Progress of reliability study and the plan of aging

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Outline

- **1. Progress of reliability study;**
- **2. Reliability qualification;**
- **3. The plan of aging;**

- 1. Progress of reliability study;
- 2. Reliability qualification;
- 3. The plan of aging;

FIT Value at 40 ℃ junction temperature for baseline

	IHEP FIT (217)	Expected by Future Test	Prediction by Test	Germany (Manufacturer)	Germany (217)	Germany (FIEDS)	Russian (FIEDS)	Value （FIT）
HV			5765@70℃		27	450	900	>27
Protection	?	?	?	?	?	?	?	4.5
IHEP FEC		<=4.5						
Tsinghua ADC		<=4.5*2						
Vulcan	?	?	?	?	?	?	?	<=4.5
GCU	>=44							>=44
Power Board				39.8				39.8
Cable & Connector	?	?	?	?	?	?	?	~30
Total								>150

Note: 1. 217 is MIL-HDBK-217, Rev. F - Notice 2 (美军可靠性预计手册);
2. FIEDS is French aircraft standard;
3. Only ICs is used for GCU without capacitors and resistors;

Need <=95fit

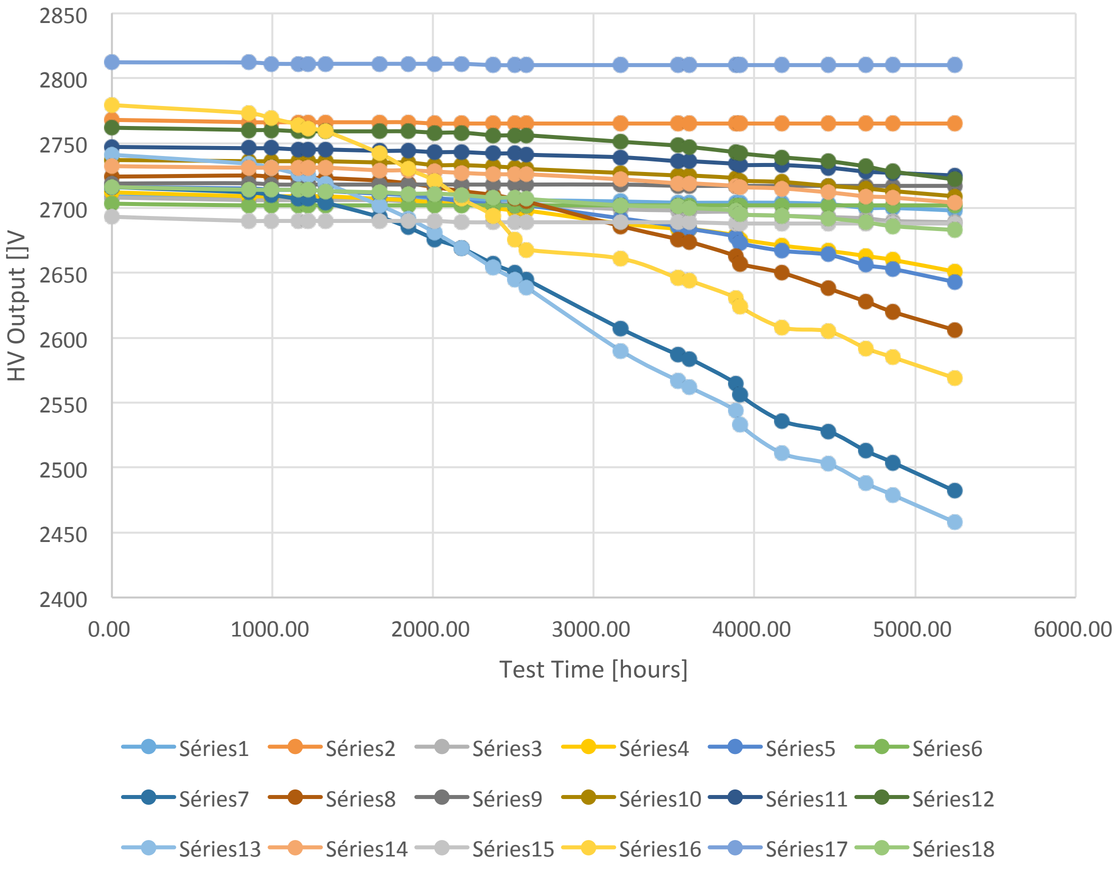
The reliability VS temperature

	30 ℃ junction temp. (FIT)	**40 ℃ junction temp. (FIT)**	**55 ℃ junction temp. (FIT)**
HV	?	?	?
Protection Circuit	?	?	?
IHEP FEC	<=2 (expected)	<=4.5 (expected)	<=14.8 (expected)
Tsinghua ADC	<=2*2 (expected)	<=4.5*2 (expected)	<=14.8*2 (expected)
Vulcan	<=2 (expected)	<=4.5 (expected)	<=14.8 (expected)
GCU	>=19 (calculation)	>=44 (calculation)	>=114 (calculation)
Power Board	<=32 (calculation)	<=40 (calculation)	<=60 (calculation)
Cable & Connector	?	?	?

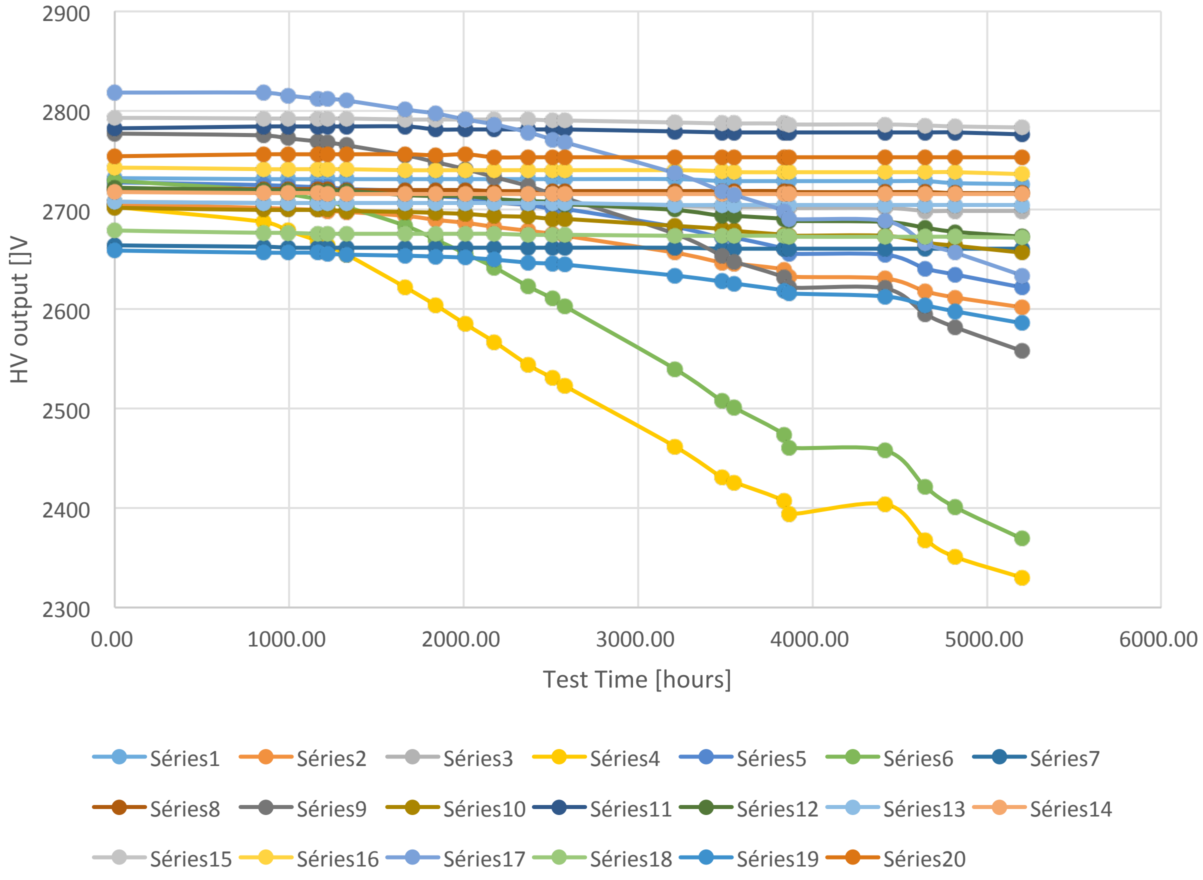
Note:

1. FIT Value of FEC and ADC is from the our expected value;
2. FIT Value of GCU and Power Board is from calculation;
3. Resistors, capacitors and some ICs is not included during GCU calculation due to lack of data;

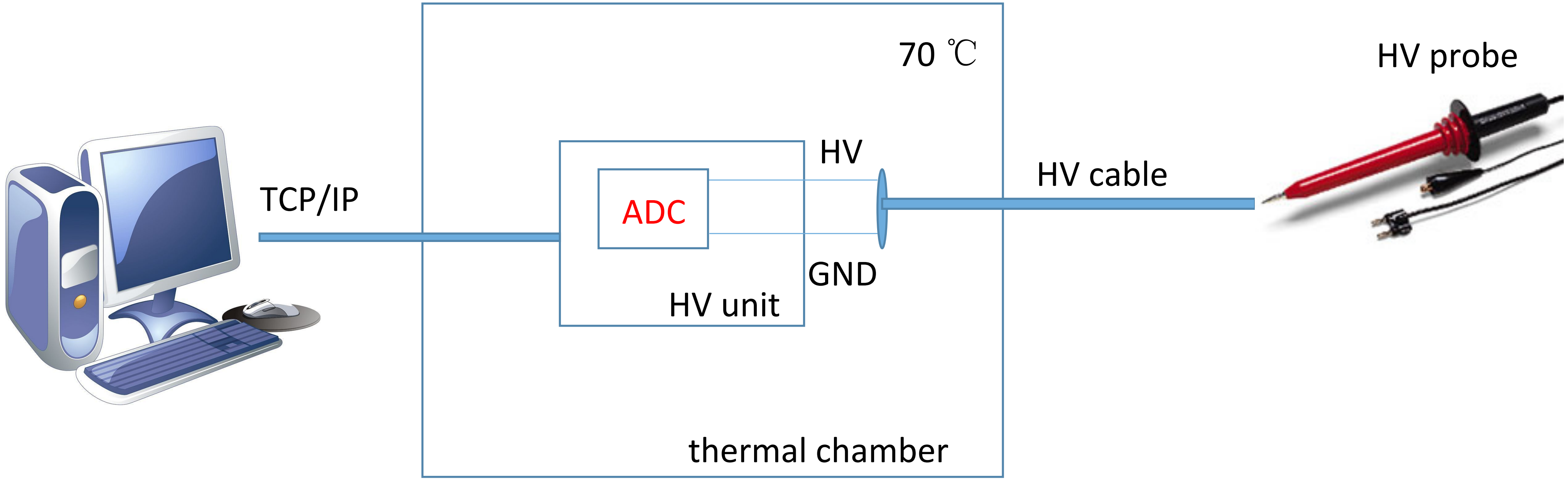
38 HVSYS units output trend



18 of 38 units



20 of 38 units



	Setting Value	Internal ADC of HV unit	HV Probe
24 ℃	2778 V	2768 V	2756 V
70 ℃	2778 V	2674 V	2663 V

Conclusion:

The degradation is from the HV output, not from the degradation of internal ADC;

Something strange about HVSYS units

1. The degradation phenomenon disappears after temperature become ambient temperature. But the degradation phenomenon appears again after temperature become 70 ℃ test temperature. The reason is unknown;
2. I tried to increase the output by controlling HV units with or without load; for example:

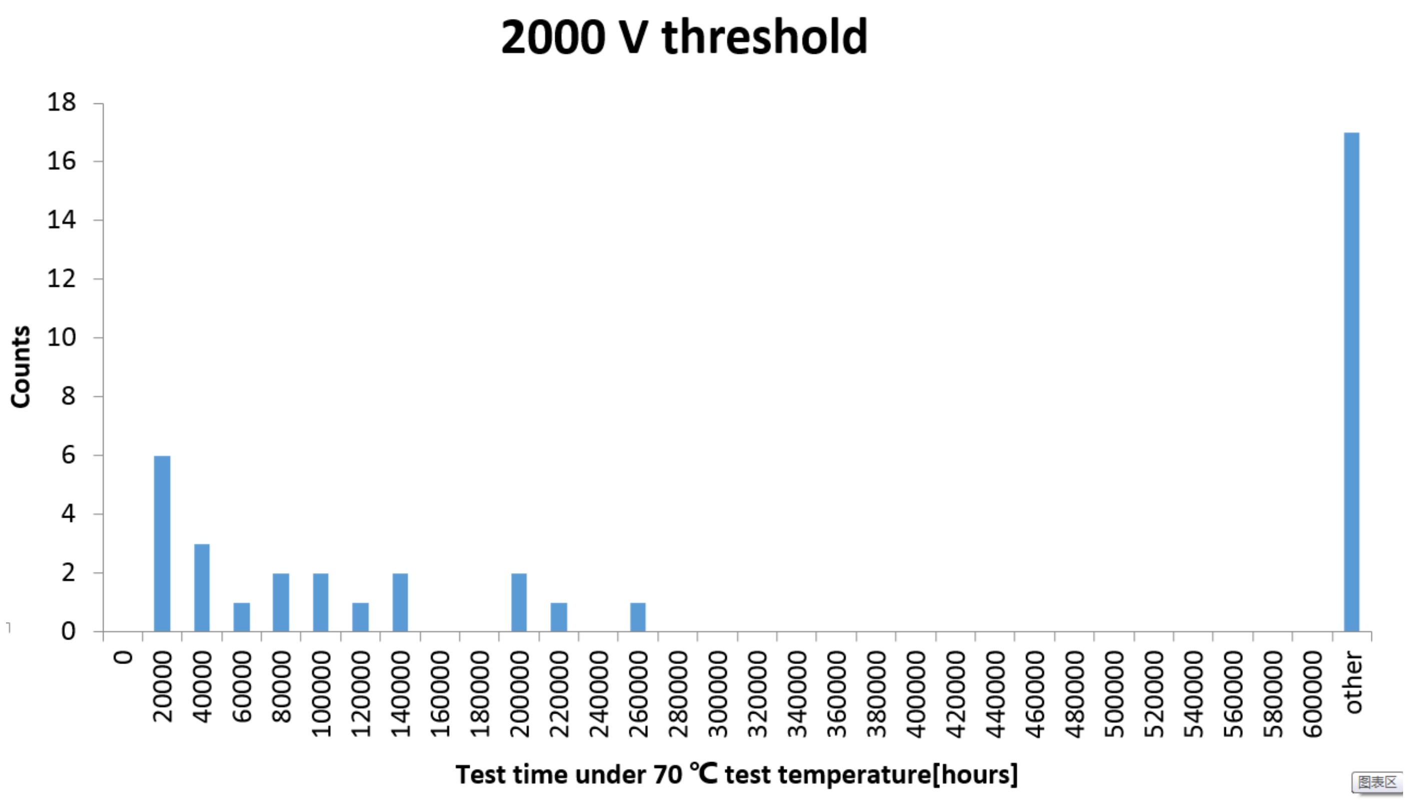
	Previous Setting Value	Internal ADC of HV unit	New Setting Value	New Internal ADC of HV unit
70 ℃	2778 V	2674 V	2900 V	2797 V

If output decrease, we can increase output by setting a big value;

The reliability of HYSYS HV units

- After 6 years, 18 of 38 HV units output is below 2000 V, they are as broken units @70℃ ambient temperature.

- The FIT of HV units is 5765 FIT.



HV Failure Rate based on 217 from Germany

A HV unit named Baikal GVD HV module is similar to Russian HVSYS Units, which is used for reliability evaluation;

FIDES was presented in Dubna by Mark Shelepov (docDB 1575-v2)

We were asked to crosscheck the calculations with the MIL-HDB

Device to check: Baikal-GVD HV module

$\Pi_{HMprocess} = 2.5, \ \Pi_{process} = 4, \ \Pi_{PM} = 1.7, \ \Pi_{induced} = 2$

$\lambda total = 26.3 * (\Pi_{HMprocess} \Pi_{process} \Pi_{PM} \Pi_{induced}) = 894$ FIT

FIT of all components including temperature Factors

Result from MIL-HDBK

Default values of process and manufacturer related factors values

Ref.: Page 3, DocDB 1700

What is Baikal GVD HV module?

It is SHV 12-2.0 K 1000 P produced by TRACO Electronic AG according to paper “The optical module of Baikal-GVD”.

From the datasheet, the company give the MTBF is

Reliability, calculated MTBF (MIL-HDBK-217 D)	>300’000 h @ + 25 °C

But page 2, one electronics' reliability is 94 FIT@60% confidence level for JUNO, equals about 10^7 hours MTTF;

So I prefer 300’000 hours (3333 FIT) as reference value , comparing with 27 FIT based on 217;

If this HV modules is similar to HYSYS HV units, it is impossible to let HV work underwater even there is a backup for HV units;

SHV 12-2.0 K 1000 P

Ref: http://www.epj-conferences.org/articles/epjconf/pdf/2016/11/epjconf-VLVnT2015_01003.pdf
http://www.datasheetspdf.com/datasheet/MHV12-2.0K1000P.html

Marathon HV units ERROR

CAN node	Setpoint V		Voltage V	Curr mcA	Temp C	HV		NMT state	Errors
100	Set	2700	0	0	68	ON	OFF	Operational	Emergency code 4280h received; The device temperature
101	Set	2700	2700	339	84	ON	OFF	Operational	Emergency code 0000h received; Error RESET / NO error;
102	Set	2700	0	0	69	ON	OFF	Operational	Emergency code 4280h received; The device temperature
103	Set	2700	0	0	70	ON	OFF	Operational	d; The device temperature exceeded; Error register 0Dh
104	Set	2700	2700	336	87	ON	OFF	Operational	Emergency code 4280h received; The device temperature
105	Set	2700	2700	335	85	ON	OFF	Operational	Emergency code 4280h received; The device temperature
106	Set	2700	0	0	84	ON	OFF	Operational	Emergency code 4280h received; The device temperature
107	Set	2700	0	0	73	ON	OFF	Operational	Emergency code 4280h received; The device temperature
108	Set	2700	0	0	70	ON	OFF	Operational	Emergency code 4280h received; The device temperature
109	Set	2700	2700	337	85	ON	OFF	Operational	Emergency code 4280h received; The device temperature
	Set	0	---	---	---	ON	OFF	Uncertain	

1. Before test, I was informed that I can test them in 70 ℃ ambient temperature environments;
2. But they just work in 70 ℃ ambient temperature for 1 day;
3. According to the check from Russian, the temperature of triggering protection is 95 ℃ ;
4. It is proved that the maximum ambient temperature is 55 ℃ according to Russian's check;;

The Expected result for Vulcan ADC

Junction Temperature

	MTBF/FIT		MTBF/FIT supporting data						
Part number	MTBF	FIT_{test}	Usage temp (℃)	Conf level (%)	Activation energy (eV)	Test temp (℃)	Test duration (hours)	Sample	Fails
Vulcan ADC	2.21×10^8	4.53	40	60.0	0.7	125	4000	200	0
Vulcan ADC	1.66×10^8	6	40	60.0	0.7	125	3000	200	0
Vulcan ADC	6×10^7	15	55	60.0	0.7	125	4000	200	0
Vulcan ADC	5×10^7	20	55	60.0	0.7	125	3000	200	0

Note: if no failure happens for Vulcan ADC, the result is a upper limit of failure in time;

$$FIT_{Real} \leq FIT_{test}$$

Some ICs in GCU not included

Name	SCEM	FIT @ 55 ℃	Used for calculation	Reason
Temperature Sensor	MAX1617AMEE	12	NO	No bad effect for GCU
Hot Swappable 2-wire Bus Buffer with Enable	LTC4300-1CMS 8	107.3	NO	The test time is too short for Linear
Integrated 4-Port 10/100 Managed Switch with Two MACs MII/RMII Interfaces	KSZ8864CNXCA	14	YES	
350MHz (Integer+Fractional), 10-Channel, Any-Frequency, Any-Output Jitter Attenuator/Clock Multiplier	SI5344B-B-GM	14.8	YES	

Fgcu >= 44 FIT:
Calculation is based on the ICs reliability data from manufacturer, and not include capacitors, resistors and connectors.
More information need to be collected in order to know exact reliability of GCU such as resistors actual power consumption;
I have upload a excel file about GCU reliability, hope for cross-check from others;

Advices

1. The reliability of components should be collected by manufacturer:

Some manufacturers are recommended such as TI, ANALOG, NXP, Xilinx and Semi conductor;

Some manufacturers are not recommended such as Linear Technology, MICREL, Microchip and ATMEL, for whom the reliability test time is too short or no any reliability data;

2. As mentioned above, the reliability evaluation of baseline scheme is not satisfied. A backup scheme should be considered.

What about capacitors and resistors in GCU?

1. Resistors could not be calculated due to lack of power consumption of resistors (possibly auto level resistor); Hope for more information about it from Padova;
2. Capacitors failure rate is calculated based on MIL-217F;

It should be noted that Vishay's capacitors failure rate is calculated on its website by using a MIL-217F calculator:

http://www.vishay.com/capacitors/tantalum-reliability-calculator-list/

Capacitors

Capacitors	30 ℃ Junction Temperature	40 ℃ Junction Temperature	55 ℃ Junction Temperature
Failure rate	>3722 FIT	>5670 FIT	>10310 FIT

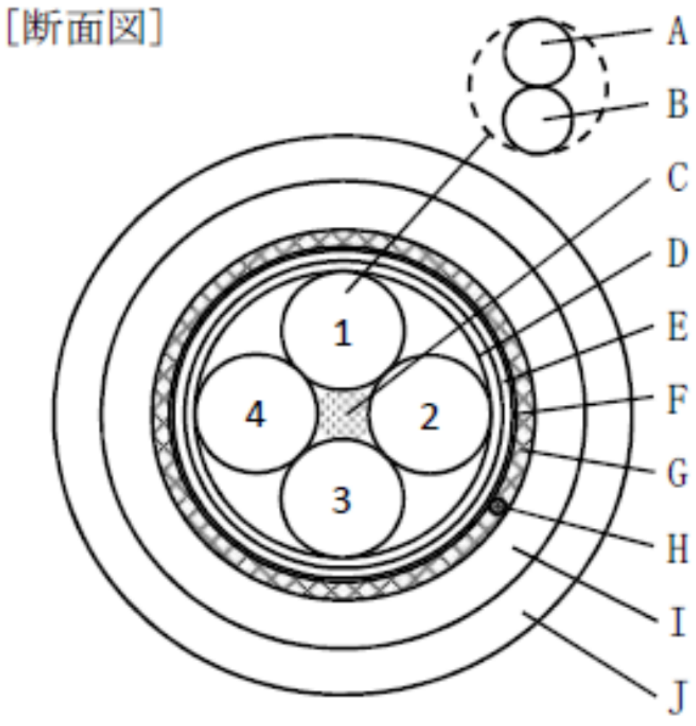
Note:

1. Although if some capacitors open circuit will not cause GCU work normally, but capacitor short circuit will cause GCU work abnormally; And most failure mode of capacitors is short circuit;
2. The capacitor calculation is based on old BOM, I will update it later;

Advices: the redundancy design should be added when using capacitors;

Other problems

1. The reliability of cable and connectors which is similar to ours should be collected, and right now there is few papers about underwater



A)copper wire with insulator
B)copper wire with insulator
C)support member (glass fiber)
D)PTFE tape
E)PTFE tape
F)Polyester with Alminum
G)Sn wire for shield
H)Sn wire for drain wire
I) Polyethylene for inner sheath (sleeve)
J)Polyethylene for outer sheath (sleeve) → redundancy design

Note:
1. PE just for verification;
2. No any pressure tolerant test;

cable weight : ~ 90g / m

http://indico.ipmu.jp/indico/getFile.py/access?

Cable Expected Failure Rate

If we hope Failure rate <0.5% in 20 years at 60% C.L. for 20000 pieces of cables,

Failure rate < 30 FIT

Calculation Website:

https://www.maximintegrated.com/cn/design/tools/calculators/general-engineering/qafits.cfm#

Other problems

2. The protection circuit reliability should be verified;

A high voltage pulse generator (maximum amplitude 100 V, 1.2 ns rise time, 250 mA maximum current) will be bought, whose type is AVR E3A-B;

We will use it to simulate PMT signal to verify the shock of big pulse;

A high voltage pulse generator

Outline

- **1. Progress of reliability study;**
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Reliability qualification

1. Why we need a reliability qualification?

The calculation is not so reliable enough, so the test of qualification should be used for verification;

2. How to do it?

1. Components qualification;
2. ADC + GCU + Power Board + Cable;
3. ADC + GCU + Power Board + Cable + potting + water;

Components qualification;

Hu Jun will report components qualification including FEC + Tsinghua ADC;

	MTBF/FIT		MTBF/FIT supporting data						
Part number	MTBF	FIT_{test}	Usage temp (℃)	Conf level (%)	Activation energy (eV)	Test temp (℃)	Test duration (hours)	Sample	Fails
FEC+ADC	2.21×10^8	4.53	40	60.0	0.7	125	4000	200	0
FEC+ADC	1.66×10^8	6	40	60.0	0.7	125	3000	200	0
FEC+ADC	6×10^7	15	55	60.0	0.7	125	4000	200	0
FEC+ADC	5×10^7	20	55	60.0	0.7	125	3000	200	0

Note: it will take 4000 hours for reliability qualification;

That means a reliability conclusion will be gotten at Oct 1, 2017 at 4.5 FIT failure rate;

But this is not enough, because we should know the whole system reliability;

The whole system reliability

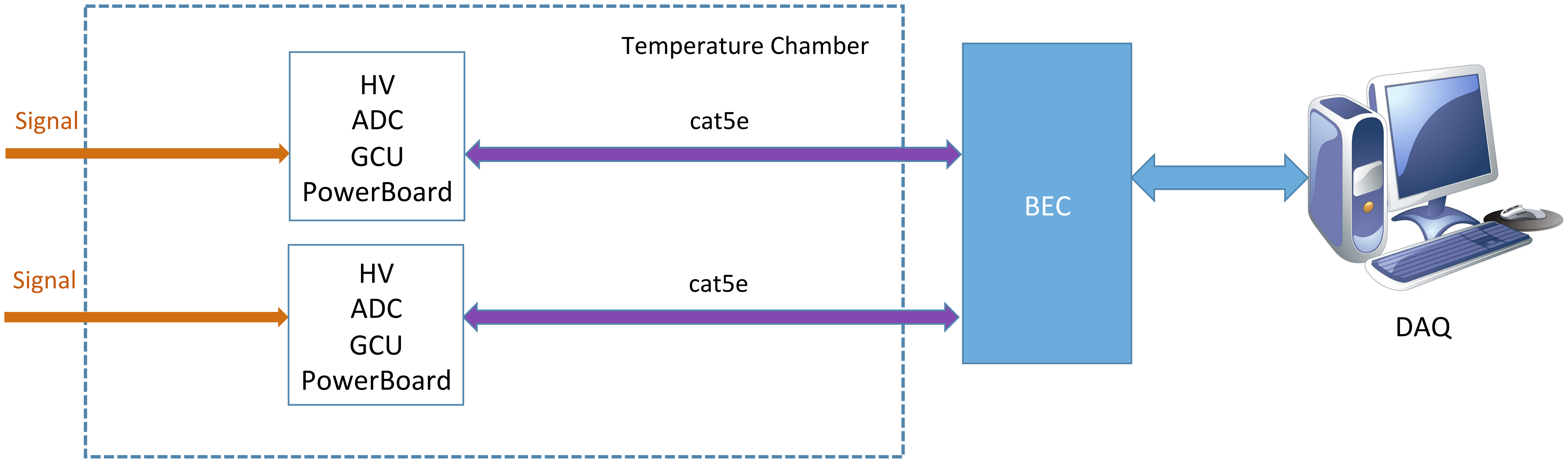
Pure electronics: HV+ADC + GCU + Power Board + Cable;

Real environment: HV+ADC + GCU + Power Board + Cable + potting + water;

Test detail:

1. The test units are divided into 3 or more groups, which operate in different temperature;
2. Take all units as a whole group, which operate in the same temperature;

Pure Electronics Reliability Test System



The test scheme in details

There are two common reliability schemes for industry:

1. The test units are divided into 3 or more groups, which operate in different temperature;
2. Take all units as a whole group, which operate in the same temperature; when exact fail reason is known, the activation energy could be queried by using handbook;

No matter which scheme will be used, failed components should happened, or else no conclusion about reliability will be given;

Scheme 1

GCU + Power board
GCU + Power board
GCU + Power board

125 ℃

thermal chamber

GCU + Power board
GCU + Power board
GCU + Power board

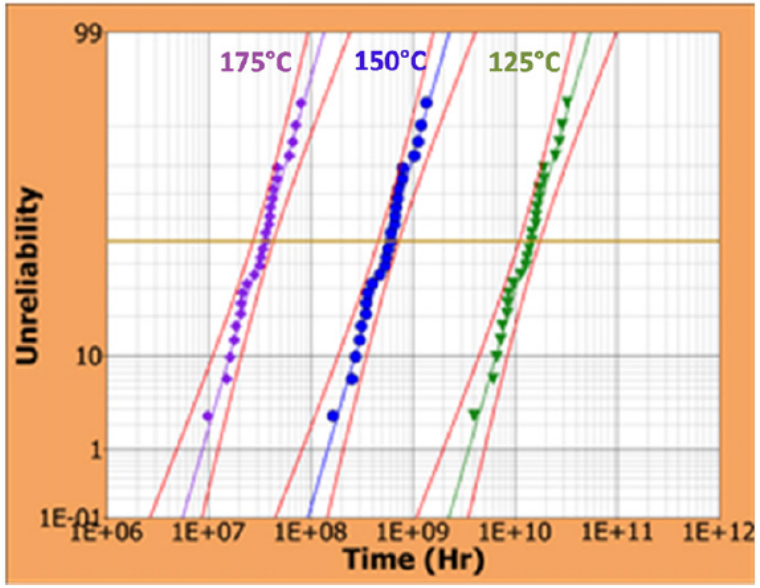
150 ℃

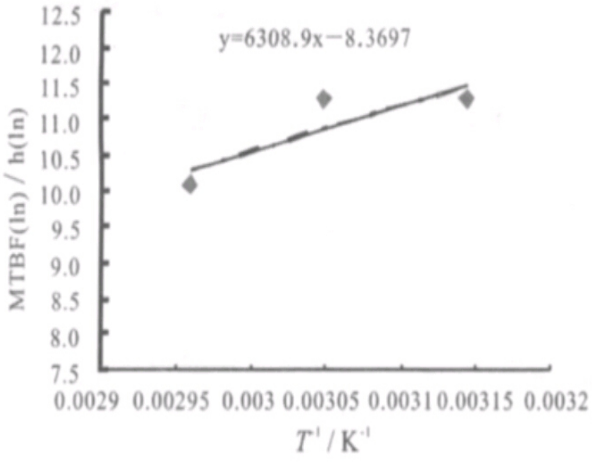
thermal chamber

GCU + Power board
GCU + Power board
GCU + Power board

175 ℃

thermal chamber

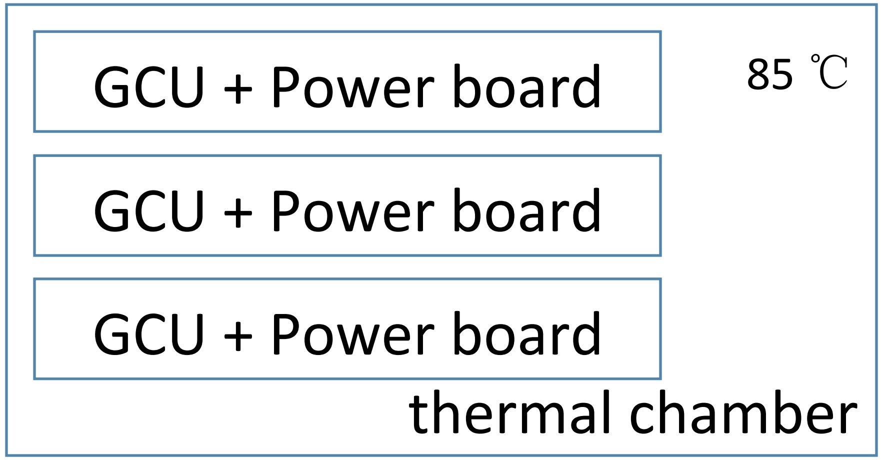




Risk Analysis

- 1. At least 30% PCBs should not work for each group of three groups during the test, but the risk is that there is no enough broken units during 4000 hours test;
- 2. According to linear fit, the activation energy can be calculated; but if the root cause is not the same for each group, it means the points could be used for fitting, so at least 3 groups are needed in case of it;
- 3. But this is the most common method for industry;

Scheme 2



$$\lambda = \sum_{i=1}^{\beta} \left(\frac{x_i}{\left(\sum_{j=1}^{k} TDH_j \times AF_{ij} \right)} \right) \times \frac{M \times 10^9}{\sum_{i=1}^{\beta} x_i}$$

where,

λ = failure rate in FITs (Number fails in 10^9 device hours)

β = Number of distinct possible failure mechanisms

k = Number of life tests being combined

x_i = Number of failures for a given failure mechanism i = 1, 2,... β

TDH_j = Total device hours of test time for life test j, j = 1, 2,... k

AF_{ij} = Acceleration factor for appropriate failure mechanism, i = 1, 2,... k

$M = X^2_{(\alpha,\, 2r+2)} / 2$

where,

X^2 = chi square factor for 2r + 2 degrees of freedom

r = total number of failures ($\Sigma\, x_i$)

α = risk associated with CL between 0 and 1.

Table 6.1 — Failure Mechanisms and Model Parameters (cont'd)
All these models are inherently Eyring; so, take product of Arrhenius & other functions
NOTE: Add Section Number to suffix find full citation (e.g., 1st Short, leakage citation is: [5.7.3] & [5.7.5])

Sect.	Failure Mode	Failure Mechanism	Activation Energy	Non-Arrhenius Model Parameters				Annex A Citation Suffix
			E_{aa} (eV)	Type	Variable	Units	Parameter	
5.8	Short, leakage	TDDB; traps & percolation	0.75	Exponential	E	MV/cm	4	3, 5
5.8	Short, leakage	Cu ion drift	1.0	Concentration gradient	Conc	cm^{-2}	1	10
5.9	Open	Al EM; vacancy transport	0.8	Power	J	A/cm^2	2	2, 7, 11, 17
5.9	Open	Al EM; grain-boundary diffusion	0.68	Power	J	A/cm^2	2	18, 19
5.9	Open	Al EM; interfacial diffusion	0.95	Power	J	A/cm^2	2	18, 19
5.10	Open	Cu EM; vacancy transport	0.9	Power	J	A/cm^2	1.1	3
5.11	Open	Al corrosion (Chloride)	0.75	Power	RH	%	2.7	8
5.11	Open	Al corrosion (Chloride)	0.75	Exponential	1/RH	$\%^{-1}$	529%	15
5.11	Open	Al corrosion (Phos Acid)	0.3	Exponential	1/RH	$\%^{-1}$	300%	7
5.11	Open	Al corrosion (Chloride)	0.75	Exponential	RH	%	$0.12\ (\%)^{-1}$	10
5.11	Leakage	Diffusion thru passivation cracks	0.79	Power	RH	%	4.64	23
5.11	Open	Ion transport thru PolyImide	1.15	Power	RH	%	0.98	23
5.11	I_{cc} quiescent	Water diffusion	0.73	Power	RH	%	1	20
5.11	Leakage	Ionic conductivity – lead frame coplanarity tape 1	0.74	Power	RH	%	12	24
5.11	Leakage	Ionic conductivity – lead frame coplanarity tape 2	0.77	Power	RH	%	5	24

Page 86, JEDEC 122G.

The acceleration factor for electronics system

- Assume that 100 parts where stressed at 85°C ambient for 3000 hours, with one failure at 2000 hours for a photoresist flaw (0.7eV) and one failure at 3000 hours for an oxide defect (0.3eV); the internal temperature rise (Tj) of the part is 20°C and the products were tested at 1000, 2000 and 3000 hours.

$$AF_1 = \exp\left[\frac{0.7}{8.63\times10^{-5}}\left(\frac{1}{273.15+40+20} - \frac{1}{273.15+85+20}\right)\right] = 18.2$$

$$AF_2 = \exp\left[\frac{0.3}{8.63\times10^{-5}}\left(\frac{1}{273.15+40+20} - \frac{1}{273.15+85+20}\right)\right] = 3.5$$

$$TDH = 1000\times100+1000\times99+1000\times98 = 297000$$

$$M = 3.1 \text{ } (60\% \text{ } C.L., r=2)$$

$$\Lambda = \left(\frac{1}{297000\times18.2} + \frac{1}{297000\times3.5}\right)\times\frac{3.1\times10^{9}}{2} = 1777 \text{ } FITs$$

Pure Electronics Reliability Possible Result

Only one part fail:

	MTBF/FIT		MTBF/FIT supporting data						
Part number	MTBF	FIT_{test}	Usage temp (℃)	Conf level (%)	Activation energy (eV)	Test temp (℃)	Test duration (hours)	Sample	Fails
Pure Electronics	$2.21x10^8$	54	40	60.0	0.7	125	4000	50	1
Pure Electronics	$1.66x10^8$	120	40	60.0	0.6	125	4000	50	1
Pure Electronics	$6x10^7$	264	40	60.0	0.5	125	4000	50	1
Pure Electronics	$5x10^7$	582	195	60.0	0.4	125	4000	50	1

Note: the activation energy could not be known exactly before test, because it is difficulty to know which will fail;
Only we know the exact failure mechanism, we can know the activation energy;
Only red fonts could prove that the system is OK about reliability if only a IC failed whose activation energy is 0.7 eV;

Risk Analysis

- 1. Not all the failure mechanism have relative activation energy;
- 2. The result shows a big error for fixed time test, and the best way is to test in real time;

Pure Electronics Reliability Test Scheme

Steps:

- 1. The complete performance test for all the channels before high temperature test;
- 2. The maximum operation temperature test (高温摸底试验)；
- 3. The temperature cycling test;
- 4. The high temperature operation life test for 4000 hours;
- 5. The complete test for all the channels after high temperature test;
- 6. Failure Analysis for the failure parts;

Device: thermal chambers

Temperature Range: 70℃~250℃;
Temperature Variation: ±1℃;
Workspace: 500mm*600mm*750mm;
Outer size: 690mm*600mm*760mm;
Price：¥6200;
Power: 2040 V*A
Note:

Ref: http://www.shfuma.com/Fuma_ProductView.aspx?id=33

The PCB size is 10 cm* 10 cm, so 70 units can be put into a thermal chamber and 3 chambers is needed;

Device: thermal chambers

Thermal Chamber Volume: 500mm*600mm*750mm;
Number : 0.3*0.3*0.3*50/(0.5*0.6*0.75) = 10 pieces

Total Fee: 10 * ￥7k = ￥70 k;

Type	Number	Price	Model
Thermal Chamber （Renting）	10 pieces	￥7,000	ESPEC
ADC+GCU+PowerBoard	50 piece	￥10,000	
BEC	2 pieces	￥5,000	
Cable	20 pieces	￥600	
Total Fee		>￥592,000	

Risk and questions

1. Is it possible for HV unit tested with GCU for reliability test?

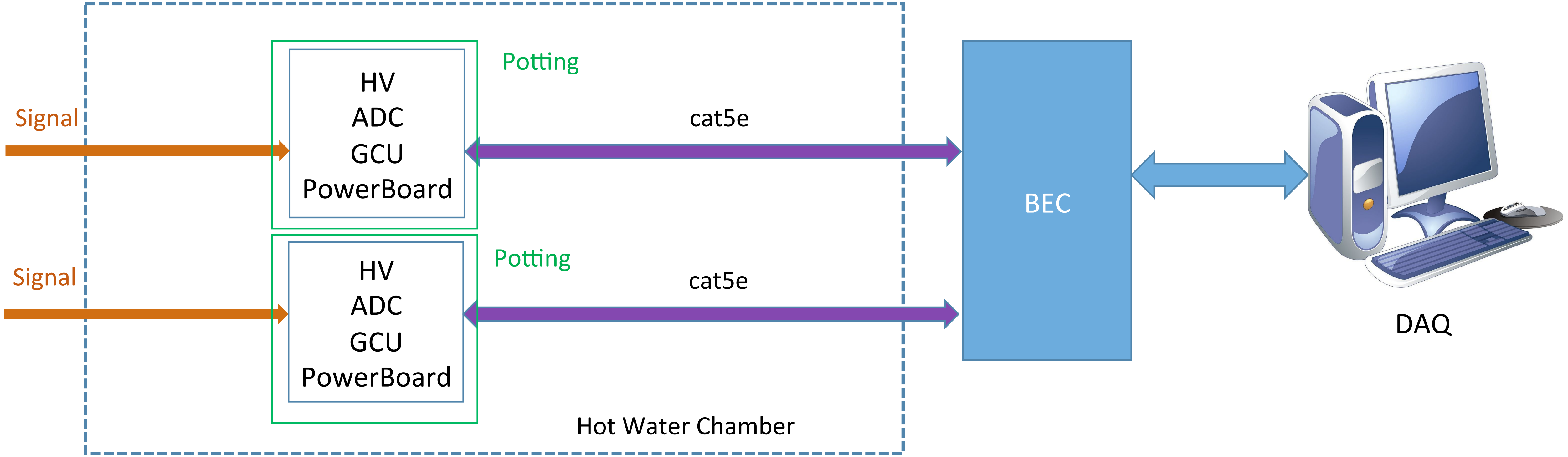
If yes, the ambient temperature of HV units could not higher than 70 ℃, which means the junction temperature of components from GCU or ADC and so on is not reach 125 ℃ junction temperature;

2. If no any broken component happens during test, how to evaluate the reliability, which is similar to HVSYSY units reliability test right now?

It is possible that due to project process a conclusion should be gotten, but at that time we could not give enough evidence for proving and should continue to do it.

3. The test environment is different from real environment, is the result from test environment suitable for real environment?

Real Environment Reliability Test System



Note:

1. Both reliability of electronics and potting will be checked at the same time;
2. In order to accelerate the devices aging, hot water instead of 20 ℃ water will be used;

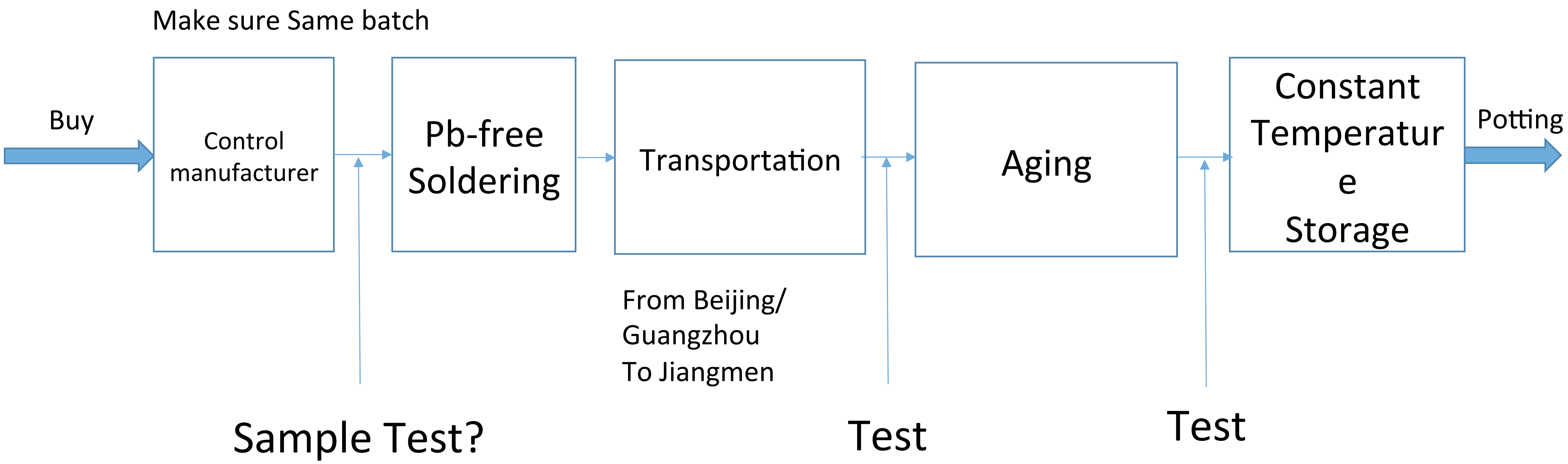
- **1. Progress of reliability study;**
- **2. Reliability qualification;**
- **3. The plan of aging;**

Two Possible Scheme about aging

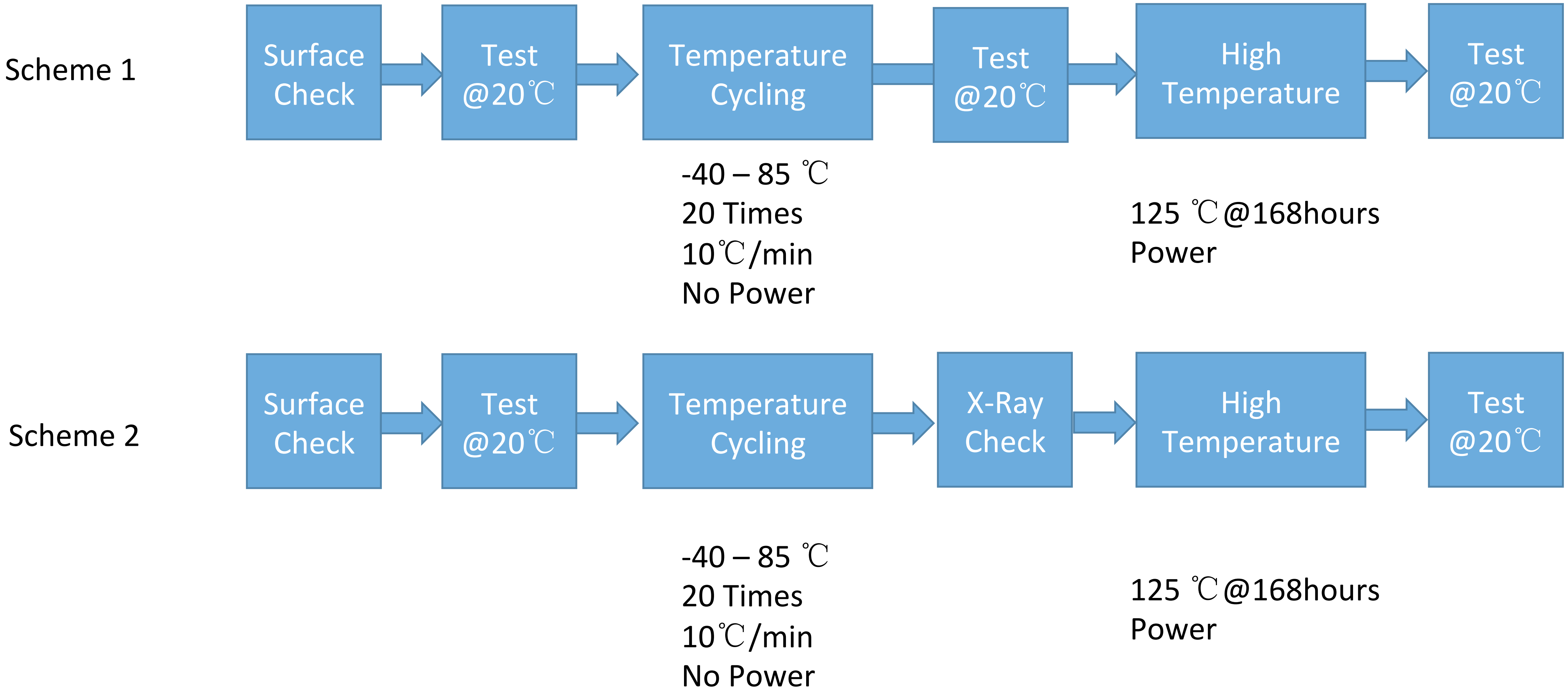
Scheme 1: do it by ourselves, so we have to buy or rent devices, room, and need many persons (A device renting company named Su Shi Chuang Bo is contacting with us) including the test persons, shifters during aging;

Scheme 2: a company named Guang Wu Suo will provide aging services, and it just need a few of persons, who is responsible for monitoring their work;

Mass Production



The plan of aging in details



Scheme 1 Fee

	Temperature Cycling Device	Constant High Temperature Device
Price	￥600/hours	￥600/hours
Volume	22 m^3	45 m^3
Size for one batch	500	1000
Batch	4	2
Time for one batch	20 hours	168 hours
Fee	￥480,000	￥2,020,000

Note:

1. Not include electricity fees;
2. Not include the storage fee;

Comparison

	Person	Fee	Time	Location	Note
Scheme 1	few	￥2,500,000	10 months	Beijing	Do it by ourselves
Scheme 2	more	￥2,000,000	13 months	Guangzhou	Monitor it

Note: it is possible for us to cut more cost by negotiating with service providers.

Summary

1. The reliability problems of current system are shown;
2. The reliability qualification schemes of electronics are advised;
3. The aging plan including time, implement and fees is shown;

Welcome for comments!