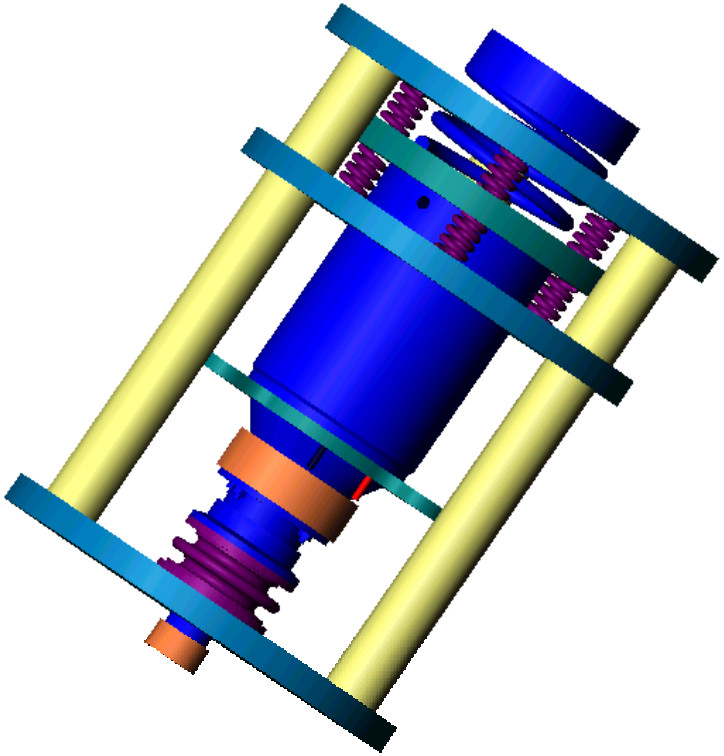
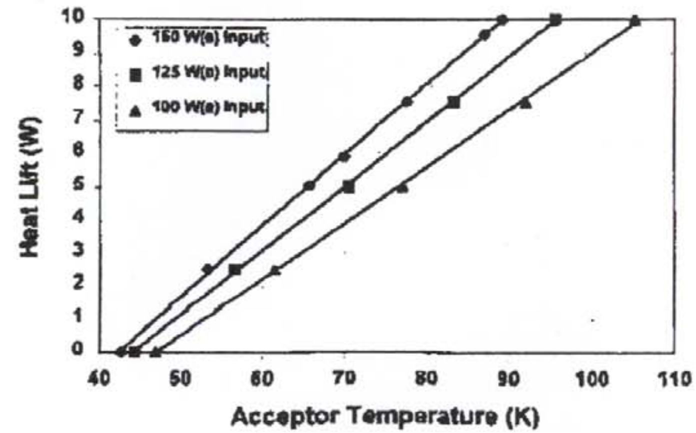
Status Report: Cryo-Cooler Electronics



ETH / GSFC / MIT / RWTH

Cryocooler Selection

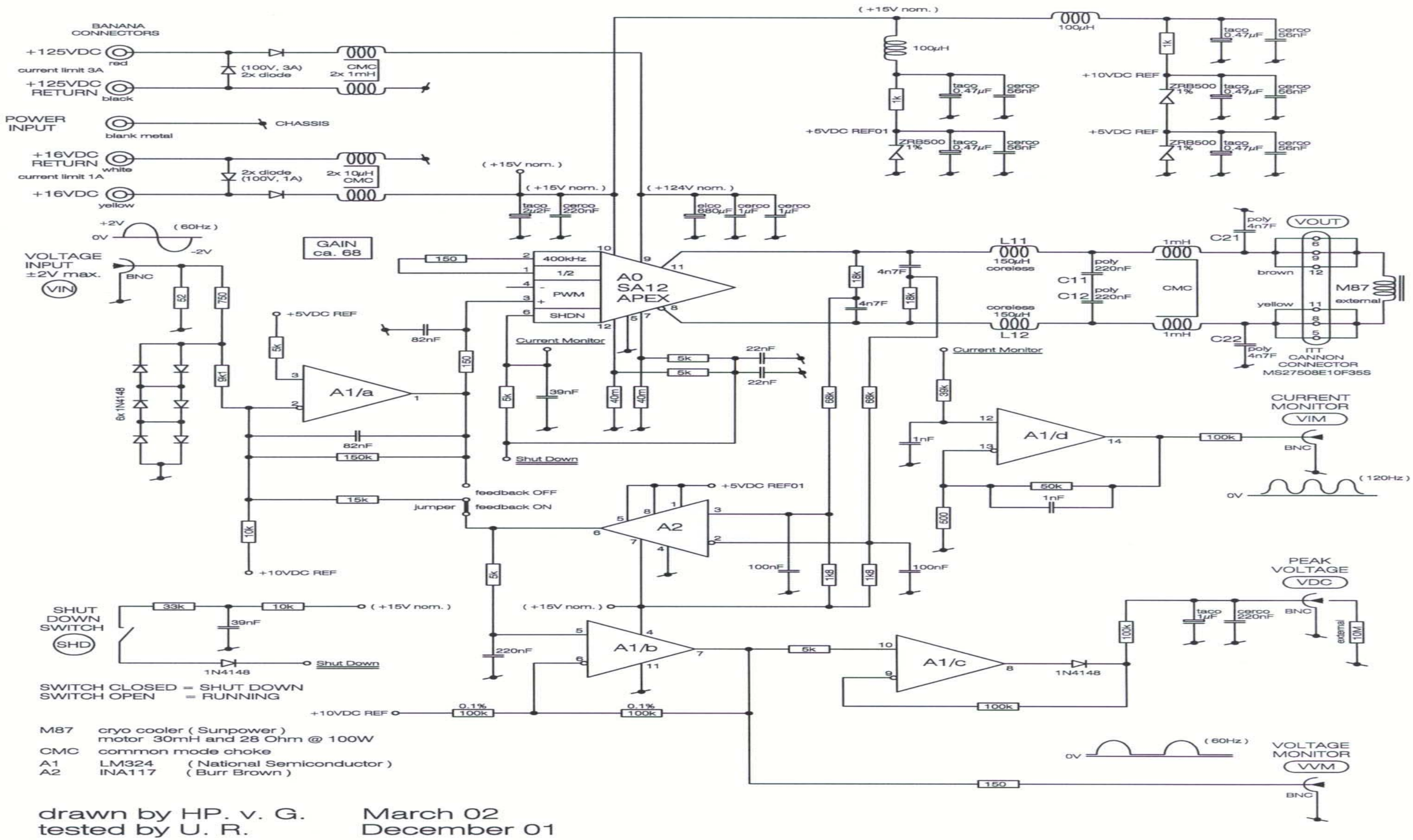
- **Sunpower M87**
  - *Newest Sunpower cryocooler design*
  - *Closely matches AMS thermal requirements as currently known*
    - 7.5watts lift @77K/35C w/150watts
  - *Compact Packaging (w/passive balancer)*
    - Mass: 2.6Kg (5.7 lbs)
    - Length: 271mm (10.7 in)
    - Diameter: 91mm (3.6 in)
  - *Not yet in full commercial production*
  - *Modifications may be needed for 0-g use*
    - Issue has to do with the location of piston at startup. Commercial version has an orientation constraint that sets the piston to a known location
    - Trade off between mechanical fix to cryocooler itself and electrical startup algorithm solution still to be determined



M87 Performance Curve w/ 35C Warm End

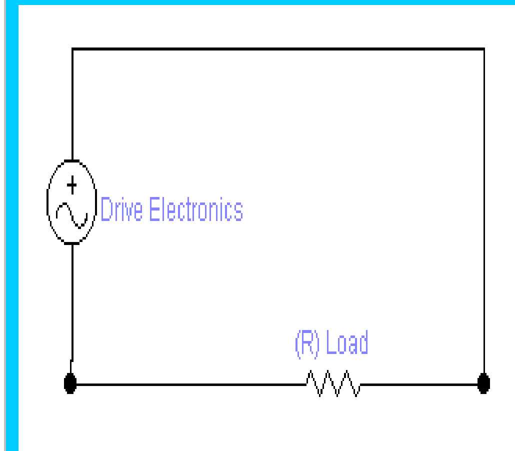
AMS02 Cryo Cooler Power Driver PD01

Prototype PWM Amplifier based on APEX SA12/EK17 Eval. Kit



Prototype Cryocooler Electronics (Ulf Roeser / December 2001)

Test Results on PD01 [GSFC, February 2002]

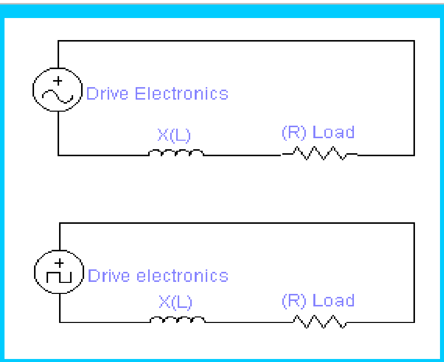


Terms:

Drive:	Amplifier used to drive load,
Load:	Resistor
Wave:	Drive waveform
Vp in:	Input signal to ETH amp
Cryocooler Power:	Power to cooler (read from Power meter)
Phase:	Voltage / current phase angle (read from O-scope)
ETH Sig out:	Signals from ETH amp
Load:	Characteristics of the load, calculated from power meter values
Power to ETH Drive:	Only considering the 120 VDC power supply (read from power meter)
Required Comp. uF:	Compensation capacitance required, calculated by Extech power meter
Load (W):	Heat load on cryocooler
CTT (K):	Cryocooler cold tip temperature
Reject (K):	Cryocooler heat reject temperature

				Cryocooler Power					ETH Sig. Out			Load				Power to ETH Drive (120 VDC)		
Drive	Load	Wave	Vp in (V)	Power (W)	PF	V	A	Phase (deg	Vdc	VIM(rms)	VVM(rms)	Zt	R	X(L)	L (mH)	P (W)	Pf	Volts (V)
ETH	Pure R	Sine	0.81	50.3	1	37.1	1.29	0	1.52	0.681	0.879	28.75969	28.75969	0	0	84.1	1	119.3
ETH	Pure R	Sine	0.995	75	1	45.5	1.584	0	1.86	1.02	1.08	28.72475	28.72475	0	0	110	1	119.3
ETH	Pure R	Sine	1.16	100.2	1	52.7	1.833	0	2.18	1.25	1.26	28.75068	28.75068	0	0	138.5	0.972	119.2
ETH	Pure R	Sine	1.285	120.5	1	57.9	2.01	0	2.41	1.49	1.4	28.80597	28.80597	0	0	161.2	0.95	119.2
ETH	Pure R	Sine	1.45	149.6	1	64.6	2.24	0	2.72	1.77	1.59	28.83929	28.83929	0	0	193.6	0.928	119.2

Test Results on PD01 [GSFC, February 2002]

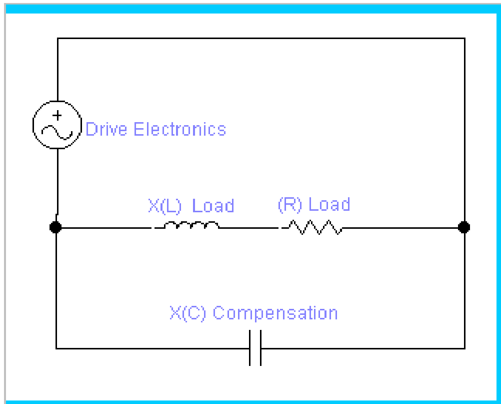


Terms:

Drive:	Amplifier used to drive load, Techron, high power linear rack mount (for comparison)
Load:	M87 Cryocooler
Wave:	Drive waveform
Vp in:	Input signal to ETH amp
Cryocooler Power:	Power to cooler (read from Power meter)
Phase:	Voltage / current phase angle (read from O-scope)
ETH Sig out:	Signals from ETH amp
Load:	Characteristics of the load, calculated from power meter values
Power to ETH Drive:	Only considering the 120 VDC power supply (read from power meter)
Required Comp. uF:	Compensation capacitance required, calculated by Extech power meter
Load (W):	Heat load on cryocooler
CTT (K):	Cryocooler cold tip temperature
Reject (K):	Cryocooler heat reject temperature

				Cryocooler Power					ETH Sig. Out			Load				Power to ETH Drive (120 VDC)		
Drive	Load	Wave	Vp in (V)	Power (W)	PF	V	A	Phase (deg)	Vdc	VIM(rms)	VVM(rms)	Zt	R	X(L)	L (mH)	P (W)	Pf	Volts (V)
Techron	M87	Sine		50	0.944	37.7	1.4	19.4				26.93	25.42	8.88	23.57			
Techron	M87	Sine		49.3	0.961	40.1	1.283	16.2				31.25	30.04	8.64	22.93			
Techron	M87	Sine		75	0.936	47	1.7	20				27.65	25.88	9.73	25.81			
Techron	M87	Sine		75.3	0.937	49.5	1.622	20				30.52	28.60	10.66	28.28			
Techron	M87	Sine		100.3	0.936	55	1.95	20.5				28.21	26.40	9.93	26.34			
Techron	M87	Sine		100.3	0.921	57.2	1.9	21.6				30.11	27.73	11.73	31.11			
Techron	M87	Sine		120.3	0.926	60.4	2.15	21.6				28.09	26.01	10.61	28.13			
Techron	M87	Sine		119.7	0.914	62.6	2.09	23.2				29.95	27.38	12.15	32.23			
ETH	M87	Sine	0.82	49.9	0.959	37.3	1.395	15.1	1.52	0.714	0.879	26.74	25.64	7.58	20.10	84.4	1	119.2
ETH	M87	Sine	0.87	49.8	0.973	38.9	1.281	15.1	1.61	0.71	0.937	30.37	29.55	7.01	18.59	83.1	1	119.2
ETH	M87	Sine	1.03	75.2	0.948	46.6	1.702	19.4	1.91	1.04	1.11	27.38	25.96	8.71	23.11	112.7	0.996	119.2
ETH	M87	Sine	1.075	74.7	0.95	48.9	1.608	20.5	2	1.13	1.16	30.41	28.89	9.50	25.19	111.2	1	119.2
ETH	M87	Sine	1.215	100.2	0.943	54.2	1.96	20.5	2.24	1.36	1.31	27.65	26.08	9.20	24.41	141.2	0.95	119.2
ETH	M87	Sine	1.26	100.2	0.931	56.5	1.904	21	2.34	1.35	1.37	29.67	27.63	10.83	28.73	140.9	0.948	119.2
ETH	M87	Sine	1.34	120.7	0.938	59.6	2.16	20.5	2.51	1.59	1.45	27.59	25.88	9.56	25.37	164.8	0.924	119.2
ETH	M87	Sine	1.39	120.2	0.92	61.6	2.12	21	2.57	1.58	1.5	29.06	26.73	11.39	30.21	163.7	0.918	119.2
Techron	M87	Square		50.1	0.847	41.7	1.418					29.41						
Techron	M87	Square		50	0.856	44.7	1.3					34.38						
Techron	M87	Square		100.1	0.835	60.8	1.97					30.86						
Techron	M87	Square		99.8	0.825	63.3	1.912					33.11						
Techron	M87	Square		150.5	0.825	75.1	2.43					30.91						
Techron	M87	Square		149.8	0.805	77.5	2.4					32.29						
ETH	M87	Square	0.645	50.5	0.896	40	1.406		1.52	0.566	0.865	28.45				85.7	1	119.2
ETH	M87	Square	0.688	49.8	0.908	42.4	1.29		1.61	0.531	0.917	32.87				83.7	1	119.3
ETH	M87	Square	0.94	100.4	0.879	58	1.97		2.2	1.1	1.28	29.44				141.8	1	119.3
ETH	M87	Square	0.975	100	0.869	60.2	1.912		2.28	1.18	1.33	31.49				140.9	1	119.3
ETH	M87	Square	1.155	149.8	0.865	69.6	2.49		2.7	1.78	1.58	27.95				196	0.939	119.2
ETH	M87	Square	1.19	150	0.841	71.6	2.49		2.8	1.36	1.63	28.76				196	0.927	119.2

Test Results on PD01 [GSFC, February 2002]



Terms:

- Drive: Amplifier used to drive load, Techron, high power linear rack mount (for comparison)
- Load: M87 Cryocooler; M87 Cryocooler || with Power Factor compensation
- Wave: Drive waveform
- Vp in: Input signal to ETH amp
- Cryocooler Power: Power to cooler (read from Power meter)
- Phase: Voltage / current phase angle (read from O-scope)
- ETH Sig out: Signals from ETH amp
- Load: Characteristics of the load, calculated from power meter values
- Power to ETH Drive: Only considering the 120 VDC power supply (read from power meter)
- Required Comp. uF: Compensation capacitance required, calculated by Extech power meter
- Load (W): Heat load on cryocooler
- CTT (K): Cryocooler cold tip temperature
- Reject (K): Cryocooler heat reject temperature

				Cryocooler Power					ETH Sig. Out			Load				Power to ETH Drive (120 VDC)		
Drive	Load	Wave	Vp in (V)	Power (W)	PF	V	A	Phase (deg)	Vdc	VIM(rms)	VVM(rms)	Zt	R	X(L)	L (mH)	P (W)	Pf	Volts (V)
Techron	M87	Sine		50.00	0.949	37.60	1.404	21.6				26.78	25.41	8.44	22.40			
Techron	M87	Sine		50.00	0.962	40.20	1.292	18.36				31.11	29.93	8.50	22.54			
Techron	M87 ||30uf	Sine		50.00	1.000	37.50	1.305	0				28.74	28.74	0.00	0.00			
Techron	M87 ||30uf	Sine		50.00	1.000	40.20	1.213	0				33.14	33.14	0.00	0.00			
ETH	M87	Sine	0.820	50.00	0.963	37.20	1.393	20.5	1.55	0.705	0.872	26.70	25.72	7.20	19.09	83.9	1	119.3
ETH	M87	Sine	0.875	50.20	0.974	40.10	1.285	17.3	1.62	0.741	0.937	31.21	30.39	7.07	18.75	82.9	1	119.3
ETH	M87 ||30uf	Sine	0.820	50.30	1.000	37.50	1.282	5.4	1.53	0.709	0.882	29.25	29.25	0.00	0.00	83.5	1	119.4
ETH	M87 ||30uf	Sine	0.870	50.10	1.000	40.10	1.195	0	1.62	0.701	0.937	33.56	33.56	0.00	0.00	82.6	1	119.4
Techron	M87	Sine		75.00	0.934	47.00	1.710	21.6				27.49	25.67	9.82	26.05			
Techron	M87	Sine		75.00	0.938	49.40	1.620	23.76				30.49	28.60	10.57	28.04			
Techron	M87 ||30uf	Sine		75.00	1.000	46.90	1.570	0				29.87	29.87	0.00	0.00			
Techron	M87 ||30uf	Sine		75.10	1.000	49.40	1.488	0				33.20	33.20	0.00	0.00			
ETH	M87	Sine	1.035	74.80	0.944	46.70	1.693	23.76	1.94	1.02	1.11	27.58	26.04	9.10	24.14	111.8	0.996	119.2
ETH	M87	Sine	1.090	75.30	0.947	49.30	1.613	22.68	2	0.997	1.17	30.56	28.94	9.82	26.04	111.6	0.995	119.2
ETH	M87 ||30uf	Sine	1.030	74.90	1.000	46.80	1.561	0	1.91	0.954	1.11	29.98	29.98	0.00	0.00	110.9	1	119.3
ETH	M87 ||30uf	Sine	1.080	74.90	1.000	49.30	1.483	0	2	1.08	1.16	33.24	33.24	0.00	0.00	110	1	119.3
Techron	M87	Sine		100.00	0.932	54.70	1.960	21.6				27.91	26.01	10.12	26.83			
Techron	M87	Sine		100.00	0.925	57.00	1.894	22.68				30.10	27.84	11.44	30.33			
Techron	M87 ||30uf	Sine		100.00	1.000	54.70	1.798	0				30.42	30.42	0.00	0.00			
Techron	M87 ||30uf	Sine		100.00	1.000	57.10	1.722	0				33.16	33.16	0.00	0.00			
ETH	M87	Sine	1.225	99.90	0.939	54.80	1.953	25.9	2.28	1.61	1.32	28.06	26.35	9.65	25.60	140.4	0.947	119.3
ETH	M87	Sine	1.280	100.10	0.920	57.20	1.901	27	2.36	1.68	1.38	30.09	27.68	11.79	31.28	140	0.941	119.3
ETH	M87 ||30uf	Sine	1.220	100.10	1.000	54.80	1.800	0	2.27	1.54	1.32	30.44	30.44	0.00	0.00	139	0.96	119.3
ETH	M87 ||30uf	Sine	1.275	100.10	1.000	57.30	1.731	0	2.36	1.18	1.39	33.10	33.10	0.00	0.00	138.2	0.966	119.3

Telecon March 6th 2002 on Cryo Cooler Electronics

Susan Breon, Stuart Banks and Kimberly Shirey (GSFC), Rick Foster (MIT), Gerald Kenney, Gert Viertel, Hanspeter von Gunten, Ulf Roeser (ETHZ)

The three tables of test measurements from GSFC were discussed (K.Shirey, e-mail, March 4th 2002)

Table 1 Power Driver from ETH (PD01), connected to a resistive load, input sine wave

Table 2 Comparison of Standard Techron Driver with PD01, connected to a M87 cryo cooler, both drivers with sine and square wave at the input

Table 3 Test of compensation by 30uF in parallel to the M87

1) The PD01 was tested by GSFC, could be connected to the M87 cryo cooler without problem.

2) Table 1 shows that PD01 works on the pure resistive load in the expected power range. The efficiency measured is about 10% below the design goal. Comment: Filter inductors of better quality in hand, will be tested in a next step. The clock frequency may be not at its optimum.

3) Table 2 shows that the test with both, sine and square wave input, could be done. Operation with sine wave seems better, because less spikes are visible. Argument for square wave: without transformer 150W power level is possible. The efficiency itself is no argument, because very similar. The comparison with the standard driver of GSFC („Techron") shows a very similar behaviour of the switched and the linear driver.

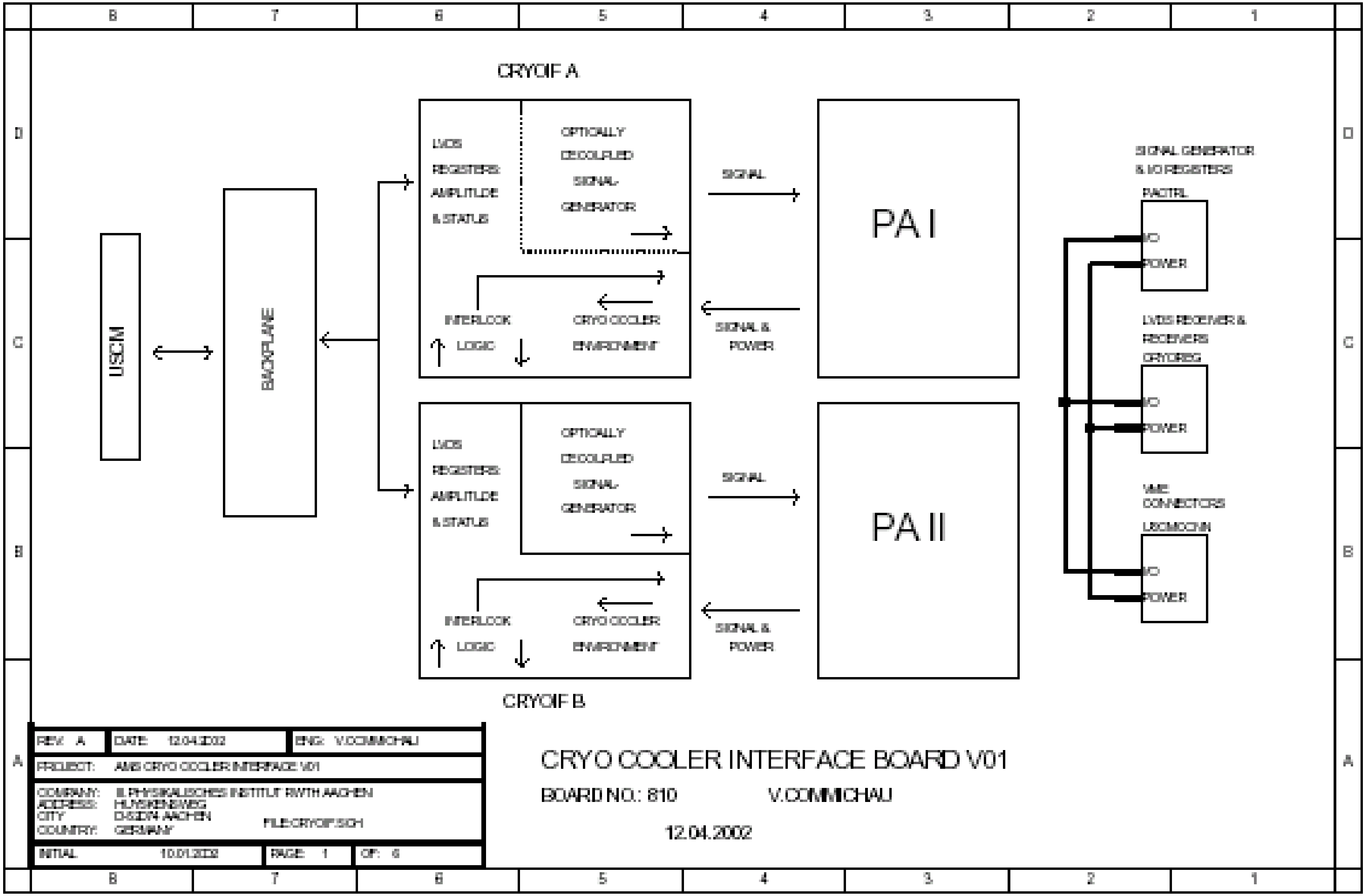
4) Table 3: The anticipated phase compensation of a 30 uF capacitor has been checked. The effect is negligible (1% or less). On the other hand, without capacitor the reliability would be improved. It was decided to work in future without compensation.

5) Activities on Interface USCM / PD01:

Meanwhile at RWTH Aachen and at ETH this interface is being developed. To complete it, the accelerometer type has to be specified. GSFC: One axis readout is sufficient per cryo cooler, the detector type is not yet evaluated, ADXL202/210 are candidates.

6) For the design of the next Power driver (again with APEX SA12). ETH may get support from Peter Berg (the designer of the HESSI M77Driver). Also the technical support group of APEX may help to improve the efficiency.

Cryo-Cooler Interface Board



Cryo-Cooler Interface Board

Circuit Description

The cryo cooler interface (CRYOIF) board serves as link between the universal slow control module (USCM) and the power amplifier (PA) stage of the cryo cooler system. Two CRYOIF boards, one hot and one cold are linked together via an interlock system. This way only one board has access to the one PA connected to the board. A system of two USCM modules (hot and cold) may access up to four pairs of CRYOIF boards, e.g. one functional block consists of 2 USCM's, 8 CRYOIF's and 8 power amplifiers. The board LVDS bus address may be set via a set of 6 SMD resistors, the board interlock function (hot/cold) is defined by a set of SMD resistors (0**Ω**).

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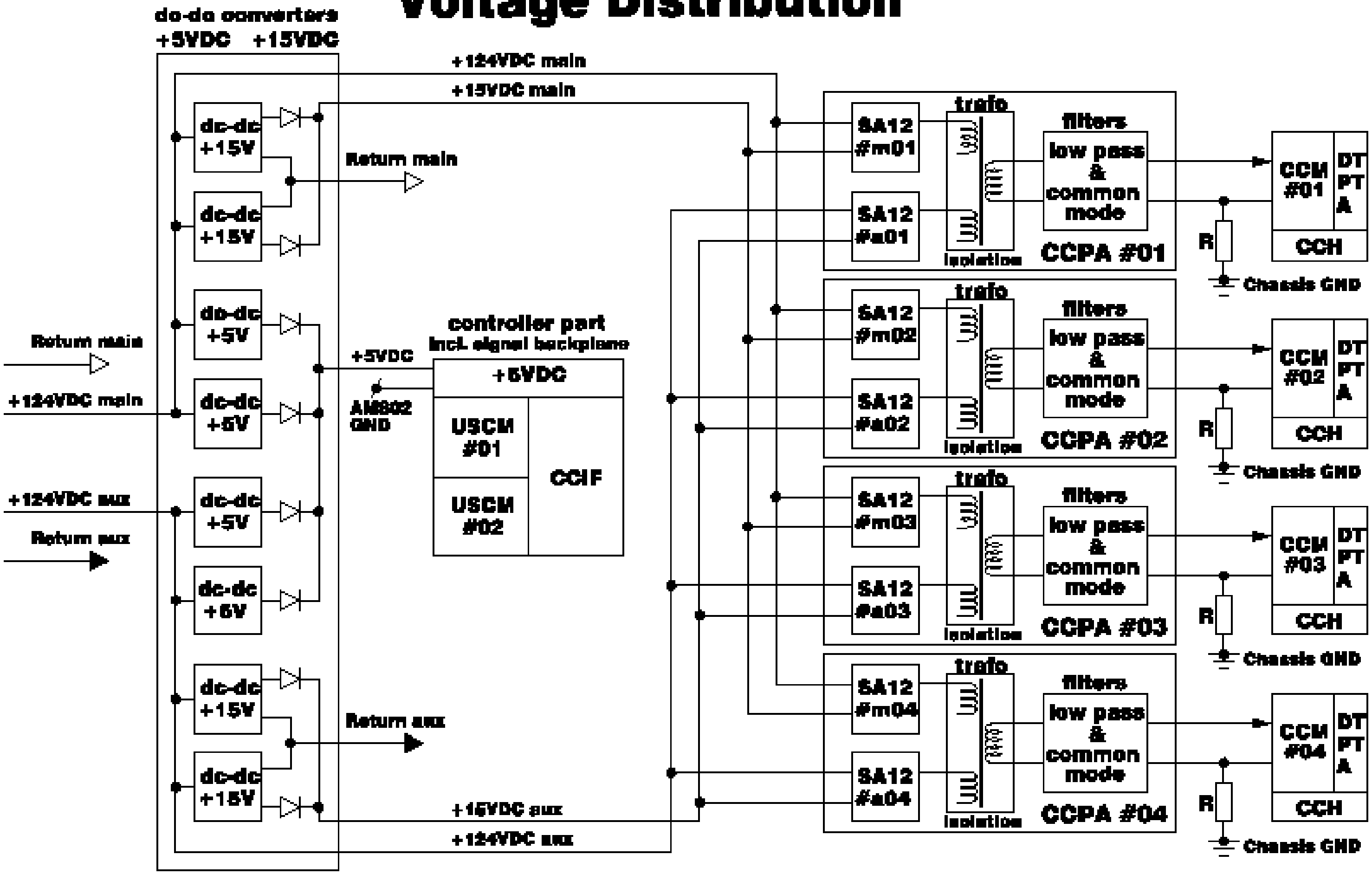
hangarter@physik.rwth-aachen.de

AMS02: CryoCooler System Cabling Scheme

Voltage Distribution

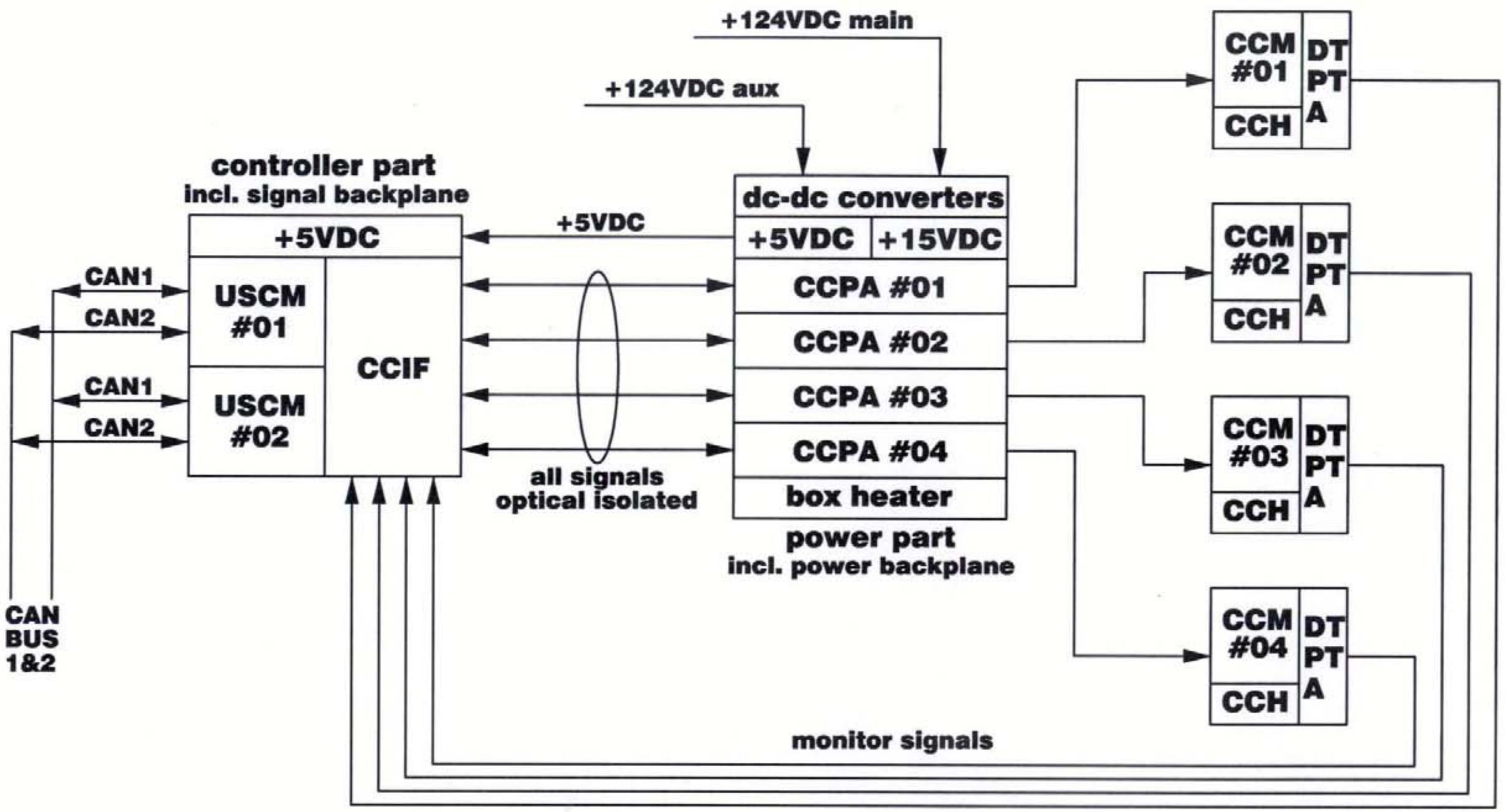


USCM	Universal Slow Control Module
CCIF	Cryo Cooler InterFace
CCPA	Cryo Cooler Power Amplifier
CCM	Cryo Cooler Motor & Phase Correction
CCH	Cryo Cooler Heater

SA12	Pulse Width Modulation (PWM) Amplifier
DT	Dallas Temperature sensors
PT	Platinum Temperature sensors
A	Accelero meter

January 21, 2002 Ulf Roeser & HP.v.G. [ETHZ] Page 1 of 1

AMS02: CryoCooler System Cabling Scheme

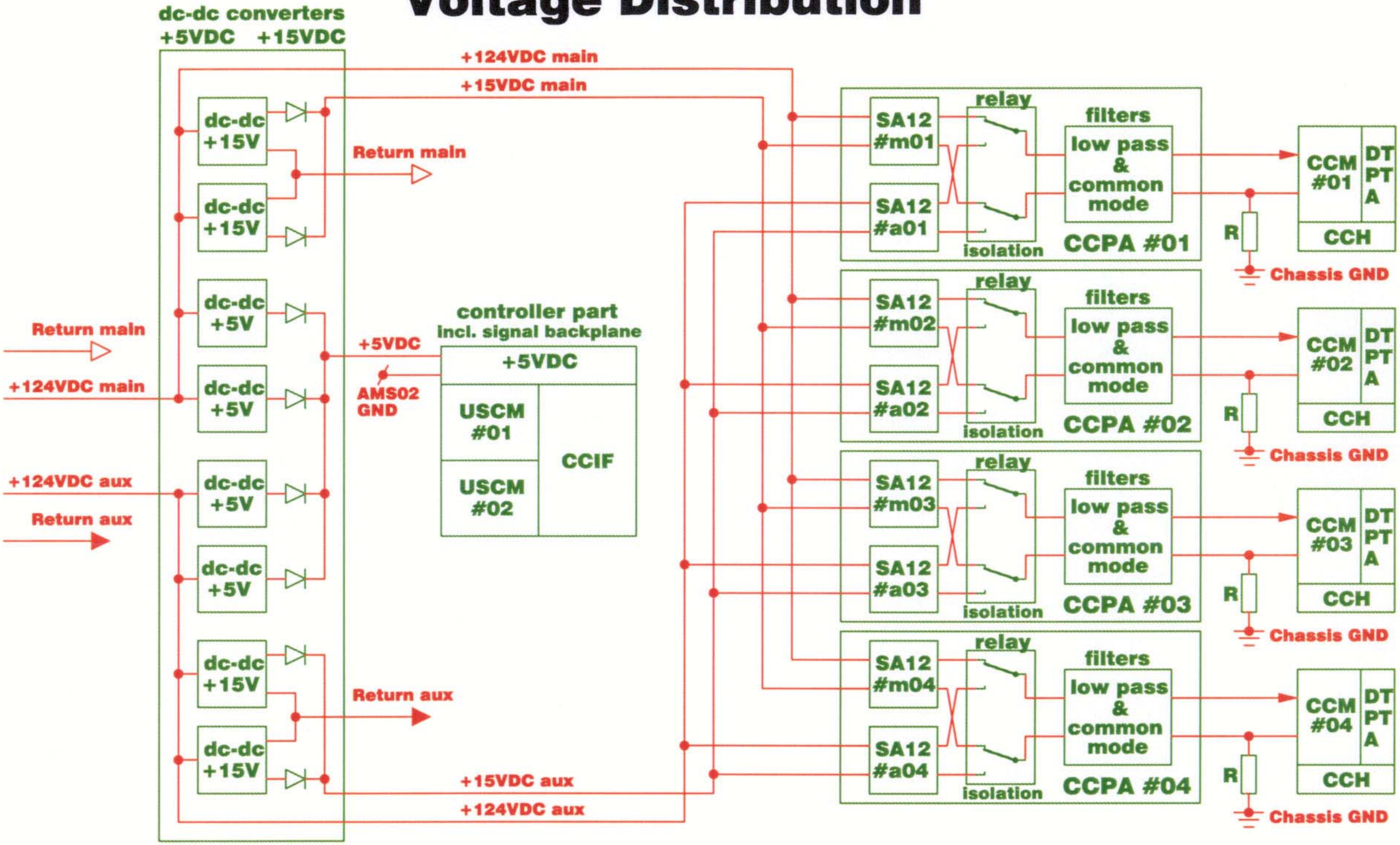


USCM	Universal Slow Control Module	DT	Dallas Temperature sensors
CCIF	Cryo Cooler InterFace	PT	Platinum Temperature sensors
CCPA	Cryo Cooler Power Amplifier	A	Accelero meter
CCM	Cryo Cooler Motor		
CCH	Cryo Cooler Heater		

January 21, 2002 Ulf Roeser & HP.v.G. [ETHZ] Page 1 of 1

AMS02: CryoCooler System Cabling Scheme

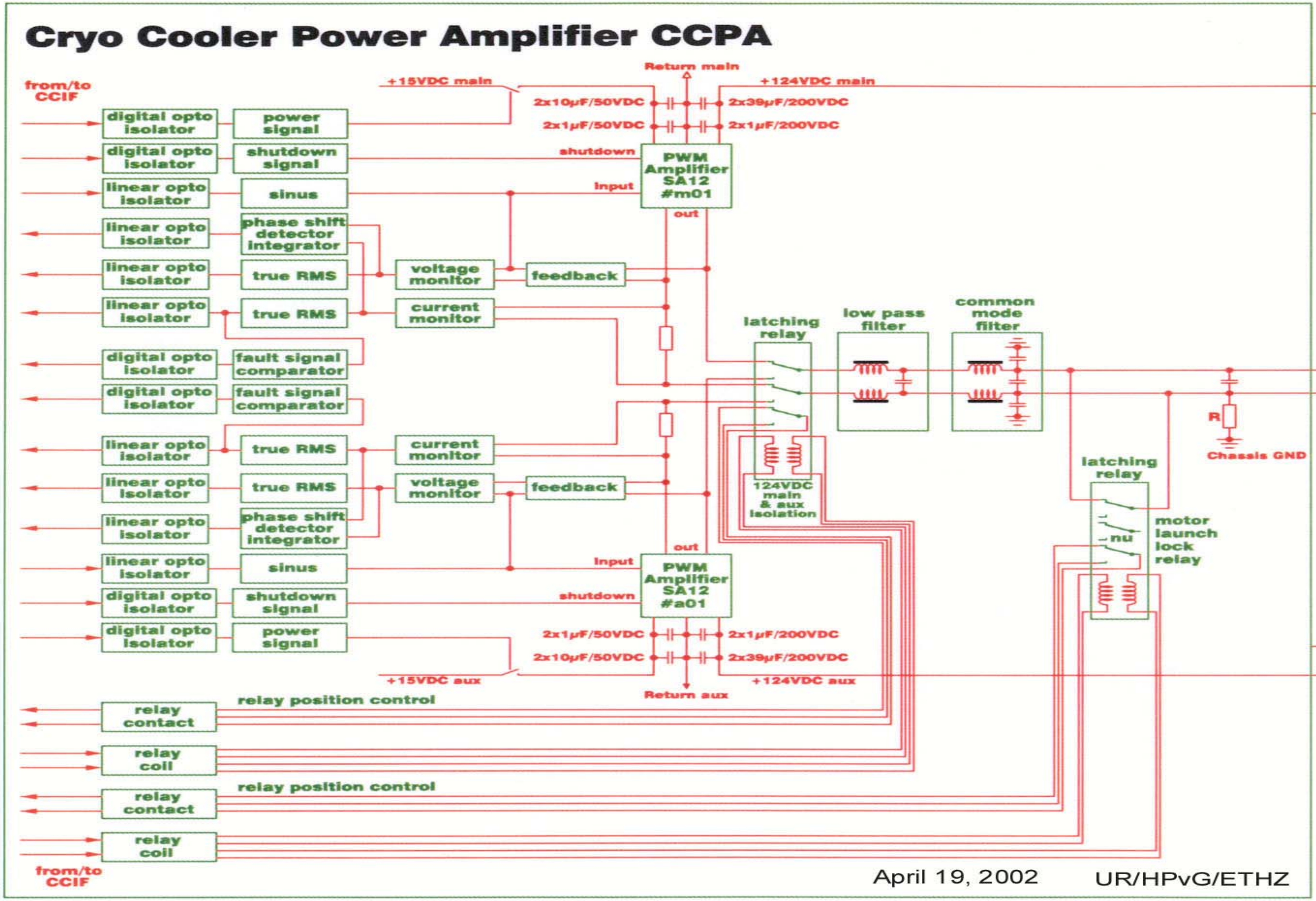
Voltage Distribution



USCM	Universal Slow Control Module
CCIF	Cryo Cooler InterFace
CCPA	Cryo Cooler Power Amplifier
CCM	Cryo Cooler Motor & Phase Correction
CCH	Cryo Cooler Heater

SA12	Pulse Width Modulation (PWM) Amplifier
DT	Dallas Temperature sensors
PT	Platinum Temperature sensors
A	Accelero meter

March 21, 2002 Ulf Roeser & HP.v.G. [ETHZ] Page 1 of 1



CCIF	Cryo Cooler InterFace
CCPA	Cryo Cooler Power Amplifier
CCM	Cryo Cooler Motor & Phase Correction
CCH	Cryo Cooler Heater

SA12	Pulse Width Modulation (PWM) Amplifier
DT	Dallas Temperature sensors
PT	Platinum Temperature sensors
A	Accelero meter
nu	not used

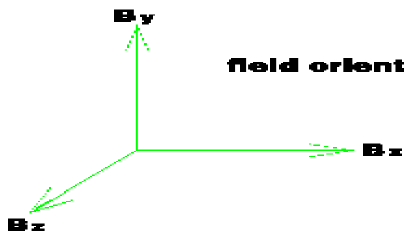
Relay Test in Magneteic Field @ Room Temperature

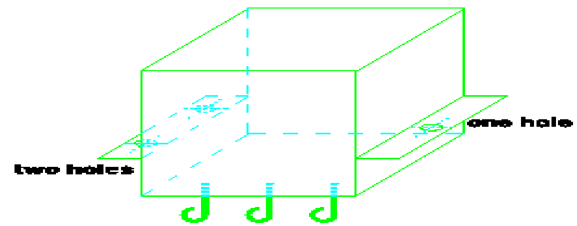
AMS02_Cryo_Cooler: Relay Test

hermetically sealed latching relays in the magnetic field
relay type: leach YCL-D2A, 10A, 3PDT
size: 0.81" x 0.81" x 0.64"

[B]=Gauss

field orientation:





1. measurement:

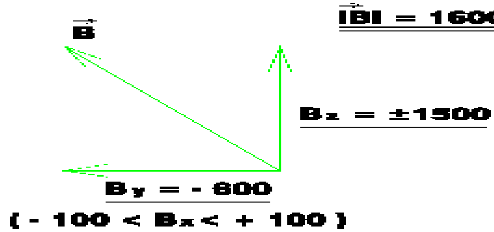
density of the magnetic flux parallel to the axes
* tolerances ±10%
* effects of remanences could be superposed

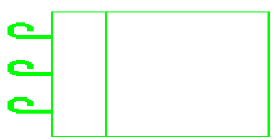
$\vec{B}$=	$\lvert B \rvert$
Bx+	200
Bx -	200
By+	100
By -	180
Bz+	840
Bz -	750

2. measurement:

maximum density of the magnetic flux

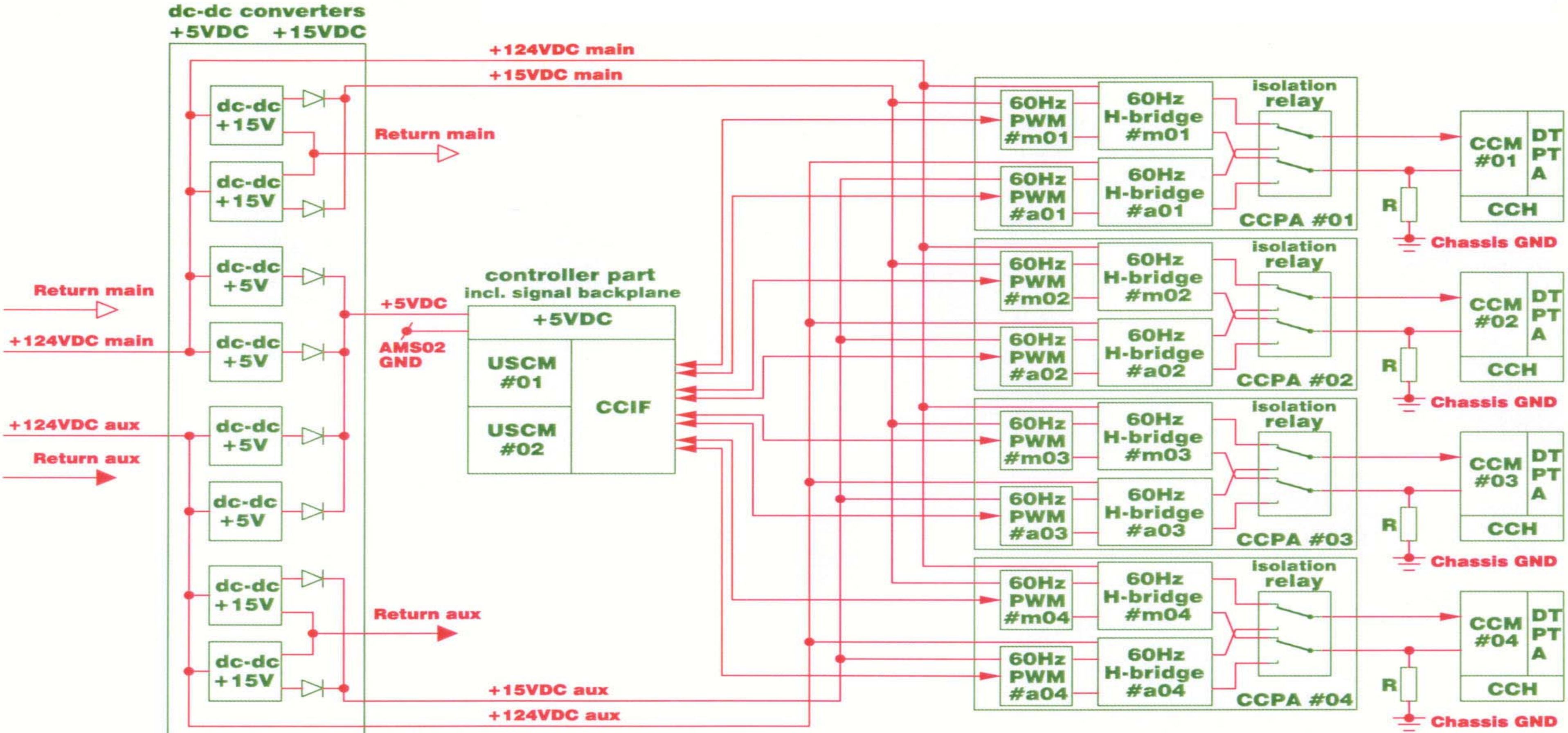
$\lvert \vec{B} \rvert = 1600$ Gs





07. September 2001   Ulf Roeser

Cryo-Cooler Driver [60 Hz PWM & 60 Hz H-Bridge]



USCM	Universal Slow Control Module
CCIF	Cryo Cooler InterFace
CCPA	Cryo Cooler Power Amplifier
CCM	Cryo Cooler Motor
CCH	Cryo Cooler Heater

isolation relay	LEACH Series KCL-D4C 3PDT, 25A, latching relay
60Hz H-bridge	DDC PWR-82332 3-phase motor drive
60Hz PWM	Pulse Width Modulation circuitry
DT	Dallas Temperature sensors
PT	Platinum Temperature sensors
A	Accelero meter

April19, 2002 UR/HPvG/ETHZ

Comparison of Power Driver Configurations

Type	Sine Wave	Square Wave	Pulse Width Modulation
Control	DAC (Amplitude)	DAC (Amplitude)	DAC (Pulse Width)
Efficiency [%] expected tested	 80 - 90 70 - 80	 80 - 90 70 - 80	 90 – 95 not tested
Max. Output Power [Watt]	120	170	> 200
Switching Frequency [kHz]	100 - 200	100 - 200	0.06
EMI	high	high	low
Comments	HESSI M77 (28 Volt)	Option 1: Sine wave generator replaced by square wave generator Option 2: DC-DC converter (200W), controlled output voltage, followed by a 60 Hz H-bridge	Will be tested By GSFC. If OK: Preferred configuration. Advantages: less EMI, higher efficiency. Disadvantage: higher current

USCM of the Cryo Cooler Electronics: Control and Monitoring of Relay Functions

Item	Realization	Function	Status
Output relay control	One latching relay per cryo cooler (2 coils digitally controled), two contacts	Toggles output of drivers to the selected one, drivers in shut down mode	TBD
Output relay monitor	Additional contact to identify status	Status of relay	TBD
Launch lock relay control	One latching relay per cryo cooler (2 coils digitally controled), one contact [*]	Short circuit on the cryo cooler coil	TBD
Launch lock relay monitor	Additional contact to identify status	Status of relay	TBD

[*] Alternative: Normaly closed MOSFET, opens when power is applied to driver. To be studied: Current generated by the cryo cooler during launch.

USCM of the Cryo Cooler Electronics: Monitoring of Slow Control Data

Item	Realization	Function	Status
Temperature on cryo cooler box	2 chains (2 Dallas sensors each) per cryo cooler	Digital measurement	Implemented, Direct coupled into USCM
Temperature on cryo cooler cold tip	2 x PT 1000 per cryo cooler, two ADC channels	Analog measurement	TBD Signal processing on CCIF
Accelerometer	Open issue	Measurement of acceleration in one coordinate Test on ground? During launch? (no power!) During mission? (amount of data)	Not implemented

Accelerometer from AD

FEATURES

2-Axis Acceleration Sensor on a Single IC Chip
Measures Static Acceleration as Well as Dynamic Acceleration
Duty Cycle Output with User Adjustable Period
Low Power <0.6 mA
Faster Response than Electrolytic, Mercury or Thermal Tilt Sensors
Bandwidth Adjustment with a Single Capacitor Per Axis
5 m*g* Resolution at 60 Hz Bandwidth
+3 V to +5.25 V Single Supply Operation
1000 *g* Shock Survival

APPLICATIONS

2-Axis Tilt Sensing
Computer Peripherals
Inertial Navigation
Seismic Monitoring
Vehicle Security Systems
Battery Powered Motion Sensing

GENERAL DESCRIPTION

The ADXL202/ADXL210 are low cost, low power, complete 2-axis accelerometers with a measurement range of either ±2 *g*/±10 *g*. The ADXL202/ADXL210 can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity).

The outputs are digital signals whose duty cycles (ratio of pulse-width to period) are proportional to the acceleration in each of the 2 sensitive axes. These outputs may be measured directly with a microprocessor counter, requiring no A/D converter or glue logic. The output period is adjustable from 0.5 ms to 10 ms via a single resistor (R_{SET}). If a voltage output is desired, a voltage output proportional to acceleration is available from the X_{FILT} and Y_{FILT} pins, or may be reconstructed by filtering the duty cycle outputs.

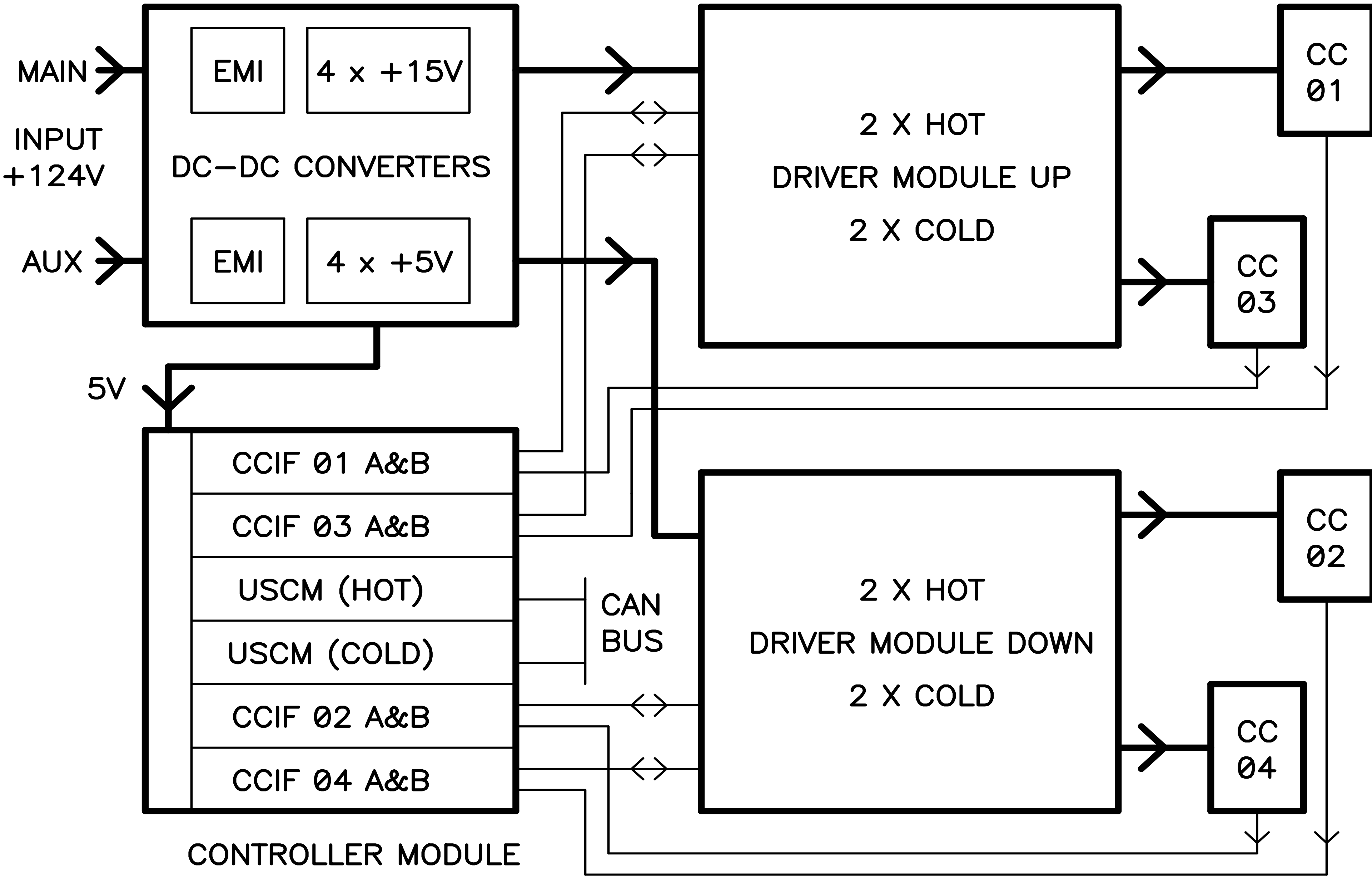
The bandwidth of the ADXL202/ADXL210 may be set from 0.01 Hz to 5 kHz via capacitors C_X and C_Y. The typical noise floor is 500 $\mu g/\sqrt{Hz}$ allowing signals below 5 m*g* to be resolved for bandwidths below 60 Hz.

The ADXL202/ADXL210 is available in a hermetic 14-lead Surface Mount CERPAK, specified over the 0°C to +70°C commercial or –40°C to +85°C industrial temperature range.

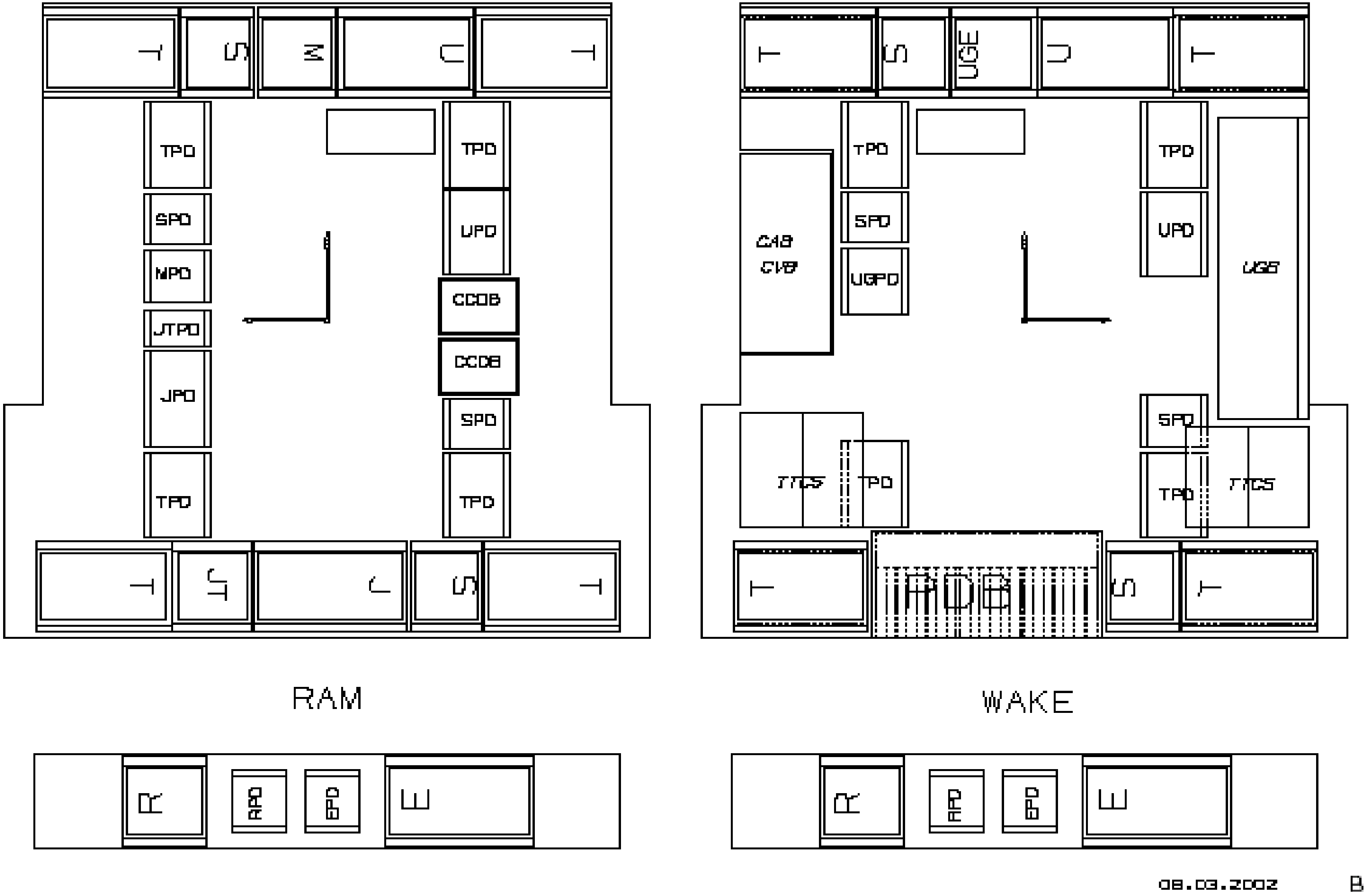
USCM of the Cryo Cooler Electronics: Control of Power and Power-up ramping

Item	Realization	Function	Status
Set: power driver supply ON	1 opto switch per driver	Put driver into operation	Implemented
Feedback: driver status OK	1 optoswitch per driver	Sets bit to start or continue	Implemented
Set: external shut down	1 opto switch per driver	In parallel to internal shut down of driver	Implemented
Control: output power	8 bit opto coupled DAC per driver	DAC sets amplitude of sinus wave amplitude of square wave pulse width	 Implemented Modification possible Not implemented
Monitor of driver output voltage	Linear optocoupler transfers RMS voltage to ADC	ADC delivers data of available output power	Implemented
Monitor of load current	Linear optocoupler transfers RMS current to ADC	ADC delivers data of realized output power (current through coil)	Implemented
Monitor of phase shift	Open issue	Needed?	Not implemented

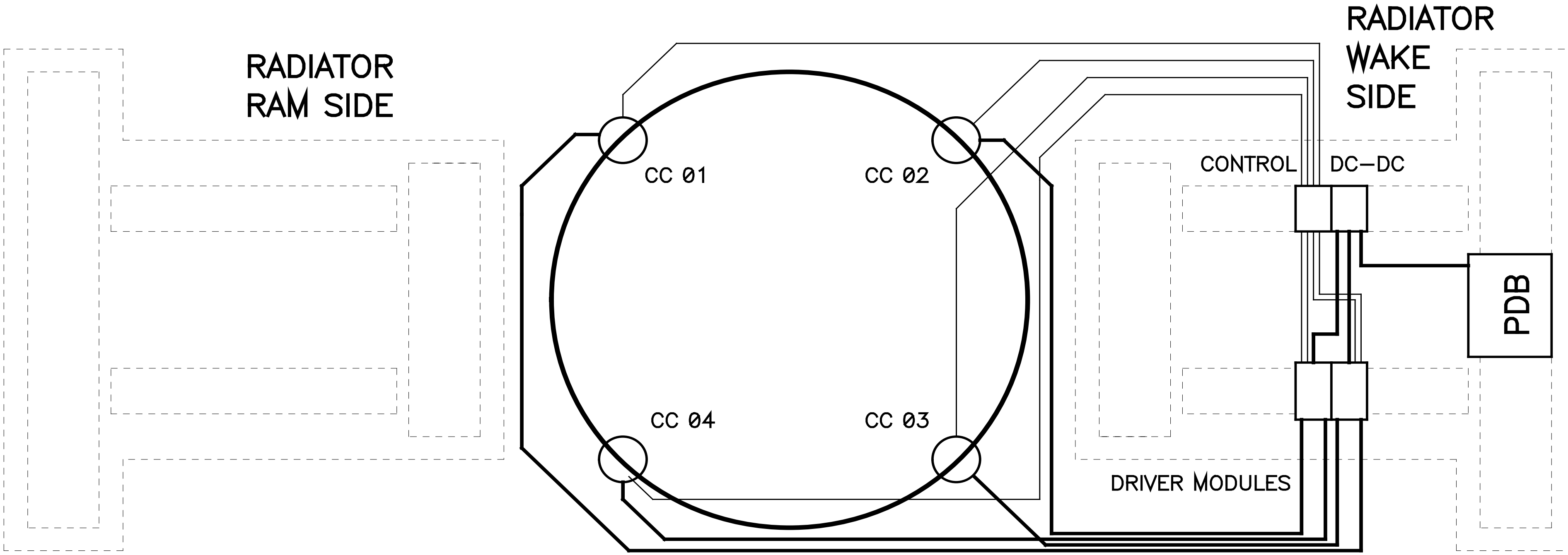
Cryo-Cooler Electronic Schematic



Boxes on Radiator [M. Capell]



Cryo-Cooler Electronics on AMS Radiator [Proposal A]



Cryo-Cooler Electronics on AMS Radiator [Proposal B]