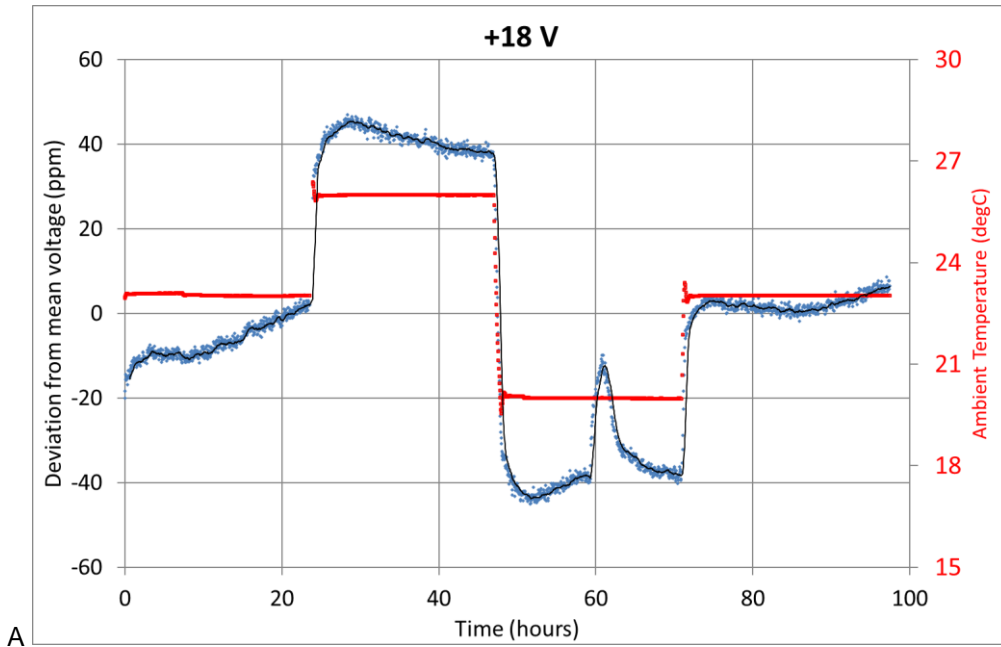


Figure 9(a) Response of +18 V output to temperature changes

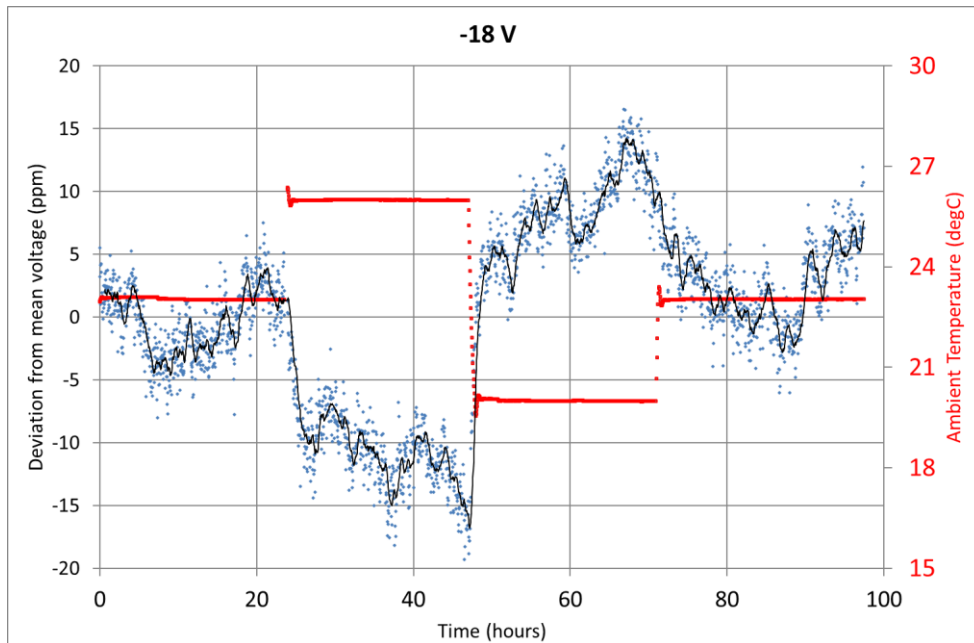


Figure 9(b) Response of -18 V output to temperature changes

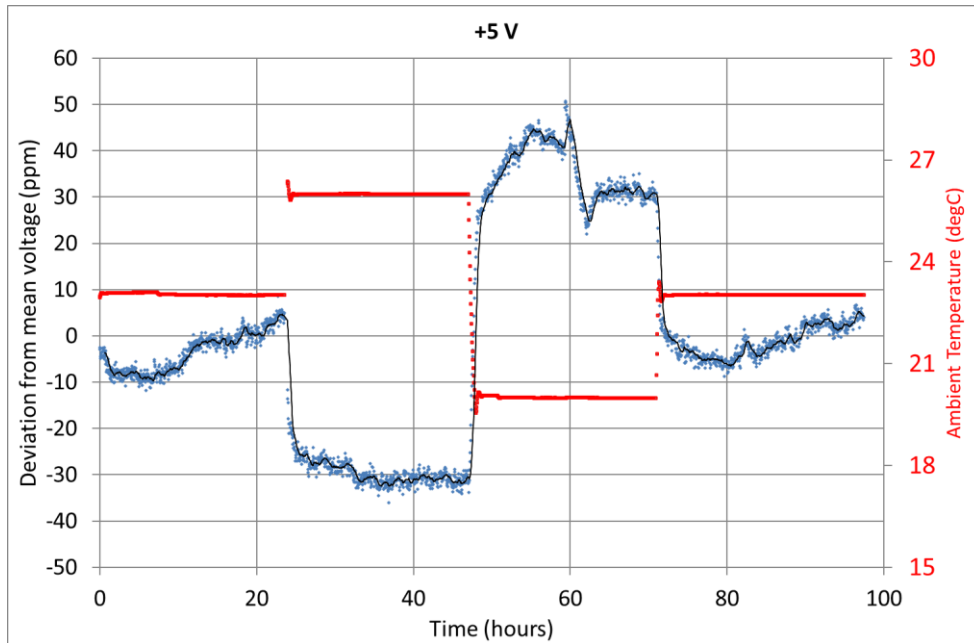


Figure 9(c) Response of +5 V output to temperature changes

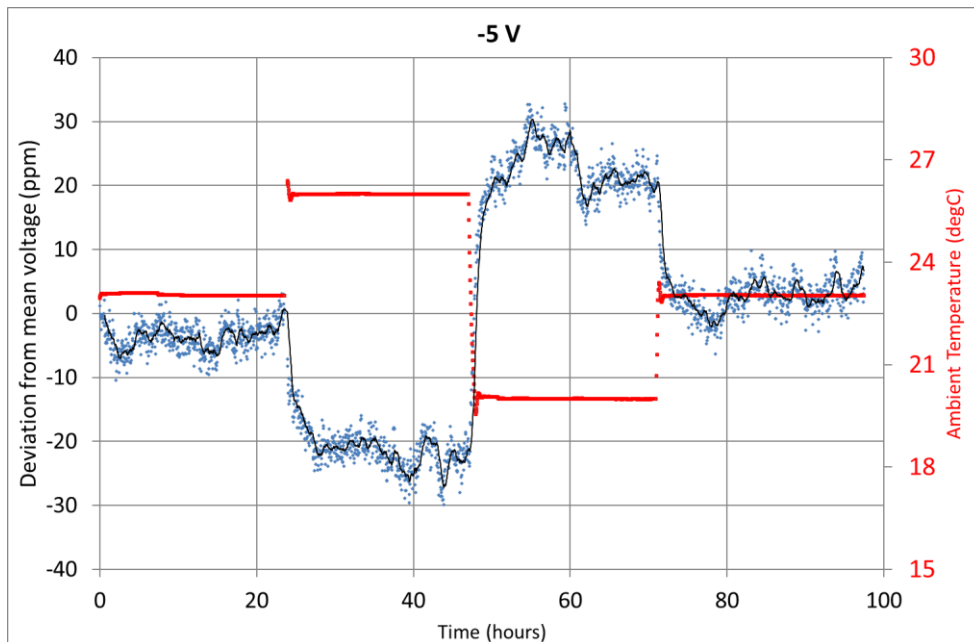


Figure 9(d) Response of -5 V output to temperature changes

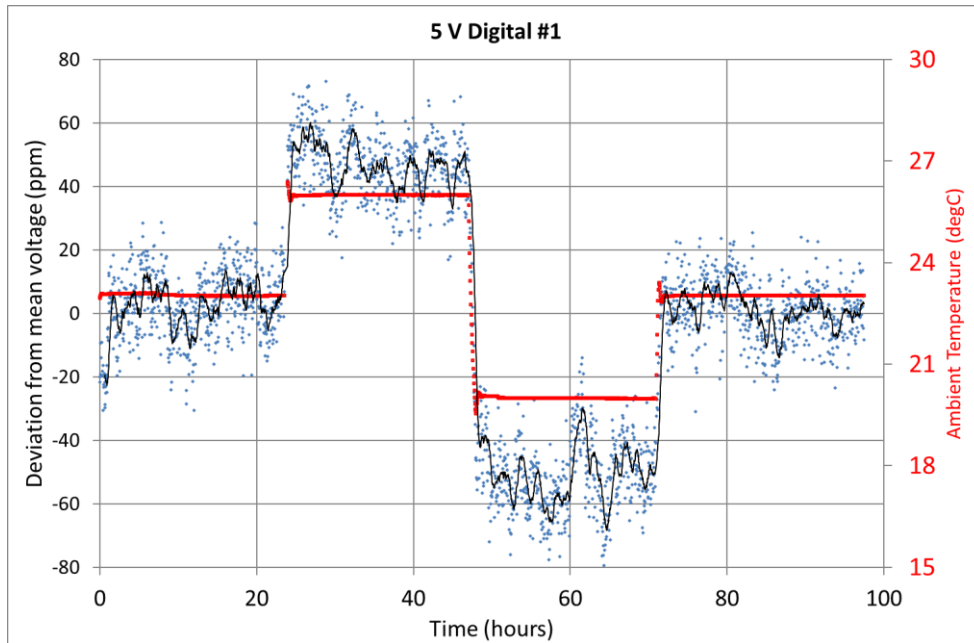


Figure 9(e) Response of 5 V Digital #1 output to temperature changes

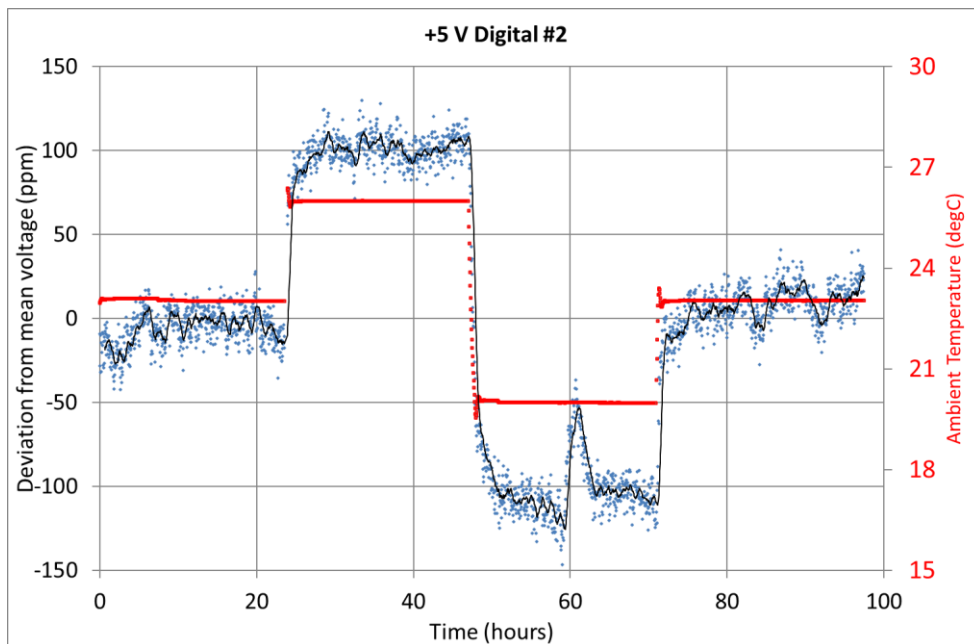


Figure 9(f) Response of 5 V Digital #2 output to temperature changes

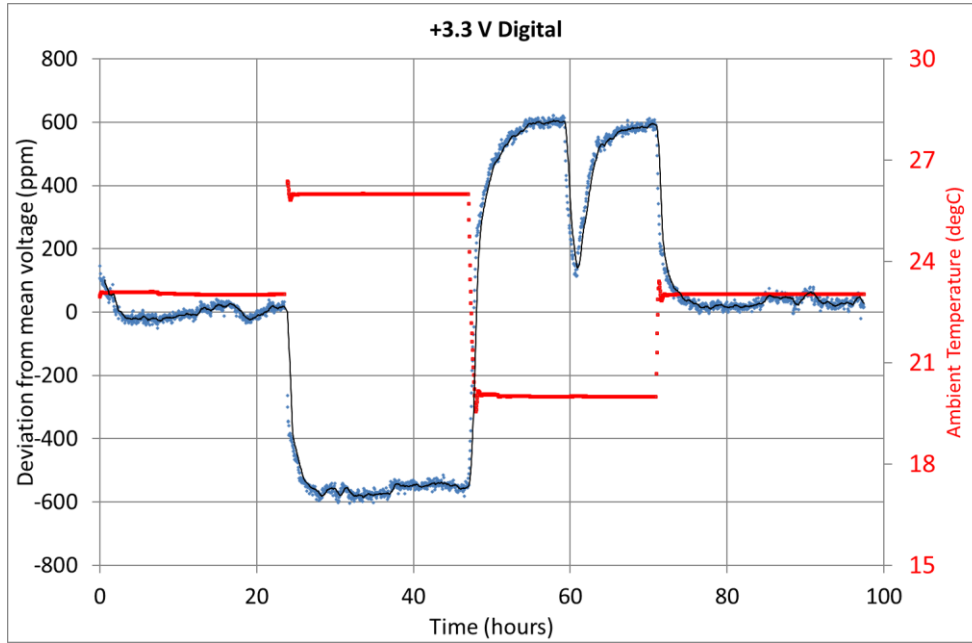


Figure 9(g) Response of 3.3 V output to temperature changes

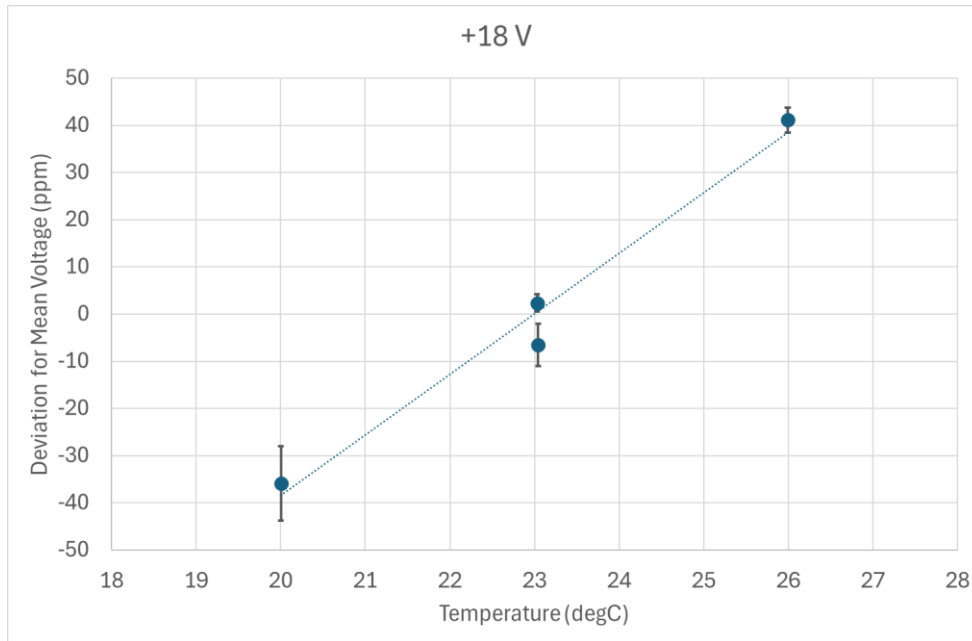


Figure 10(a) Plot of output voltage vs temperature for +18 V output

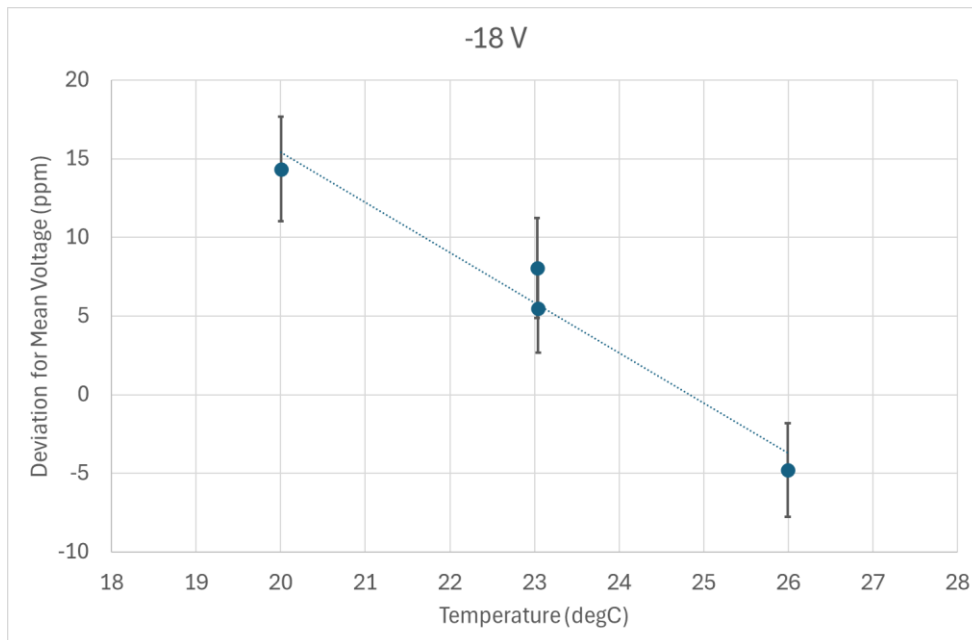


Figure 10(b) Plot of output voltage vs temperature for -18 V output

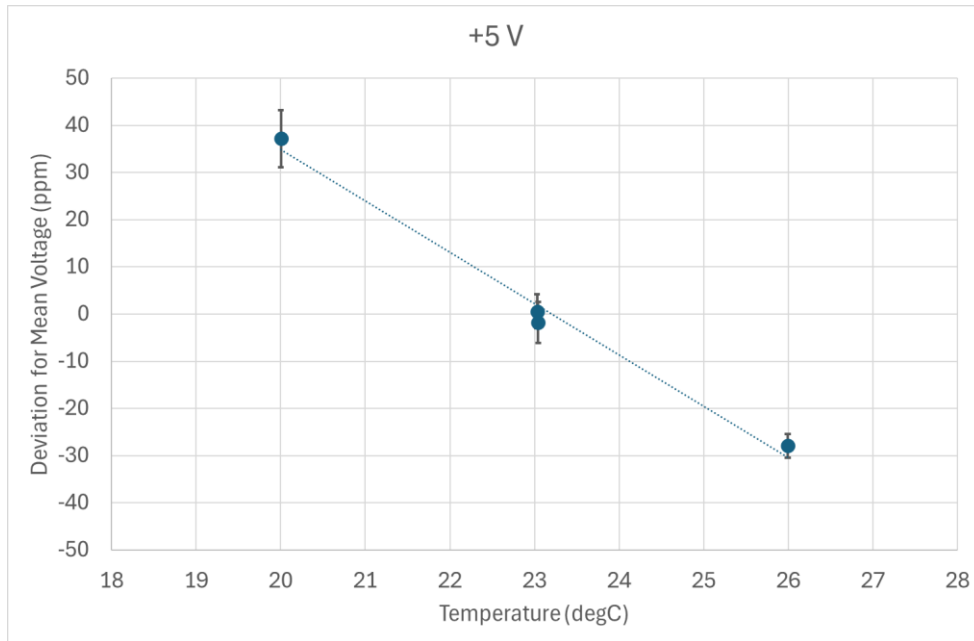


Figure 10(c) Plot of output voltage vs temperature for +5 V output

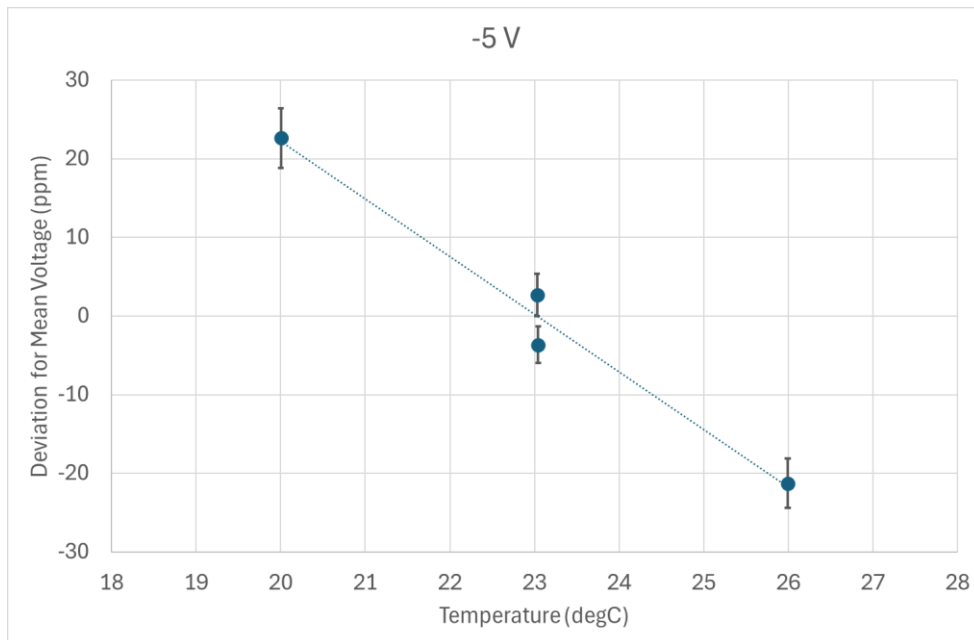


Figure 10(d) Plot of output voltage vs temperature for -5 V output

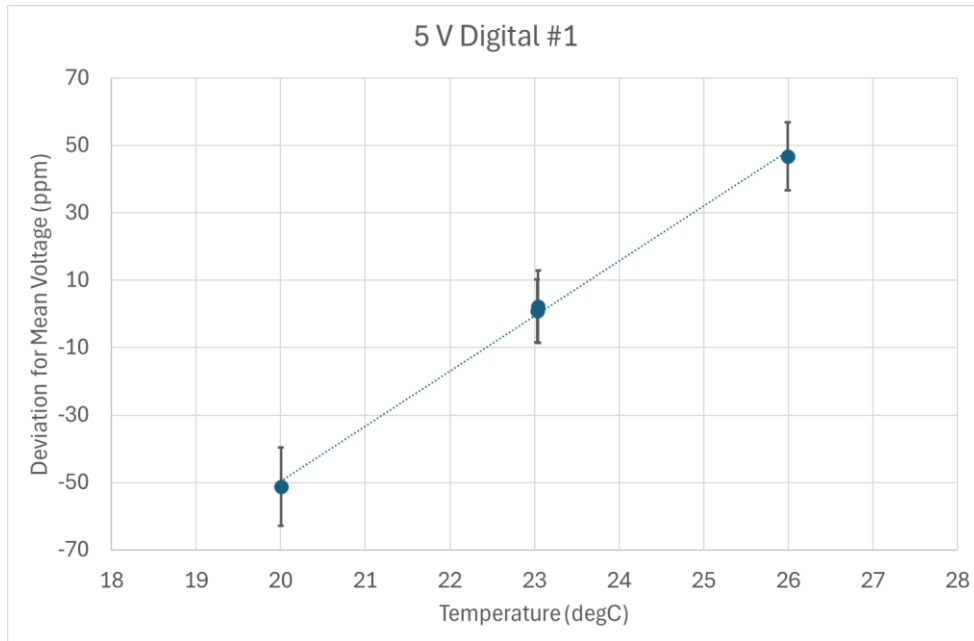


Figure 10(e) Plot of output voltage vs temperature for +5 V digital output #1

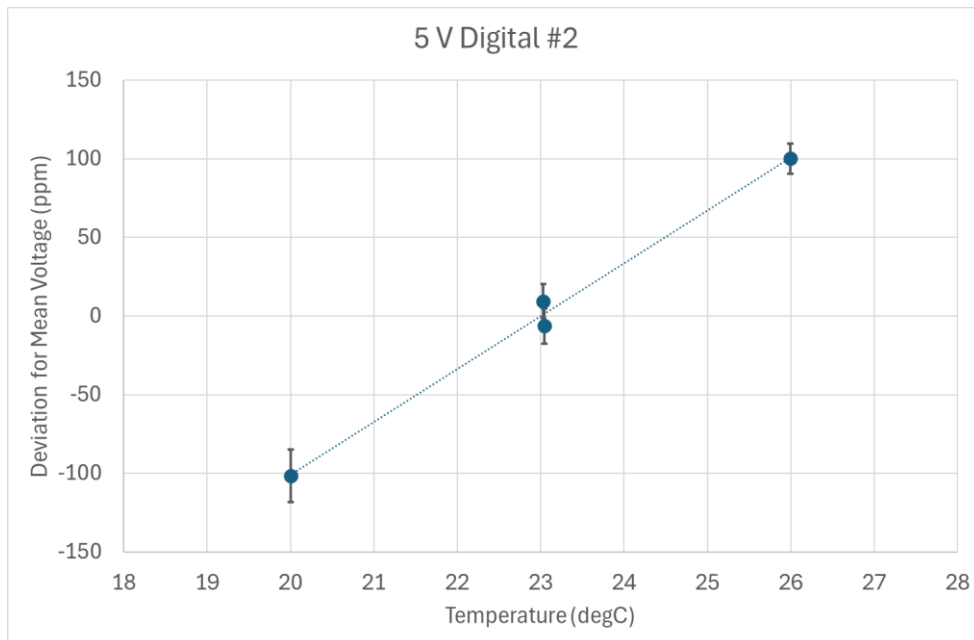


Figure 10(f) Plot of output voltage vs temperature for +5 V digital output #2

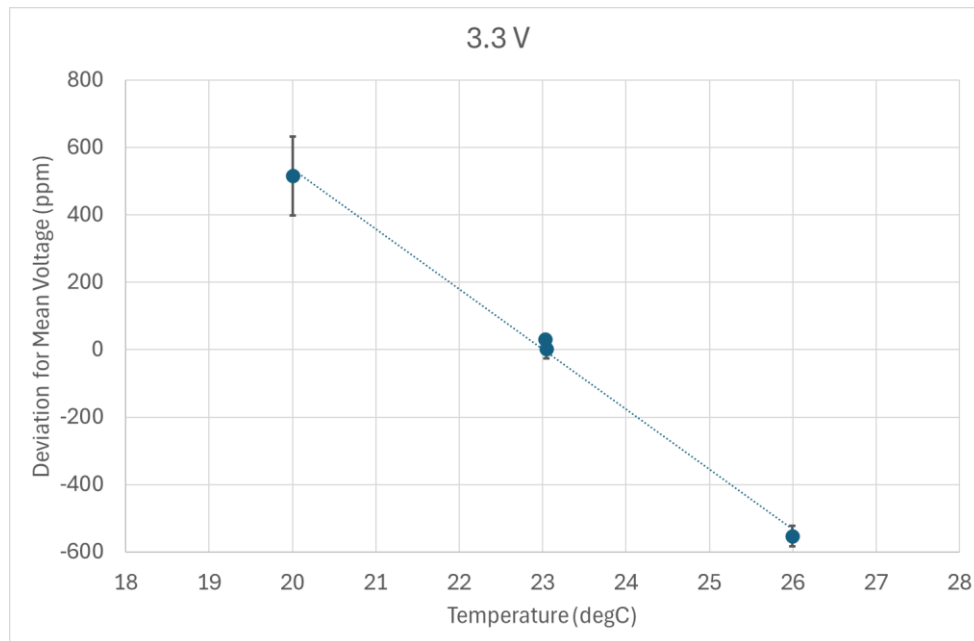


Figure 10(g) Plot of output voltage vs temperature for +3.3 V digital output #1

## 4.2 Loading Tests

The test set up for the loading tests was identical to that shown in figure 7. Tests were performed on the +18 V, -18 V and +5 V outputs. For each voltage the unloaded output voltage was monitored, the manually operated switch S1 was then closed applying a resistive load to the output terminals and the loaded output voltage was measured. The voltages were measured directly at the output terminals of the power supply. The sample rate was approximately 1.6 samples per second.

Figures 11(a)-(h) show the responses of the output voltages to the load changes. For the +18 V and +5 V tests, the output initially undergoes a sudden large change which decays in less than 10 s. The voltage then settles to a constant value albeit with a very small downward drift. The -18 V output did not show the transient effect when the load was switched in, but the steady state effect due to the loading is more than five times larger than that for the +18V output. Based on the observed voltage changes the internal impedances of the outputs are approximately 8, 40 and 18 m $\Omega$  for the +18 V, -18 V and +5 V outputs respectively.

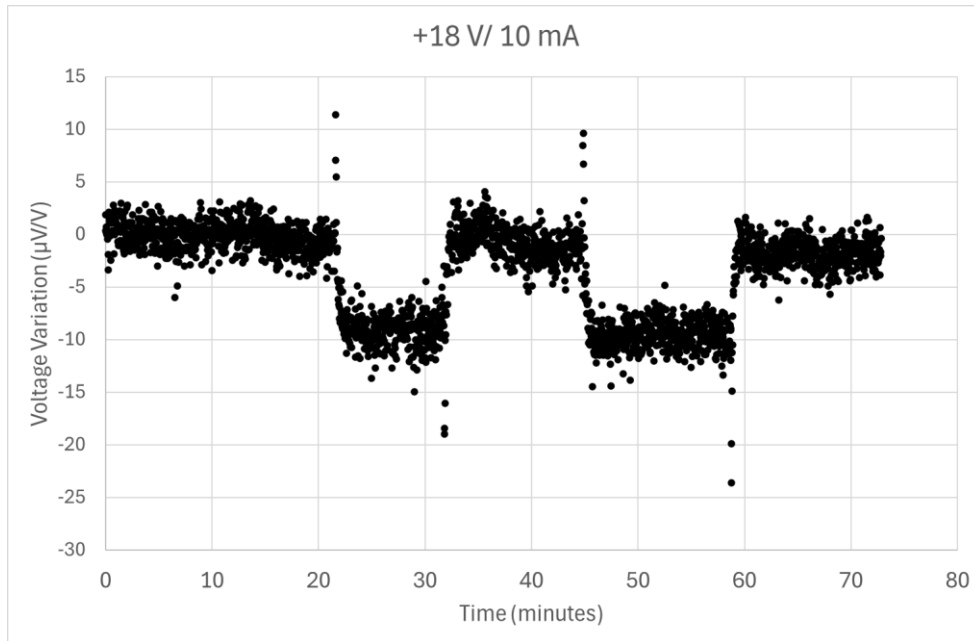


Figure 11(a) Response of +18 V output to a load of 10 mA

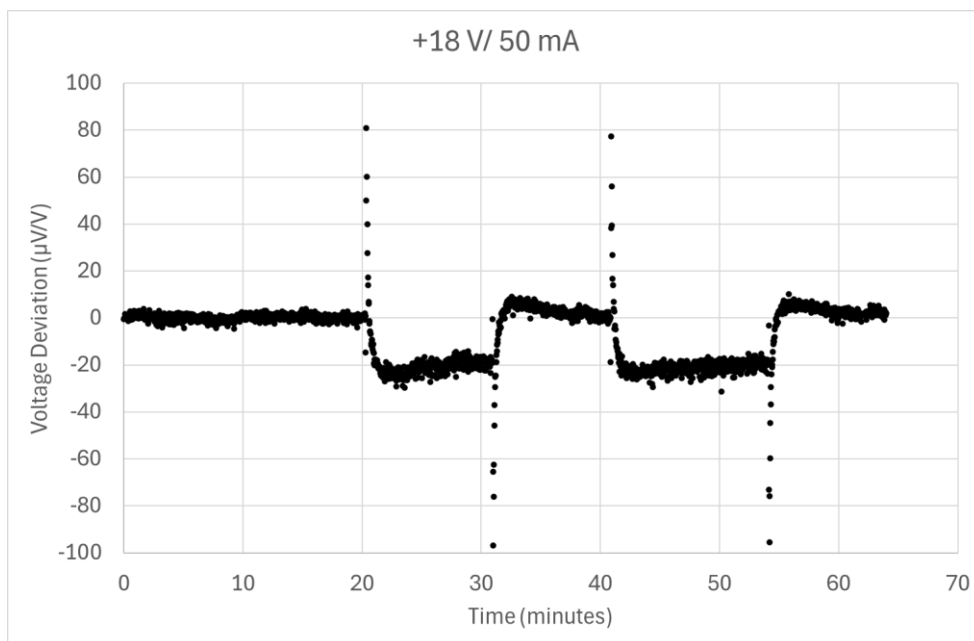


Figure 11(b) Response of +18 V output to a load of 50 mA

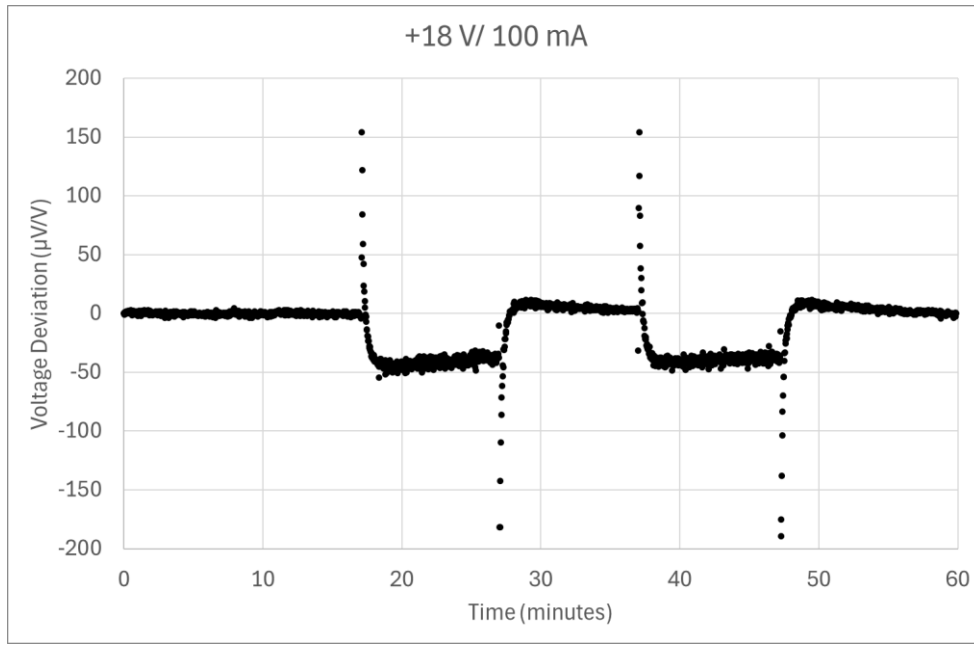


Figure 11(c) Response of +18 V output to a load of 100 mA

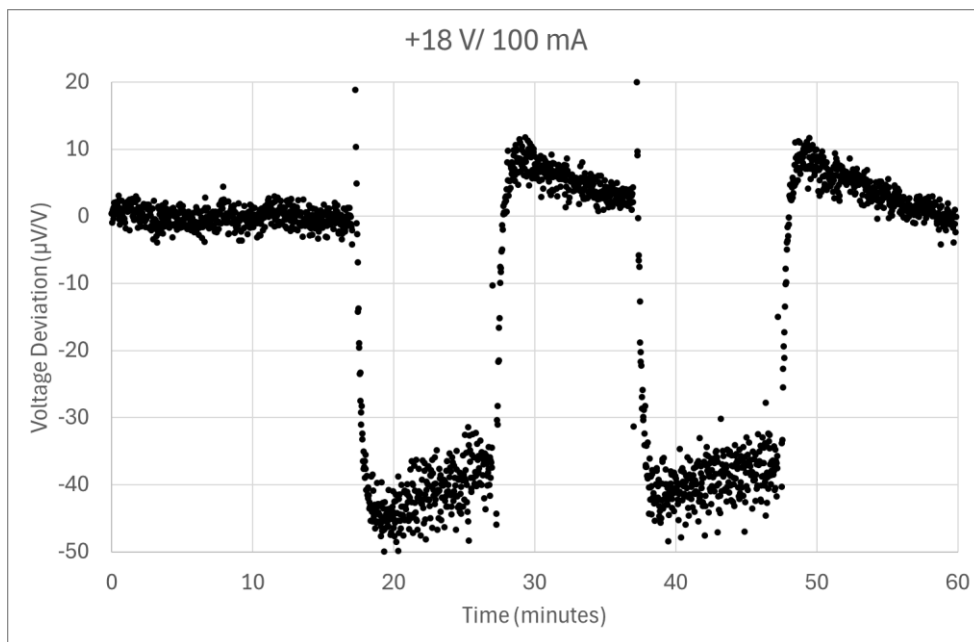


Figure 11(d) Response of +18 V output to a load of 100 mA (detail)

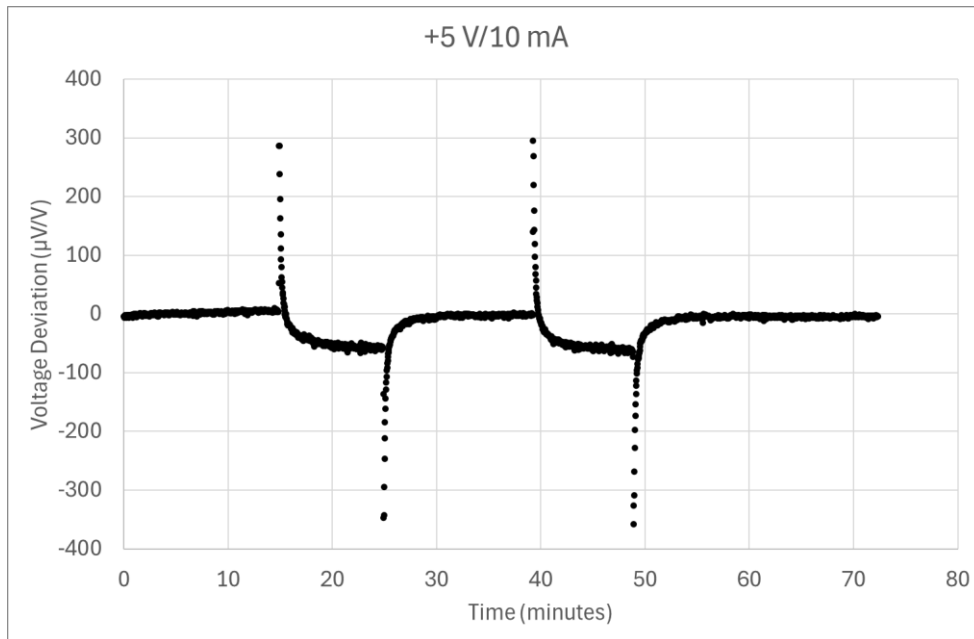


Figure 11(e) Response of +5 V output to a load of 10 mA

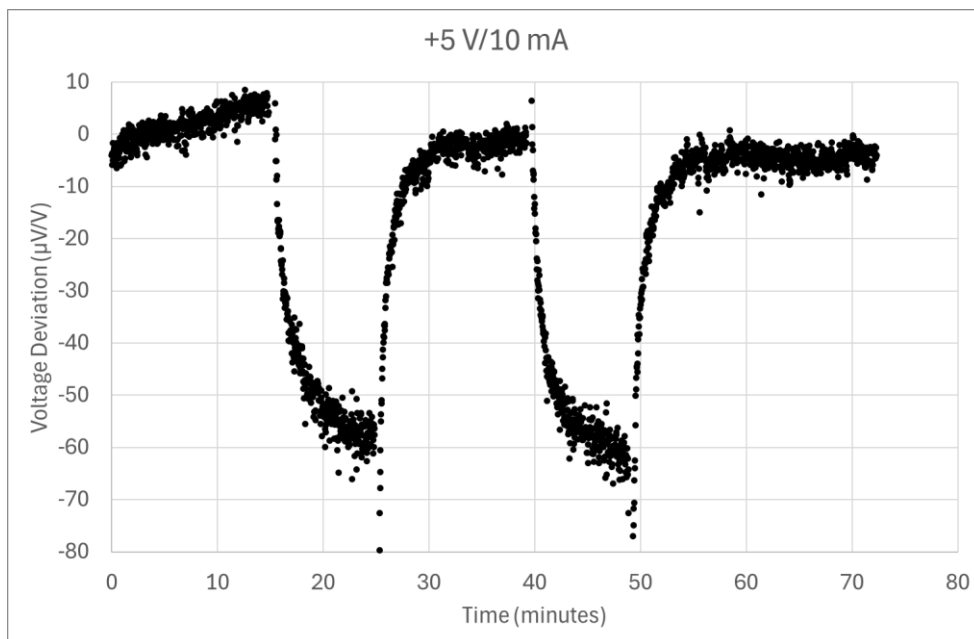


Figure 11(f) Response of +5 V output to a load of 10 mA (Detail)

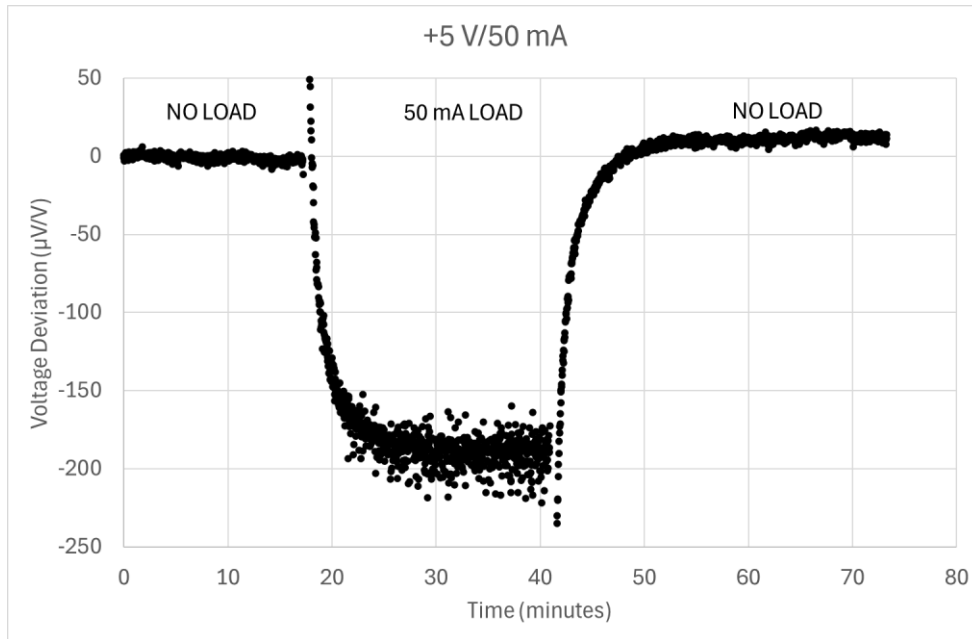


Figure 11(g) Response of +5 V output to a load of 50 mA (Detail)

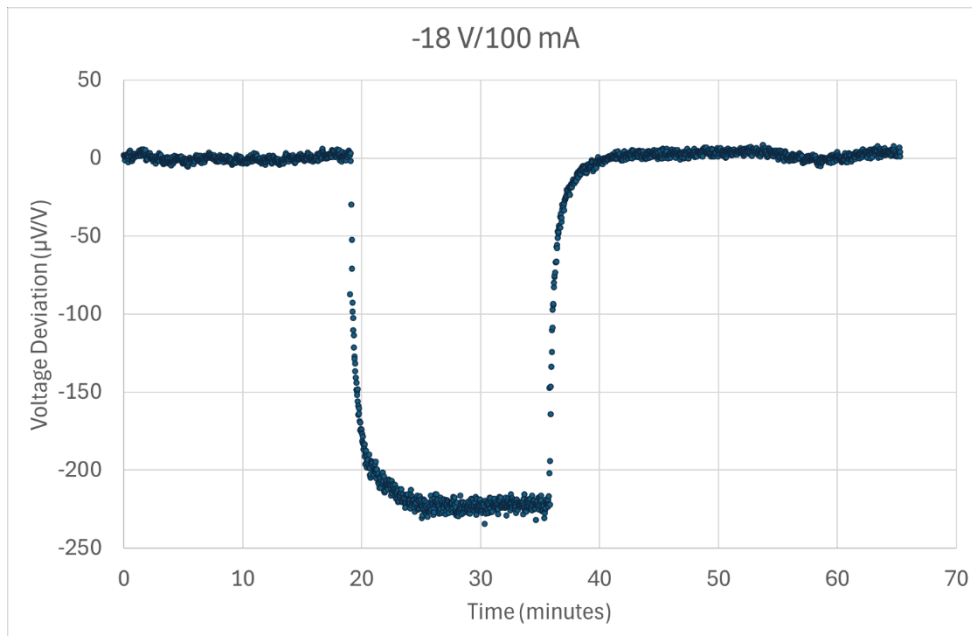


Figure 11(g) Response of -18 V output to a load of 100mA



### 4.3 Isolation Test

The isolation of the power supply, that is, how the AC signal propagates from the input to the output was tested. A transformer was placed in series with the 28 V power supply. The input of the transformer was connected to a function generator having frequency 53 Hz. As a result, approximately 220 mV AC signal was added to the 28 V DC at the input of the power supply. The resultant 53 Hz perturbation on the power supply outputs was observed again for different combinations of the batteries. As shown in Table 3 the digital outputs were found to contain a measurable level of the disturbing signal but the levels on the analogue outputs were below the detection level. It can be concluded that, for these outputs, the design provides a barrier to disturbances with an isolation level higher than 200 000, which is equivalent to isolation of about -106 dB. The measured isolation levels did not depend on the battery configurations.

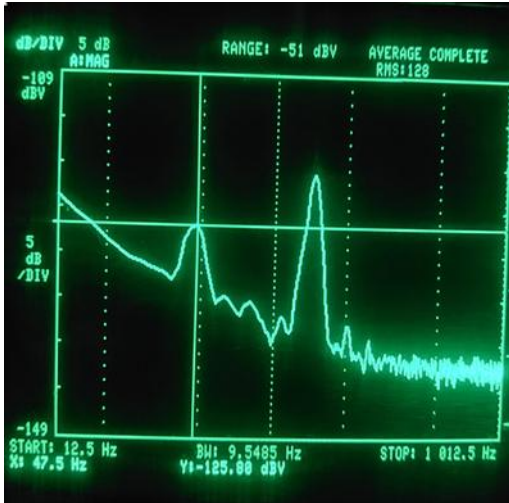
<i>Output</i>	<i>Input AC voltage</i>	<i>Output AC voltage</i>	<i>Isolation</i>
	[mV]	[mV]	
3.3 V Digital	213.248	6.465	33
5 V Digital #1	213.248	0.663	322
5 V Digital #2	213.248	0.631	338
-5 V Analogue	213.248	< 0.001	>200.000
+18 V Analogue	213.248	<0.001	>200.000
-18 V Analogue	213.248	<0.001	>200.000
+5 V Analogue	213.248	<0.001	>200.000

Table 3 Isolation Measurement Results for +18 V output

### 4.4 Noise Test

Due to time constraints, it was only possible to perform preliminary tests on the noise level of the output voltages of the power supply. A signal analyser (HP 3561A) was used to measure the spectrum of the noise level in the frequency range 12.5 Hz to 1012.5 Hz. The observed spectra are shown in Figure 12 (a)-(d). The noise spectra of the +18 V output was also measured when the linear power supply (U8002) used to charge the batteries was disconnected, when the output was under load (100 mA) and when the linear power supply was replaced by a conventional power block (MW HRP-300N3-36). The noise spectrum remained unchanged.

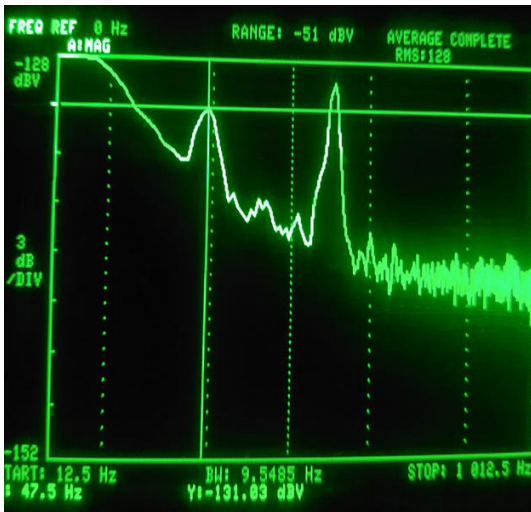
The measured noise levels are at the -120 dBV (RMS) (1  $\mu$ V RMS) level over this frequency range. There are peaks at the mains frequency and at its third harmonic. It is likely that these peaks are not inherent to the power supply but are due to external interference. Figure 12 shows the noise spectrum for a 6 V lead-acid rechargeable battery (Yucl Y12-6L) where peaks appear at these frequencies.



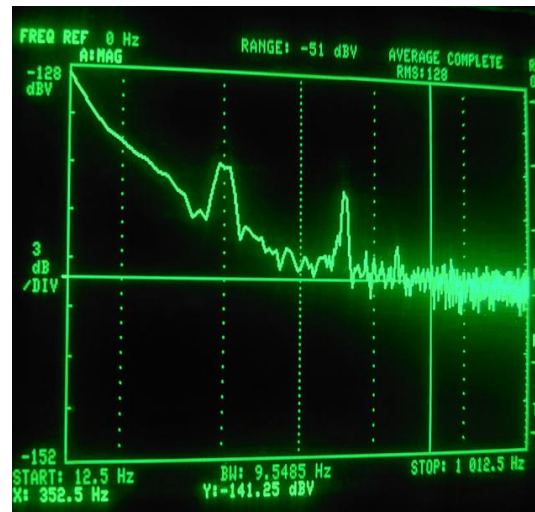
(a) +18 V Output



(b) -18 V Output



(c) 18 V Output



(d) -18 V Output

Figure 11 Noise Spectra of PSU outputs (12.5 – 1012.5 Hz)



Figure 12 Noise spectrum for a 6 V lead-acid battery

Although it is not possible, based on these preliminary measurements, to make any definitive statement about the noise level of the PSU output voltages it appears that the noise level is similar to that of a stand alone battery. The noise level at 1 kHz is at the same level as the analyser's noise floor (approx. -140 dBV RMS). The noise peaks are due probably due to coupling to external fields and need further investigation. It is possible that improved shielding will reduce these effects.

## 5 Conclusion

A power supply with full galvanic isolation, advanced battery management, and sophisticated voltage regulation has been developed. It delivers outstanding stability, immunity from temperature variations, isolation and noise performance. This 'silent' operation is particularly beneficial for low-level signal acquisition and high-resolution analog-to-digital conversion, where even minor power-supply artefacts can impair measurement accuracy. The redundant battery bank architecture supports seamless maintenance and prolonged operational lifetimes, enhancing reliability for continuous scientific work.

## REFERENCES

- [1] J. Pickering, R. Thompson, and J. M. Williams, "A new compact isolated power supply for electrical metrology at low signal levels," in BEMC 99 - 9th International Conference on Electromagnetic Measurement, 1999, p. 20.
- [2] Stanford Research Systems SIM928 Data Sheet, <https://www.thinksrs.com/products/sim928.html>
- [3] J. Kováč and J. Kučera, "A modular coaxial multiplexer with high isolation between channels," in XXI IMEKO, Prague, 2015.