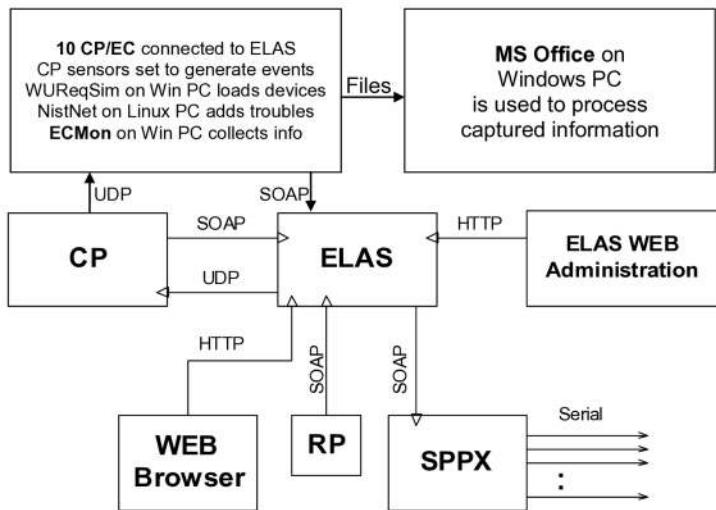
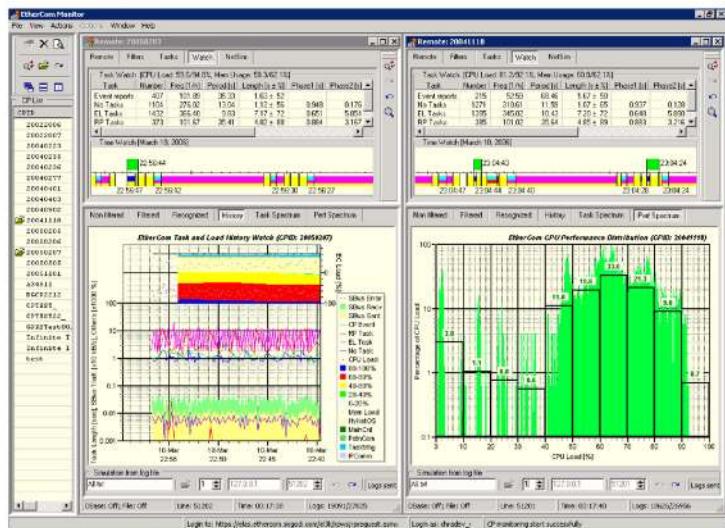


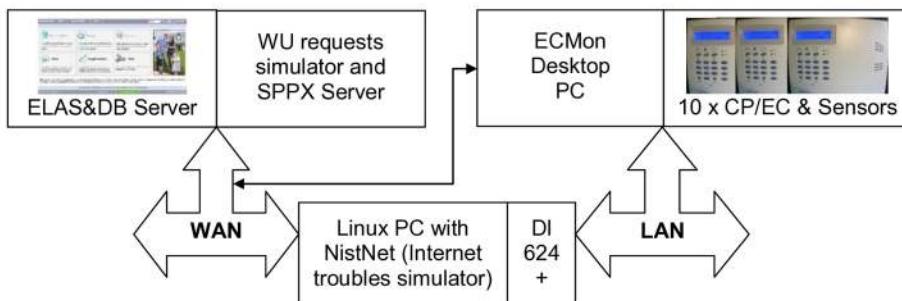
**Internet enabled security system (ELAS&SPPX and CP/EC) and long time, extremely high load testing methodology**



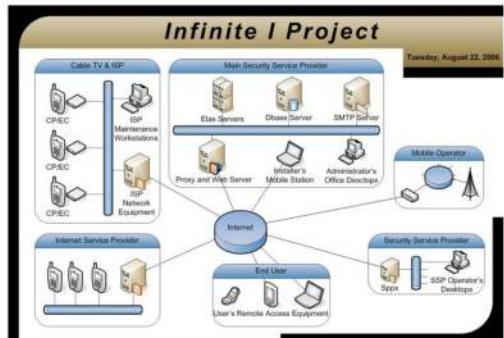
**ELAS&SPPX, CP/EC and ECMon tool architecture**



**ECMon monitoring tool in action (snapshot)**



**Test suit block diagram**



**Security system (Infinite-I) architecture**

#### **Test conditions (WU requests by testCPPProxy):**

- All CP/ECs are requested continuously and alternatively to perform SetCPState and GetCPLog with 0.5sec pause between. Periodically (when user access log records exceed 64) CP log is cleared.

#### **Test conditions (RP requests by LogCollector):**

- UploadCPLog: every 5min;
  - UploadECLog: every 4min;
  - UploadData: every 3min

#### **Test conditions (Event reporting – all CPs):**

- All CPs are set with the same parameters (close to defaults);
  - All CPs are set not to report via PSTN, no report cycles;
  - All CPs have 3 normal PIR sensors;
  - All CPs have 2 sensors generation events every minute.

#### **Test conditions (Elas settings):**

- Elas is set not to send events to Elpx/Sims or to user via SMS;
  - Elas is set to use indirect CP notification;
  - Alive cycle is set to 30 sec for both armed and disarmed CP state.

#### **Test conditions (general):**

- All ECs are connected to ECMon for monitoring;
  - In some cases CP and/or EC have been restarted depending on test case.

#### **Test conditions (infrastructure):**

- All CPs are installed behind router (DLink DI-624+ or Edimax);
  - All CPs are connected to the router via Ethernet HUB;
  - One of the interfaces of the monitoring station is connected to HUB;
  - Elas is connected to router's WAN via Linux router;
  - NestNet simulator is installed on the Linux router;
  - L2TP and PPP services are installed on Linux on VMWare box;
  - Separate Elas' CPWS is installed for independent control.

#### **Test conditions (NistNet simulator when on):**

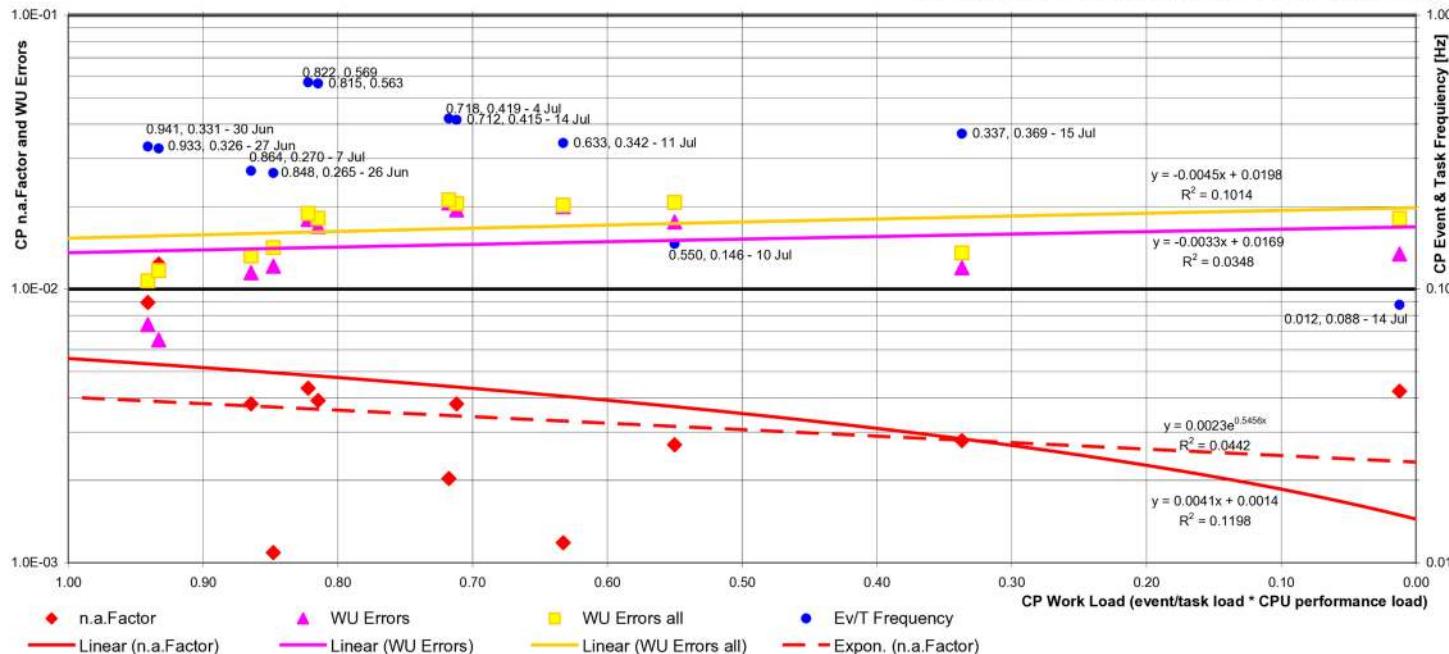
- Effects are set to change traffic between Elas and VMWare box;
  - Equal effects are set in both directions;
  - Packet delay is set to 2ms with 1ms delta and 0 correlation;
  - Packet drop ratio is set to 1% with 0 correlation;
  - Packet duplication ratio is set to 1%, with 0 correlation.

#### **Test conditions (Router settings):**

- WAN is set to use static IP address;
  - WAN is set to use L2TP on Edimax as alternative;
  - LAN is set to have one and the same IP (used as DGW);
  - DHCP is set to use one and the same IP range;
  - Routers have been exchanged or reset depending on test case.

#### **Availability and Reliability Test Results (table show)**

## Availability and Reliability Test Results (graph show)

**Test results and conclusions:**

- Web user access errors are  $1.46\% \pm 0.5\%$  and less than 2.06% for all test cases;
- There is no significant influence of CP/EC work conditions on Web user access errors;
- CP Non Availability as function of CP Work Load is like  $y=0.004x+0.0014$  (with  $R^2=0.1198$ );
- The influence of CP/EC work conditions on CP Non Availability is small and could be ignored in first approximation;
- CP Non Availability (in time measure in case of CP event and task concurrency) is  $0.43\% \pm 0.3\%$  in first approximation and less than 1.23% for all test cases;
- CP Non Availability is mainly influenced by CP/EC deadlocks causing 3 or 5 min unavailability time window for both RP and WU access while CP reports normally;
- CP/EC deadlock causing 5 min unavailability time window is more rare and could be seen at tests with largest CP Work Load (more than 80%);
- There is no bug (any of the four main issues) manifestation for all CPs and the time they are under the testing (3,254 CP\*hours).

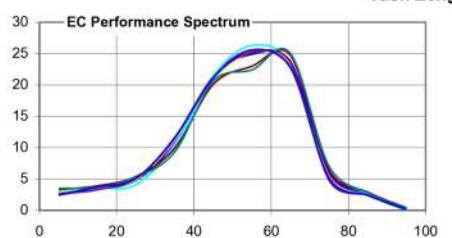
# Long Time Extremely High Load Tests of Broadband Firmware CP ver. 0.49 and EC ver. 1.08 (25.06-15.07.2008)

8 CPUs \* 19h (152 cp\*h) at: DHCP, w/o IIS req. certs, with L2TP (1492b), with NistNet (2/1,1,1), WU load (4.5-11s)

CP Even & Task Frequency [Hz]: 0.369

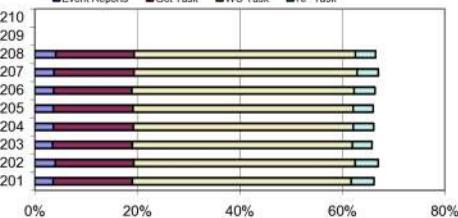
14-15.07.2008

	3M	5M	1M	n.a.F	WU Errors
1	0	1	0.31%	1.41%	1.22%
1	0	0	0.26%	1.41%	1.22%
2	0	0	0.53%	1.72%	1.35%
0	0	1	0.04%	1.21%	1.21%
1	0	2	0.35%	1.18%	1.00%
1	0	3	0.39%	1.28%	1.10%
1	0	1	0.31%	1.33%	1.14%
0	0	1	0.04%	1.32%	1.32%
			210		



Task Length [s]: 1.335 0.844 2.974 3.064

Event Reports Get Task WU Task RP Task



n.a.Factor: 0.28% 1.36% 1.20%

Work Load: 33.6%

EC CPU Load: 50.8%

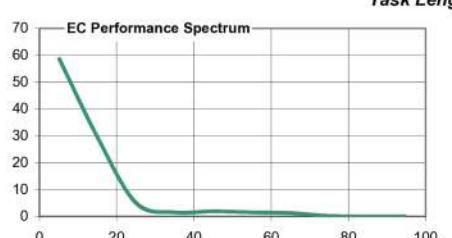
CP Even & Task Load: 66.2%

2 CPUs \* 65h (130 cp\*h) at: DHCP, w/o IIS req. certs, with L2TP (1492b), with NistNet (2/1,1,1), WU load (18-54s)

CP Even & Task Frequency [Hz]: 0.088

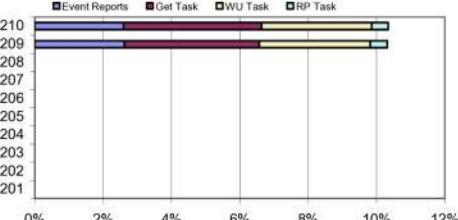
11-14.07.2008

	3M	5M	1M	n.a.F	WU Errors
7	0	0	0.54%	1.95%	1.36%
4	0	0	0.31%	1.67%	1.33%
	210				
			210		



Task Length [s]: 0.865 0.870 3.205 3.640

Event Reports Get Task WU Task RP Task



n.a.Factor: 0.42% 1.81% 1.34%

Work Load: 1.2%

EC CPU Load: 11.8%

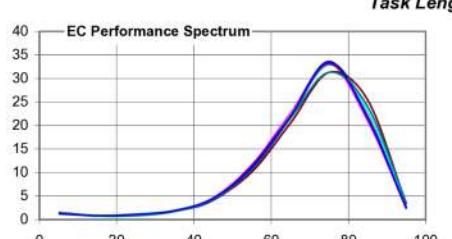
CP Even & Task Load: 10.3%

8 CPUs \* 69h (552 cp\*h) at: DHCP, w/o IIS req. certs, with L2TP (1492b), with NistNet (2/1,1,1)

CP Even & Task Frequency [Hz]: 0.415

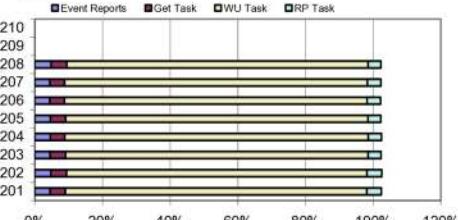
11-14.07.2008

	3M	5M	1M	n.a.F	WU Errors
5	0	7	0.45%	2.13%	1.98%
5	0	4	0.41%	2.16%	2.01%
4	0	9	0.40%	2.12%	2.00%
0	0	11	0.13%	1.96%	1.96%
5	0	13	0.52%	2.17%	2.02%
2	0	9	0.25%	1.84%	1.78%
1	0	12	0.22%	1.77%	1.74%
7	0	13	0.66%	2.29%	2.08%
	210				



Task Length [s]: 1.579 0.700 2.891 2.994

Event Reports Get Task WU Task RP Task



n.a.Factor: 0.38% 2.05% 1.95%

Work Load: 71.2%

EC CPU Load: 69.5%

CP Even & Task Load: 102.3%

# Long Time Extremely High Load Tests of Broadband Firmware CP ver. 0.49 and EC ver. 1.08 (25.06-15.07.2008)

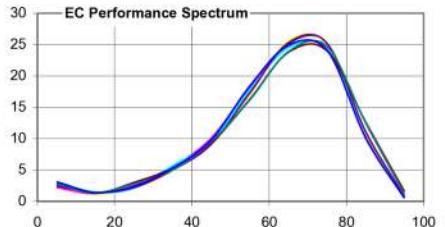
8 CPUs \* 22h (176 cp\*h) at: DHCP, w/o IIS req. certs, with L2TP (1192b), with NistNet (4/2,2,1)

CP Even & Task Frequency [Hz]: 0.342

10-11.07.2008

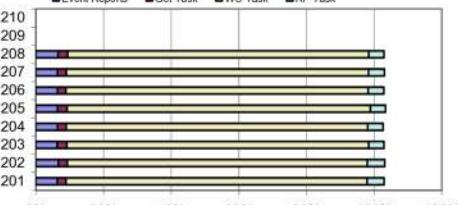
3M 5M 1M n.a.F WU Errors

1	0	0	0.23%	2.26%	2.15%
0	0	0	0.00%	2.20%	2.20%
0	0	3	0.11%	1.95%	1.95%
0	0	3	0.11%	1.99%	1.99%
0	0	5	0.19%	1.93%	1.93%
1	0	0	0.23%	2.03%	1.93%
0	0	0	0.00%	1.94%	1.94%
0	0	2	0.08%	1.91%	1.91%



Task Length [s]: 2.230 0.774 3.368 3.548

Event Reports Get Task WU Task RRP Task



n.a.Factor: 0.12% 2.03% 2.00%

Work Load: 63.3%

EC CPU Load: 61.4%

CP Even & Task Load: 103.0%

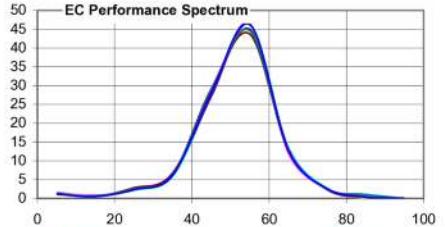
8 CPUs \* 22h (176 cp\*h) at: DHCP, with IIS req. certs, with L2TP (1192b), with NistNet (2/1,1,1)

CP Even & Task Frequency [Hz]: 0.146

09-10.07.2008

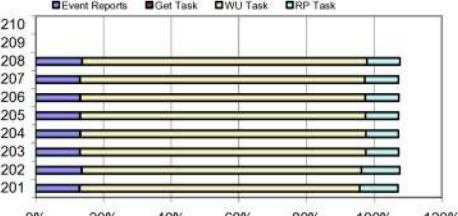
3M 5M 1M n.a.F WU Errors

1	0	1	0.27%	2.32%	2.04%
2	0	0	0.45%	2.51%	1.94%
1	0	0	0.23%	2.14%	1.87%
1	0	2	0.30%	1.98%	1.70%
2	0	0	0.45%	2.07%	1.52%
0	0	0	0.00%	1.59%	1.59%
0	0	0	0.00%	1.63%	1.63%
2	0	0	0.45%	2.33%	1.78%



Task Length [s]: 4.524 2.389 8.075 7.940

Event Reports Get Task WU Task RRP Task



n.a.Factor: 0.27% 2.07% 1.76%

Work Load: 55.0%

EC CPU Load: 51.3%

CP Even & Task Load: 107.3%

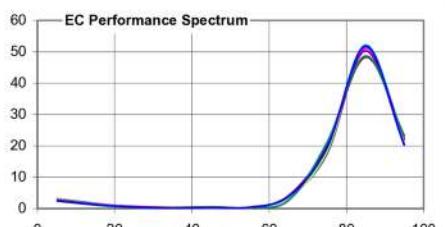
8 CPUs \* 24.5h (196 cp\*h) at: DHCP, w/o IIS req. certs, w/o L2TP, w/o NistNet

CP Even & Task Frequency [Hz]: 0.563

07-08.07.2008

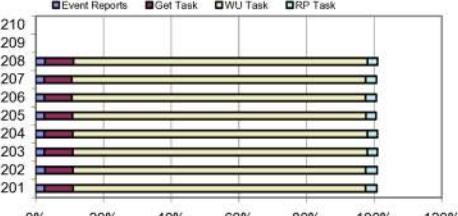
3M 5M 1M n.a.F WU Errors

1	0	1	0.24%	1.80%	1.73%
3	0	3	0.71%	2.07%	1.86%
2	0	1	0.44%	1.88%	1.74%
1	0	0	0.20%	1.73%	1.66%
1	0	1	0.24%	1.77%	1.70%
3	0	1	0.65%	1.74%	1.53%
1	0	0	0.20%	1.51%	1.44%
2	0	1	0.44%	1.99%	1.86%



Task Length [s]: 0.909 0.579 2.300 2.331

Event Reports Get Task WU Task RRP Task



n.a.Factor: 0.39% 1.81% 1.69%

Work Load: 81.4%

EC CPU Load: 80.8%

CP Even & Task Load: 100.8%

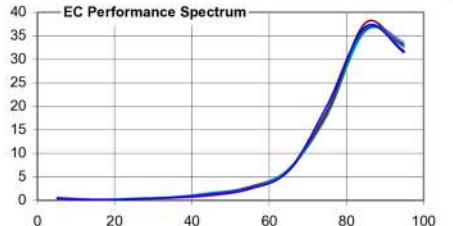
# Long Time Extremely High Load Tests of Broadband Firmware CP ver. 0.49 and EC ver. 1.08 (25.06-15.07.2008)

8 CPUs \* 72h (576 cp\*h) at: DHCP, with IIS req. certs, with L2TP (1492b), with NistNet (2/1,1,1)

04-07.07.2008

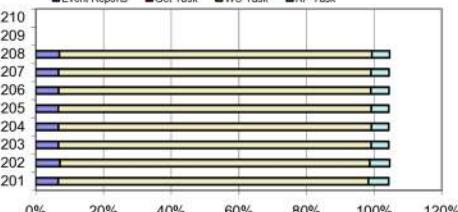
3M 5M 1M n.a.F WU Errors

3	0	3	0.24%	1.13%	1.01%
1	0	6	0.14%	1.15%	1.11%
6	0	2	0.44%	1.40%	1.17%
8	1	7	0.75%	1.51%	1.21%
6	0	4	0.46%	1.38%	1.15%
2	0	2	0.16%	1.22%	1.14%
5	0	10	0.46%	1.34%	1.14%
5	0	3	0.38%	1.42%	1.22%



Task Length [s]: 2.388 1.150 4.036 4.101

Event Reports Get Task WU Task RP Task



n.a.Factor: 0.38% 1.32% 1.15%

Work Load: 86.4%

EC CPU Load: 82.8%

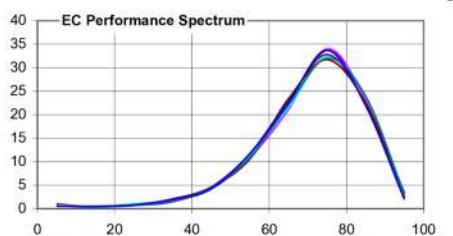
CP Even & Task Load: 104.4%

8 CPUs \* 20h (160 cp\*h) at: DHCP, w/o IIS req. certs, with L2TP (1492b), with NistNet (2/1,1,1)

03-04.07.2008

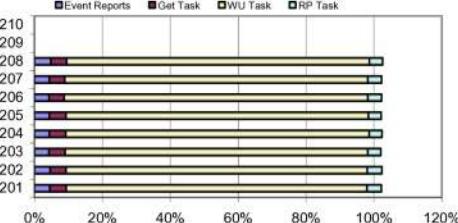
3M 5M 1M n.a.F WU Errors

1	0	1	0.29%	2.25%	2.15%
0	0	3	0.13%	1.97%	1.97%
1	0	2	0.33%	2.20%	2.10%
1	0	3	0.38%	2.20%	2.10%
0	0	2	0.08%	2.02%	2.02%
1	0	2	0.33%	2.07%	1.96%
0	0	1	0.04%	1.89%	1.89%
0	0	1	0.04%	2.33%	2.33%



Task Length [s]: 1.585 0.679 2.891 2.981

Event Reports Get Task WU Task RP Task



n.a.Factor: 0.20% 2.12% 2.06%

Work Load: 71.7%

EC CPU Load: 70.1%

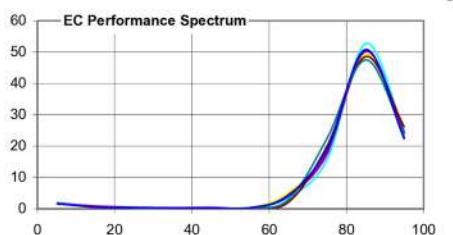
CP Even & Task Load: 102.3%

8 CPUs \* 24h (192 cp\*h) at: static IPs, w/o any extra load

02-03.07.2008

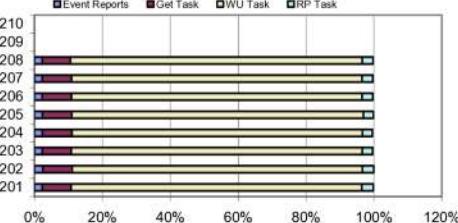
3M 5M 1M n.a.F WU Errors

0	0	2	0.07%	1.75%	1.75%
3	0	2	0.69%	2.23%	2.02%
1	0	2	0.28%	2.04%	1.96%
1	1	2	0.63%	1.98%	1.91%
2	0	2	0.49%	2.13%	1.99%
1	0	2	0.28%	1.46%	1.39%
1	0	7	0.45%	1.50%	1.43%
2	0	5	0.59%	2.04%	1.90%



Task Length [s]: 0.841 0.565 2.280 2.335

Event Reports Get Task WU Task RP Task



n.a.Factor: 0.43% 1.89% 1.79%

Work Load: 82.2%

EC CPU Load: 82.4%

CP Even & Task Load: 99.7%

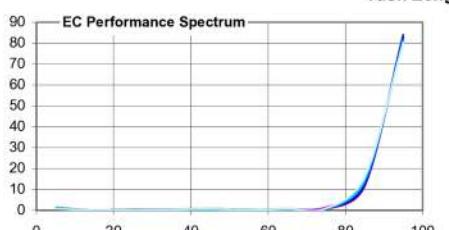
# Long Time Extremely High Load Tests of Broadband Firmware CP ver. 0.49 and EC ver. 1.08 (25.06-15.07.2008)

10 CPUs \* 66h (660 cp\*h) at: DHCP, with IIS req. certs, w/o L2TP and NistNet

27-30.06.2008

3M 5M 1M n.a.F WU Errors

9	0	4	0.73%	1.00%	0.70%
10	2	8	1.11%	1.13%	0.79%
5	0	3	0.42%	0.88%	0.71%
4	1	5	0.49%	0.78%	0.64%
15	1	4	1.31%	1.23%	0.73%
11	1	3	1.00%	1.08%	0.70%
9	0	5	0.74%	1.00%	0.70%
12	1	4	1.09%	1.14%	0.74%
14	1	3	1.22%	1.35%	0.88%
10	0	4	0.81%	1.14%	0.80%



Task Length [s]: 1.613 1.017 3.236 3.234

CP Even & Task Frequency [Hz]: 0.331



n.a.Factor: 0.89% 1.07% 0.74%

Work Load: 94.1%

EC CPU Load: 91.5%

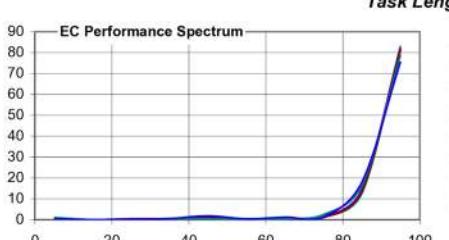
CP Even & Task Load: 102.8%

8 CPUs \* 18h (144 cp\*h) at: DHCP, with IIS req. certs, w/o L2TP and NistNet

26-27.06.2008

3M 5M 1M n.a.F WU Errors

5	0	0	1.39%	1.24%	0.64%
4	0	0	1.11%	1.21%	0.73%
4	1	0	1.57%	1.09%	0.61%
2	0	3	0.69%	0.87%	0.63%
0	0	0	0.00%	0.62%	0.53%
6	0	0	1.67%	1.36%	0.64%
3	0	0	0.83%	0.97%	0.60%
9	0	2	2.59%	1.97%	0.83%



Task Length [s]: 1.483 0.983 3.273 3.240

CP Even & Task Frequency [Hz]: 0.326



n.a.Factor: 1.23% 1.17% 0.65%

Work Load: 93.3%

EC CPU Load: 91.3%

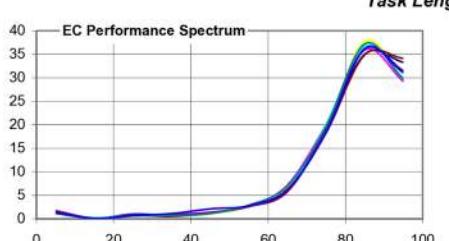
CP Even & Task Load: 102.1%

8 CPUs \* 17.5h (140 cp\*h) at: DHCP, with IIS req. certs, with L2TP (1392b), with NistNet (2/1,1,1)

25-26.06.2008

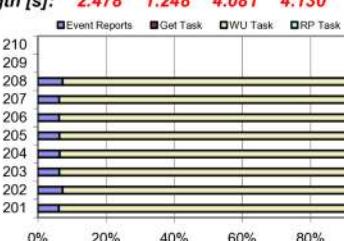
3M 5M 1M n.a.F WU Errors

0	0	0	0.00%	1.17%	1.17%
3	0	1	0.24%	1.67%	1.17%
0	0	1	0.01%	1.16%	1.16%
0	0	1	0.01%	1.26%	1.26%
1	0	2	0.10%	1.39%	1.23%
1	0	2	0.10%	1.40%	1.24%
0	0	1	0.01%	1.14%	1.14%
5	0	1	0.39%	2.13%	1.32%



Task Length [s]: 2.478 1.248 4.081 4.130

CP Even & Task Frequency [Hz]: 0.265



n.a.Factor: 0.11% 1.42% 1.21%

Work Load: 84.8%

EC CPU Load: 81.5%

CP Even & Task Load: 104.0%

**Main EC issues test made at 26.06.2008 under standard test conditions and the following actions:**

- Test was start before 11:00 after first night one (25-26.06.2008) without restarting of all 8 CP/EC and using the same test conditions;
- Elas' CNWS was updates between 11:00 and 11:30;
- At 11:52 and 11:57 Linux server (where L2TP and PPP servers are installed) was rebooted – it takes approximately 2 min to come ready;
- At 12:02 Linux server (where main routing and NistNet are installed) was rebooted – it takes approximately 2 min to come ready;
- At 12:05 Edimax router was rebooted – it takes approximately 2 min to come ready. All CPs gets new IPs between 12:27 and 12:28;
- At 12:30 Edimax router was disconnected – it takes approximately 45 sec all CPs to show LAN Trouble;
- At 12:30 DLink router was connected – it takes approximately 30 sec all CPs to continue and 40sec to drop LAN Trouble. All CPs get new IPs at 12:42;
- DLink's LAN cable was disconnected for time of ½, ¼ and the time when DHCP lease expired. 4 of the CPs get IPs at 13:28 while other 4 – at 13:45;
- DLink's router was changed with Edimax at 13:50 – it takes 2-3 min all CPs to continue normal work;
- Edimax' LAN was disconnected for 6 minutes at 13:54 and 14:09 when DHCP lease events was expected;
- Edimax' LAN was in connected condition at 14:27 and 14:42 – all CPs gets new IPs as expected (4 of them at 14:27 and 4 others at 14:42);
- Edimax router was changed with DLink's at 14:58 – All 8 CPs get new IPs at 15:00;
- Test was finished at 15:15.

**Snapshot of all ECs CPU load for the test was shown on the picture below****The following standard conditions are used at test:**

- IIS was set to require client certificates from ECs;
- Elas was set to use 30 sec alive times;
- Edimax router was set to use L2TP (1392b) WAN settings;
- Edimax' DHCP server was set to offer 30 min lease time;
- DLink router was set to use static WAN settings;
- DLink's DHCP server was set to offer 60 min lease time;
- Both routers' DHCP servers use the same IP range;
- NistNet was set at 2/1,1,1 conditions;
- LogCollector was set as usual test case (5,4,3 min);
- WU access simulator was set to reach maximal CP task load;
- All CPs have 2 sensors generation events every 1 min;
- All CPs have 3 more PIR sensors.

**EC load parameters are the following (like 25-26.06.2008 test):**

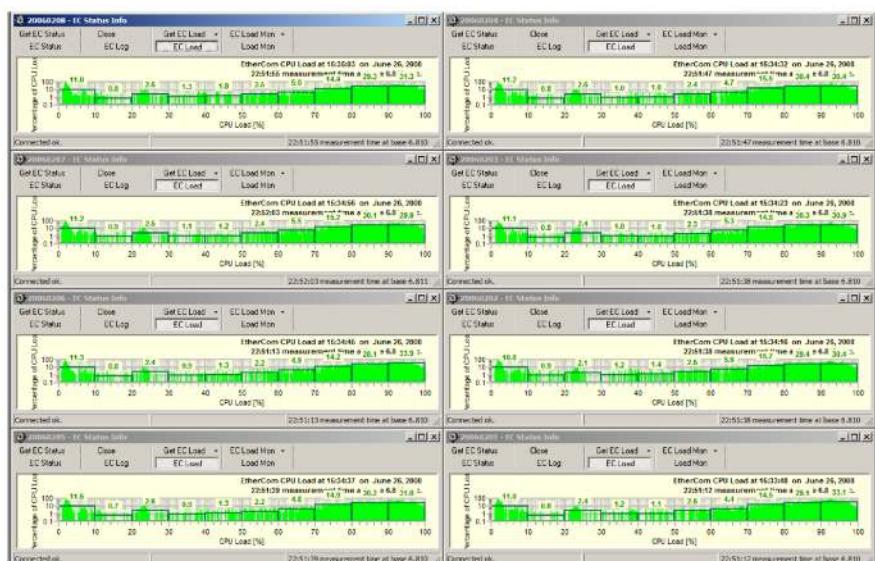
- EC CPU performance load – 81,5%;
- CP Event & Task Load – 104.0%;
- CP Work Load – 84.8%.

**Notes:**

- n.a.Factor and WU Errors was not monitored;
- CP/EC load parameters were not calculated;
- High resolution history and packed capturing is used as well.

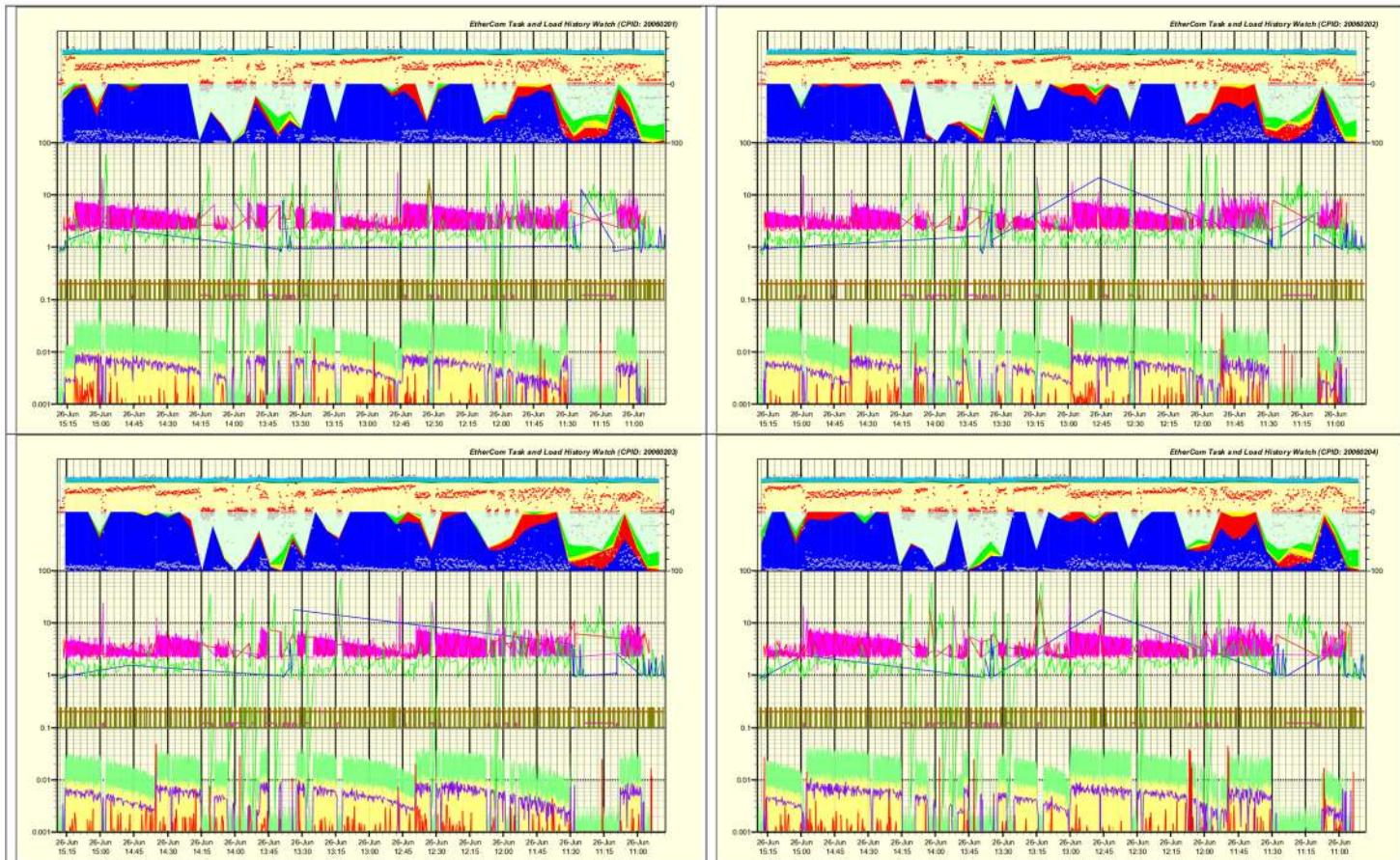
**Conclusion:**

- All ECs worked as expected without any bugs manifestation;
- EC firmware is quite responsive and adequate at all changes.



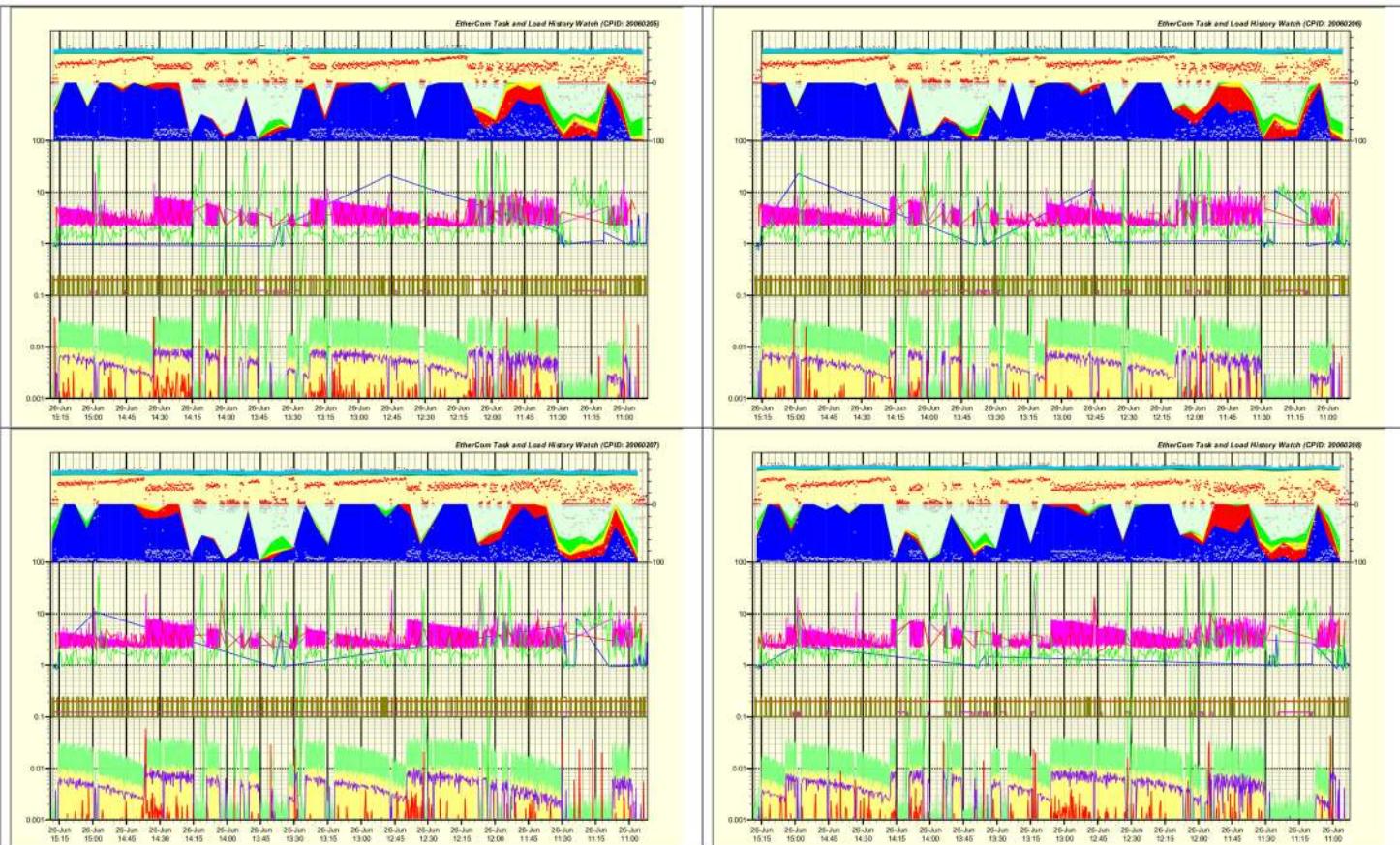
# Long Time Extremely High Load Tests of Broadband Firmware CP ver. 0.49 and EC ver. 1.08 (25.06-15.07.2008)

Snapshots of all EC History records for the whole test on 26.06.2008



# Long Time Extremely High Load Tests of Broadband Firmware CP ver. 0.49 and EC ver. 1.08 (25.06-15.07.2008)

Snapshots of all EC History records for the whole test on 26.06.2008 (continued)



**Test conditions (WU requests by testCPPProxy):**

- All CP/ECs are requested continuously and alternatively to perform SetCPState and GetCPLog with 0.5sec pause between. Periodically (when user access log records exceed 64) CP log is cleared.

**Test conditions (RP requests by LogCollector):**

- UploadCPLog: 3min;
- UploadECLog: 2min;
- UploadData: 1min.

**Test conditions (general):**

- Load assessment for 9 CP/ECs tested for more than 500 CP \* hours total;
- Elas is set (for CP 20060201 ... 20060204 only) up to not send events to Elpx/.../Sims;
- All ECs are with Release firmware build based on HyNetOS release ver. 2.4;
- 20060201, 20060202 and 20060206 (old EC hardware).

**Test conditions (EC settings):**

- All ECs are connected to ECMon for monitoring;
- All ECs were restarted (because of firmware update) before the test.

**Problems under current investigation (summary):**

- **CP/EC inaccessibility:** see table below

<b>CPID</b>	<b>EC restarts (takes 2-5min)</b>	<b>EC Task Loss (takes 10min)</b>	<b>CP Timeouts (takes ~3min)</b>	<b>Inaccessibility time (~min)</b>
20060201		4	14	82
20060202		5	12	86
20060203		3	5	45
20060204		3	9	57
20060205		3	10	60
20060206		3	14	72
20060207		3	9	57
20060208	1	1	7	34
20060209			4	12
<b>All CP/EC</b>	<b>1</b>	<b>25</b>	<b>84</b>	<b>505</b>
<b>Total [%]</b>	<b>0.01%</b>	<b>0.82%</b>	<b>0.83%</b>	<b>1.66%</b>

**Note:** CP/EC inaccessibility percentage calculation was based on total observation time 506.6 CP \* hours (for all panels under on-line monitoring).

**Tests details summary:**

- Test was started after 21:00 on 31.03.2005;
- Test was ended at ~9:00 on 03.04.2005;
- Mean Elas: CPU load was ~70%, Memory usage raised up to 2.3GB;
- Full test restart (without CP/ECs) was done 27 hours after the start;
- Off-line processing is made to summarize results;
- All values in this document have to be used only for investigation purposes and not referred to other (incl. normal work) conditions.

**Test conditions (CP settings):**

- All CPs are set with the same parameters (based on defaults);
- All CPs are set not to report via PSTN, no report cycles;
- All CPs have 2 detectors generating events automatically every 1min;
- All CPs were restarted (because of firmware update) before the test.

**Test conditions (Elas settings):**

- Alive cycle: 300sec (armed);
- Alive cycle: 600sec (disarmed);
- Service Providers were disabled for CP 20060201 ... 20060204;
- Service Providers were set for CP 20060205 ... 20060209.

**Other problems summary (including once described previously):****• Event Reporting**

- Elas say "**SPPXNotAvailable**" after 2:20 on 02.04.2006 for CP/EC 20060205 ... 20060208 (Elpx previously available);
- Delays in Event reporting chain (Elas/Elpx/.../Sims) could exceed 30sec forcing EC to timeout HTTP session every 30sec.

**• Task Performing**

- Elas has to send NoTask first after EC start/restart;
- Elas say "**ASCPLostConnection**" after daylight time change – it takes up to next CP/EC alive connection (from tests on 27-27.03).

**• CP/EC Communication**

- Internal CP Serial Bus is bandwidth overloaded and collisions reached high levels for long time intervals at Get/Upload Log, Download All parameters and at CP Image transfer to EC (at EC start-up and CP communication parameters changes);
- Incorrect CP parameters changes (causes CP loss) and EC performance degradation (causes EC loss) at Download All CP parameters (from tests on 28.02 and 27-28.03);
- High memory circulation in EC at GetCPLog after its clearing.

## Problems solved until now (thanks to EC monitoring technology):

### • CP/EC:

- Event report and RP/WU task concurrency broaden (up to highest level possible in current architecture and implementation);
- Expanding CP/EC reliability and stability making them operational for long time periods at maximal possible Event/Task intensities;
- Decreasing CP/EC inaccessibility and respective errors to lowest possible in current system architecture levels;
- Many bugs in CP firmware (including once coming from original Infinite code) caused restarts, memory faults, deadlocks etc.;
- Many bugs in EC firmware (including once coming from SND's HyNetOS) caused restarts, memory faults, deadlocks etc.;
- CP/EC interconnection issues and inter-device deadlocks.

### • Elas:

- CPWS – locking all event reporting chains;
- CPWS – RP/WU task queue blocking;
- RPWS/WUWS – task response loosing;
- WUWS – performance issue at CP log processing.

### • Elpx:

- Service malfunction at automatic pool maintenance;
- Unavailability at restarting with empty/full queue;

**Note:** Only major problems are listed above.

## Notes:

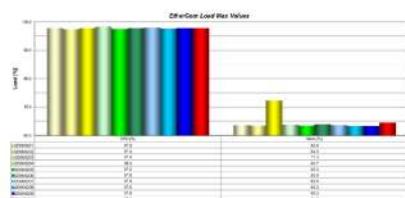
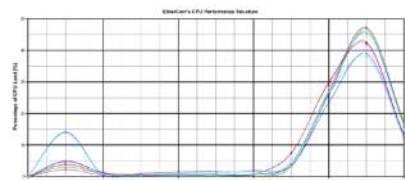
- Currently made and described tests and analyses were only targeted to CP/EC problems investigation/solving, stability/reliability increasing and finalizing CP/EC release versions.
- Problems described above could be observed rarely at extremely high load and whole system monitoring.
- There are number of potential problem sources (like complete Event reporting chain incl. PSTN backup) not investigated at all.
- Some of the problems on system level were only observed but not investigated deeper for finding out their sources and solutions.

## Conclusions:

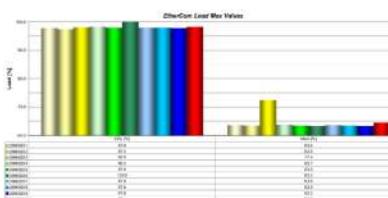
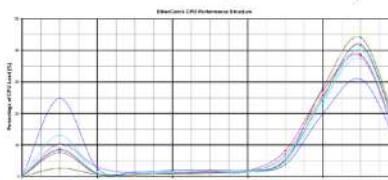
- ✓ All critical bugs in CP/EC firmware were fixed.
- ✓ CP/EC is function as close to requirements as possible.
- ✓ CP/EC firmware is proven to work in required environment.
- ✓ CP/EC is proven to work at peak load for long time periods.
- ✓ CP/EC firmware is ready to be released and used for production.
- ✓ As side results many problems on architectural and system level were found and some of them solved.

## EtherCom CPU and Memory Usage Observation

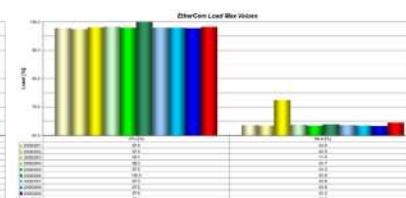
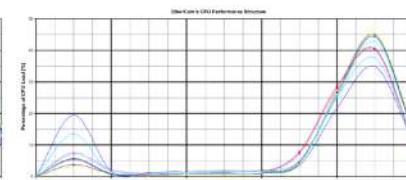
-27 hours after test start



~60 hours after test start (end of the test)



Result summarized for whole test



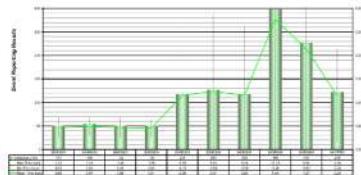
*Final Long Time Extremely High Load Tests of CP/EC firmware release versions CP100/EC100 (31.03-03.04.2006)*  
**EtherCom On-Line Statistics Results Processing**

**Task Intensities and Lengths Observation**

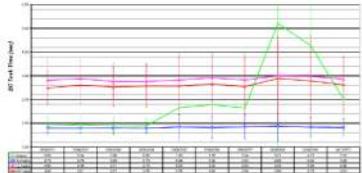
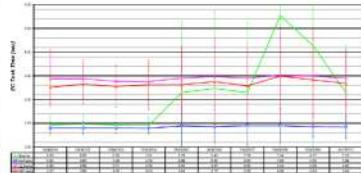
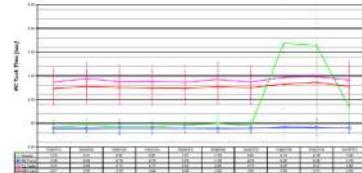
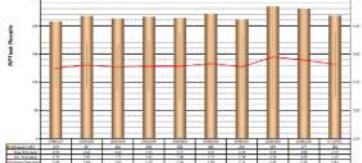
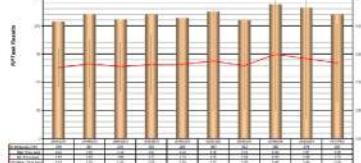
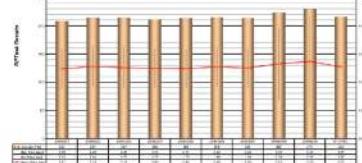
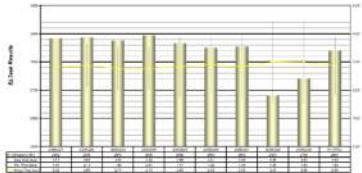
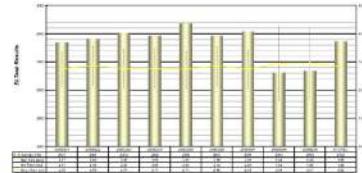
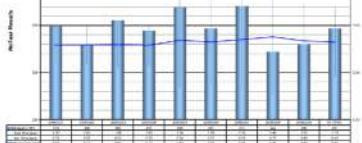
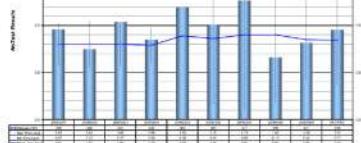
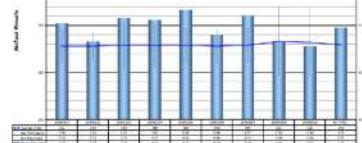
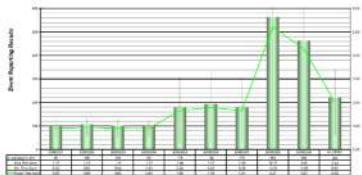
-27 hours after test start



~60 hours after test start (end of the test)



Result summarized for whole test

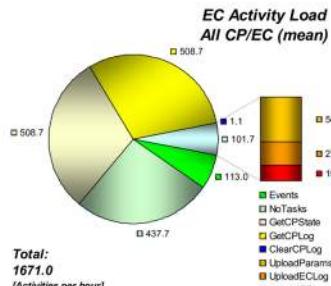


Min and Max values in above charts was calculated on standard deviation captured at on-line monitoring.

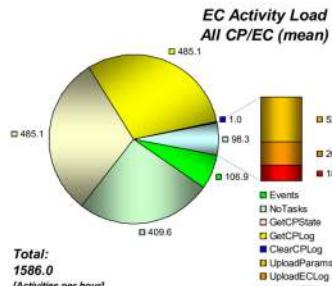
**Final Long Time Extremely High Load Tests of CP/EC firmware release versions CP100/EC100 (31.03-03.04.2006)**  
**EtherCom Off-Line Statistics Results Processing**

**EtherCom Load Assessment Snapshots**

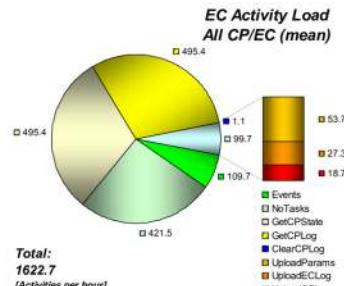
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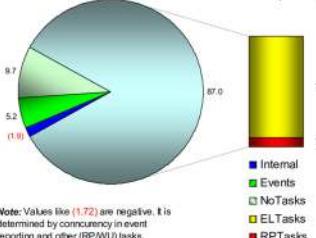
~60 hours after test start (end of the test)



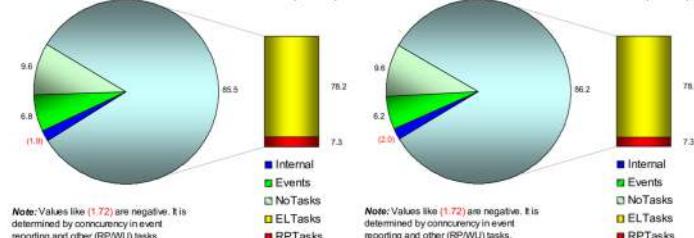
Result summarized for whole test



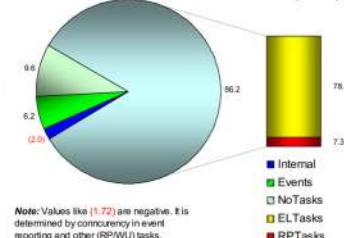
**EC Work Load  
All CP/EC (mean)**



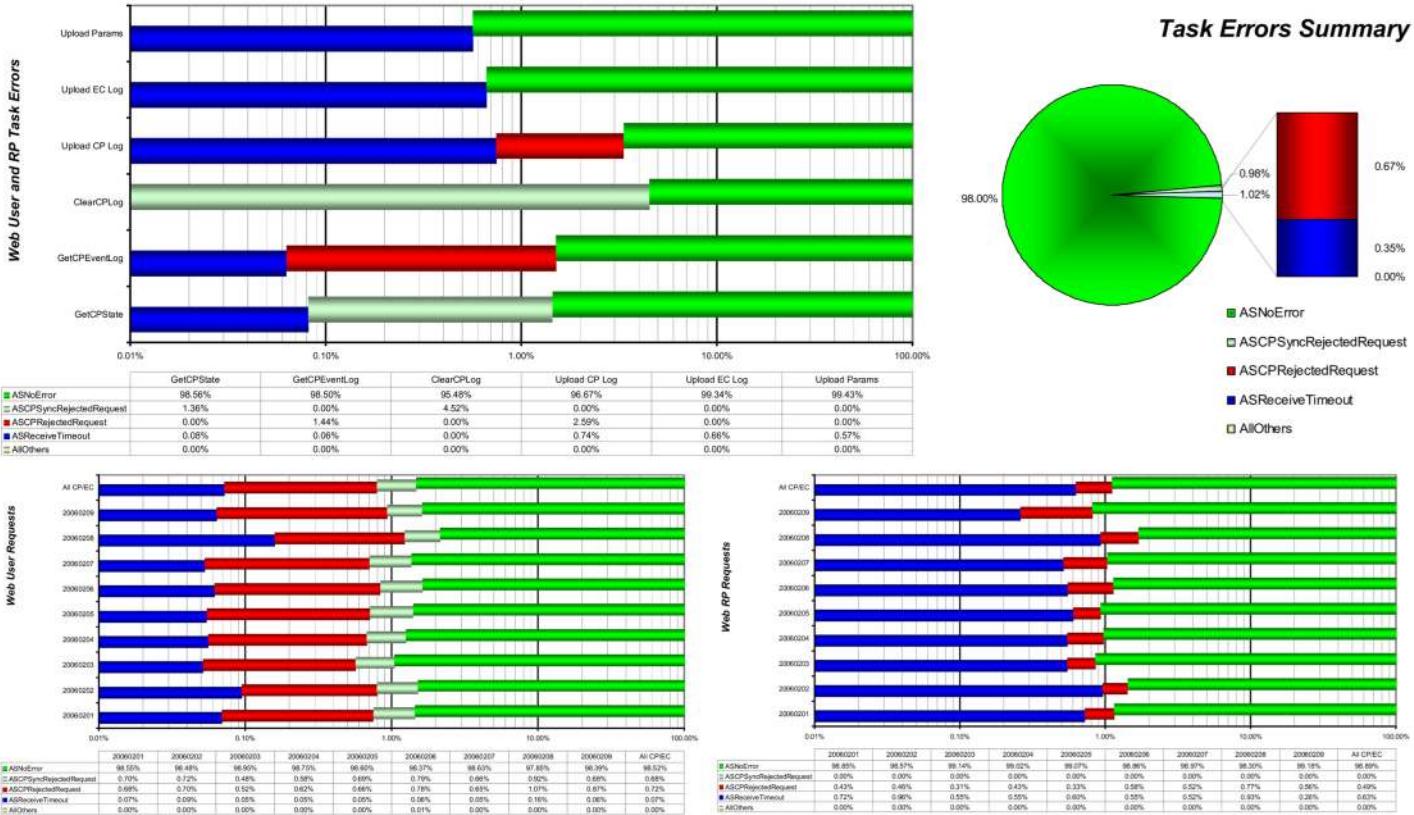
**EC Work Load  
All CP/EC (mean)**

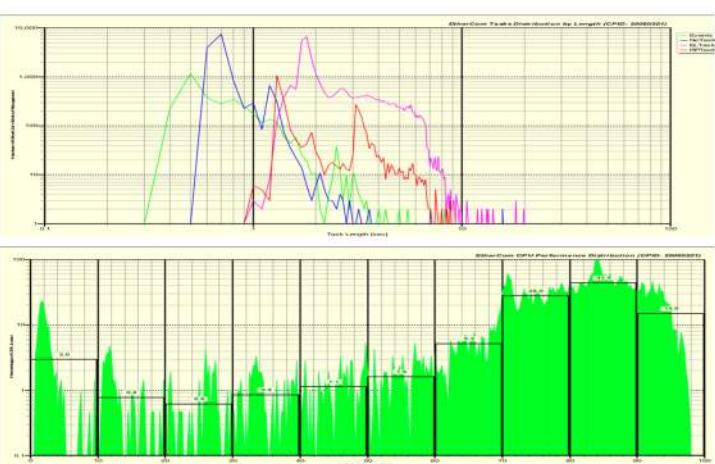
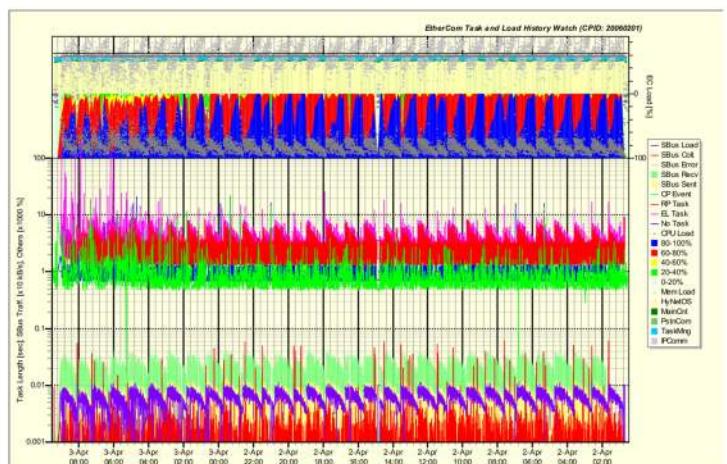
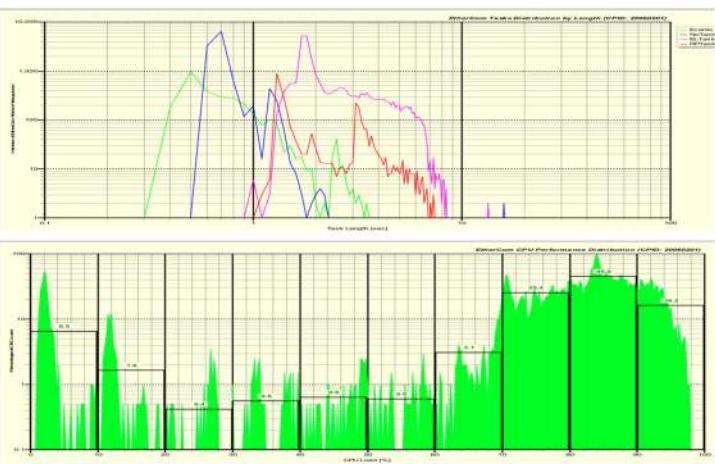
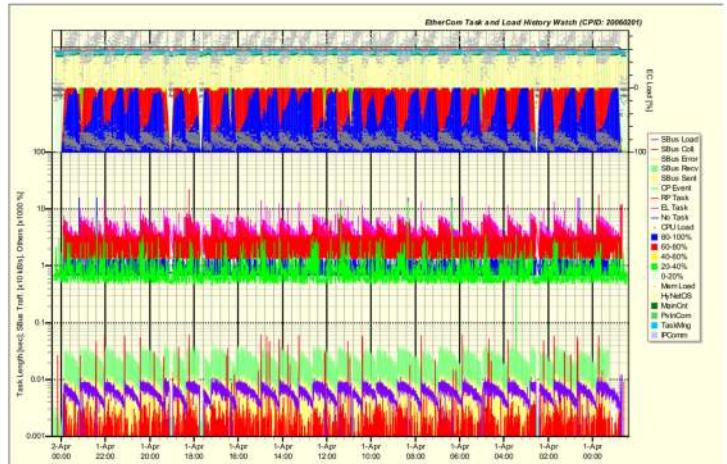


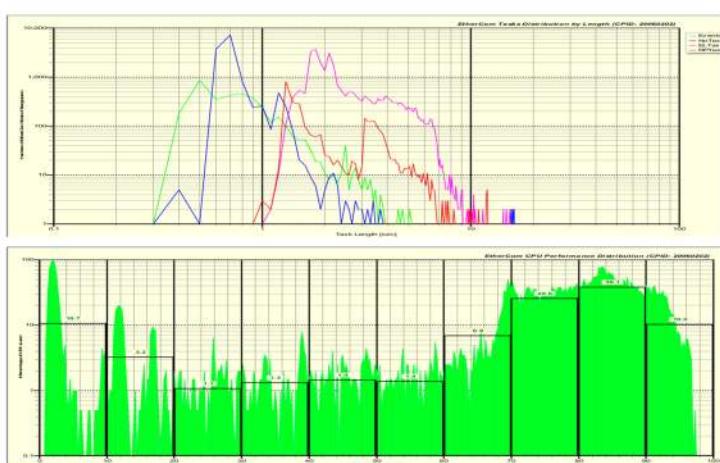
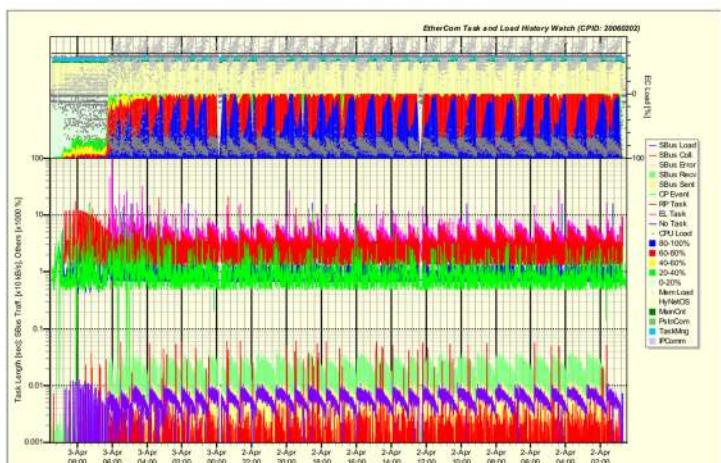
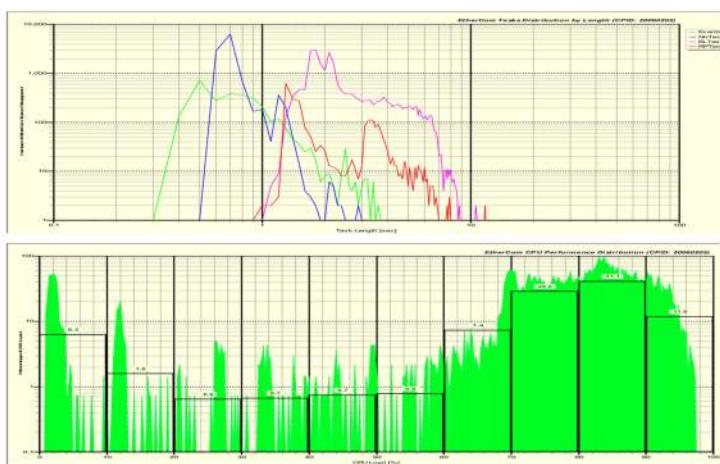
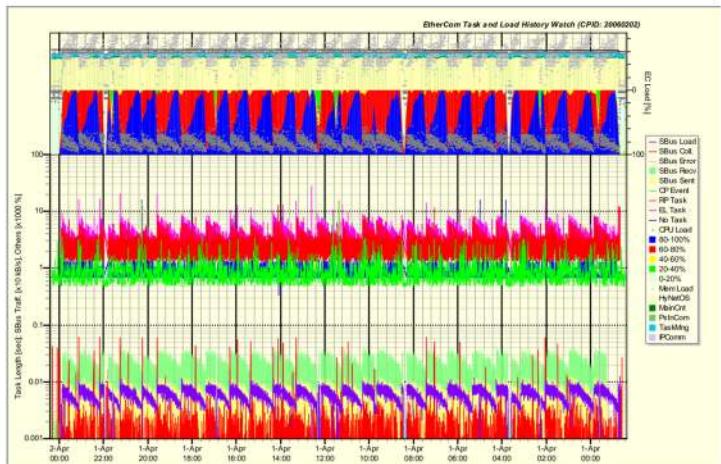
**EC Work Load  
All CP/EC (mean)**

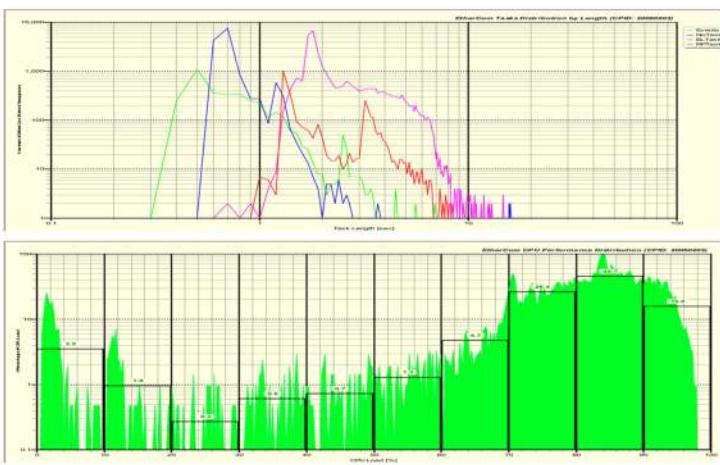
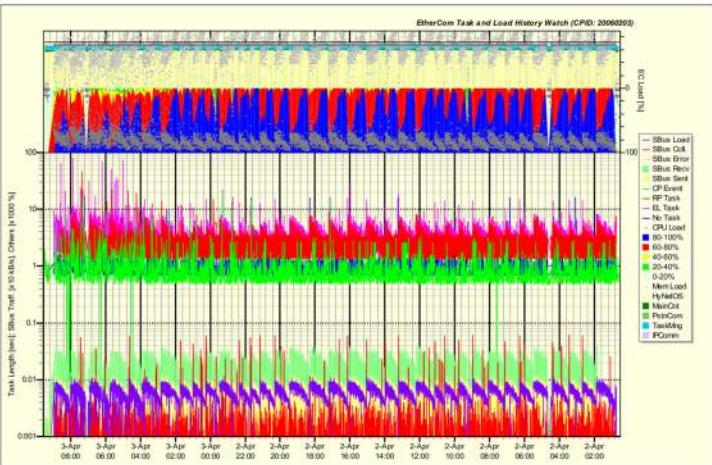
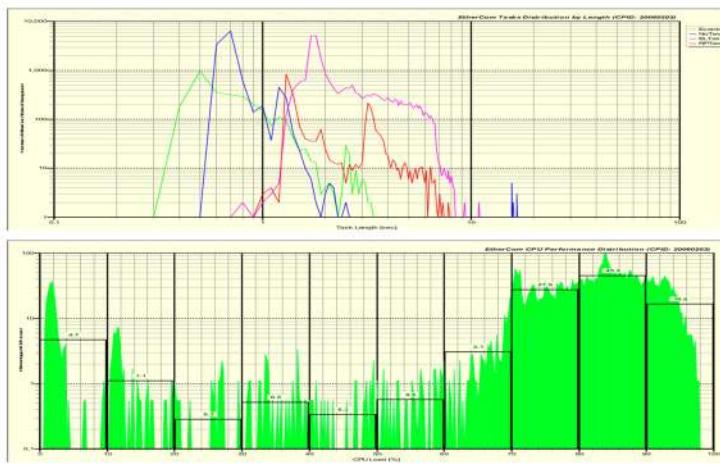
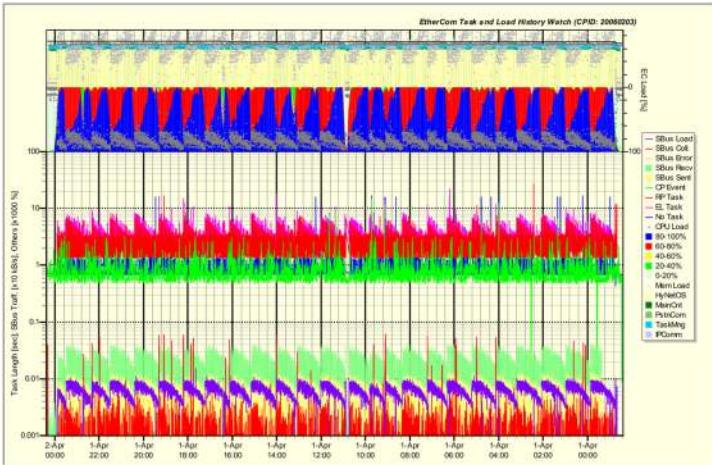


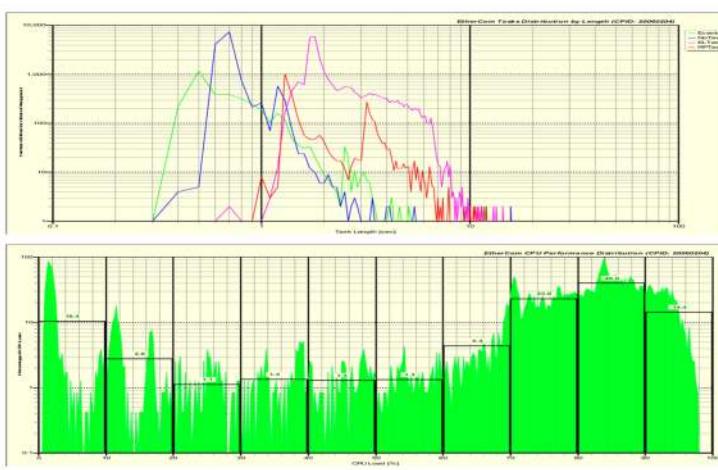
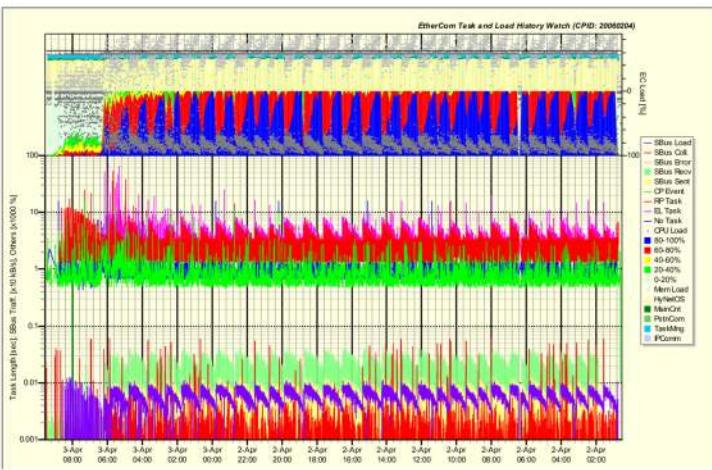
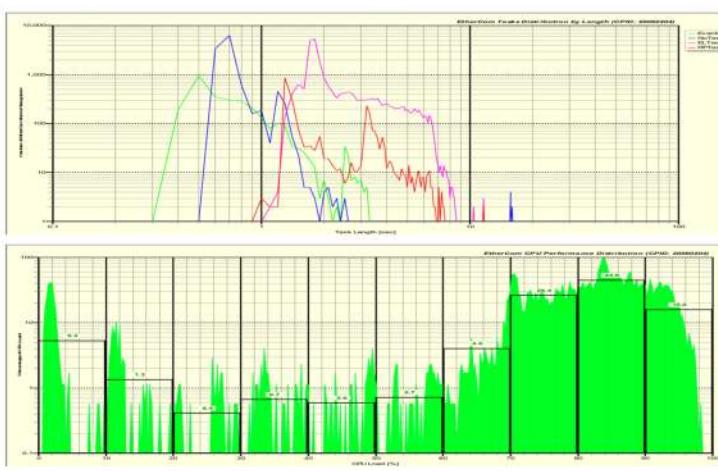
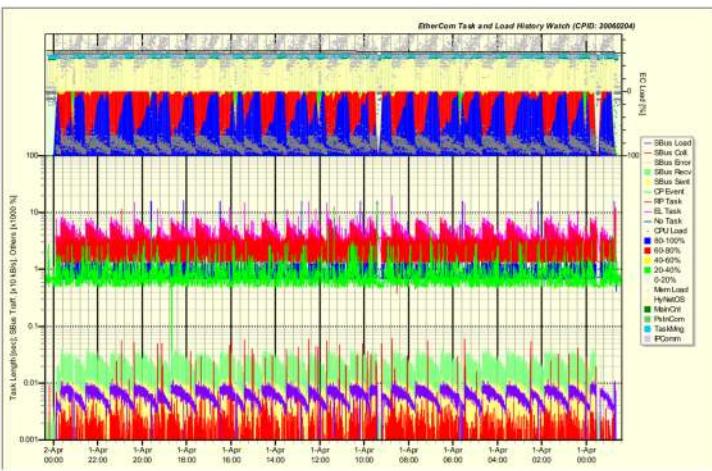
## Final Statistics Results

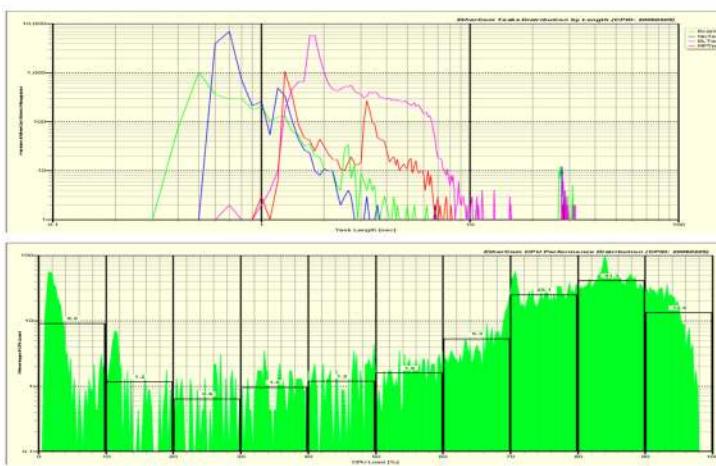
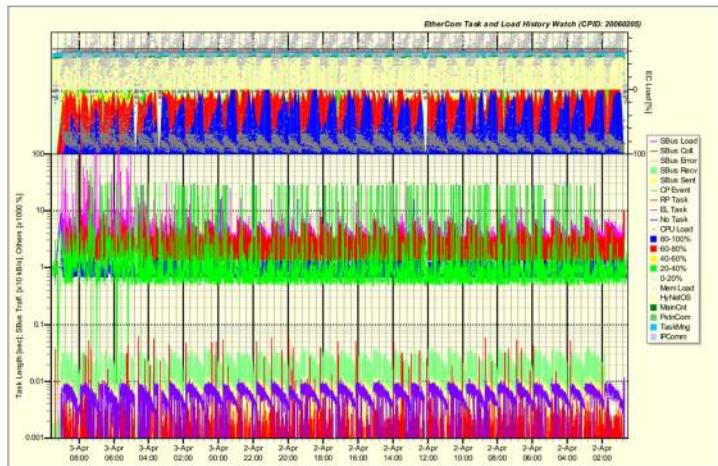
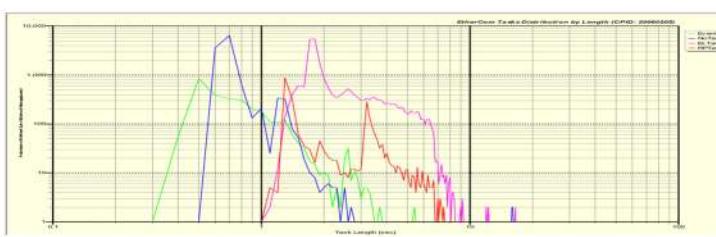
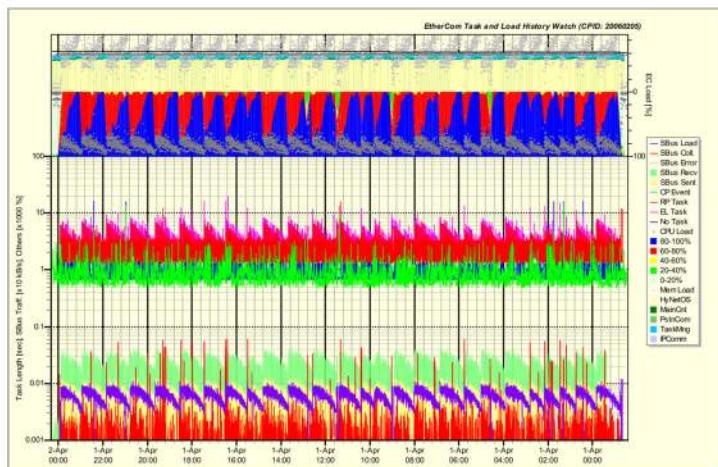


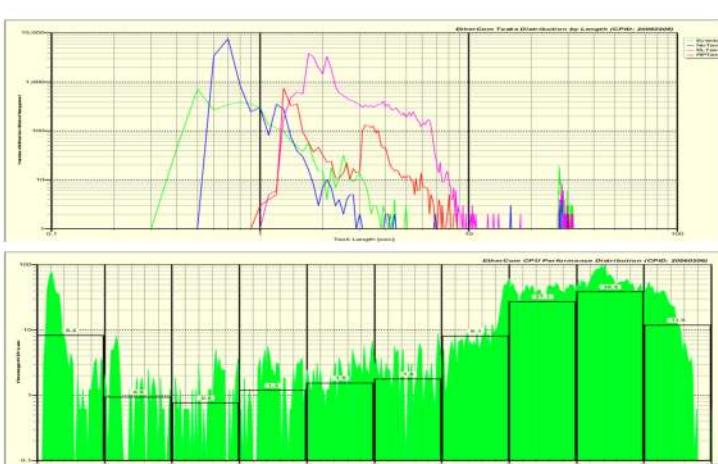
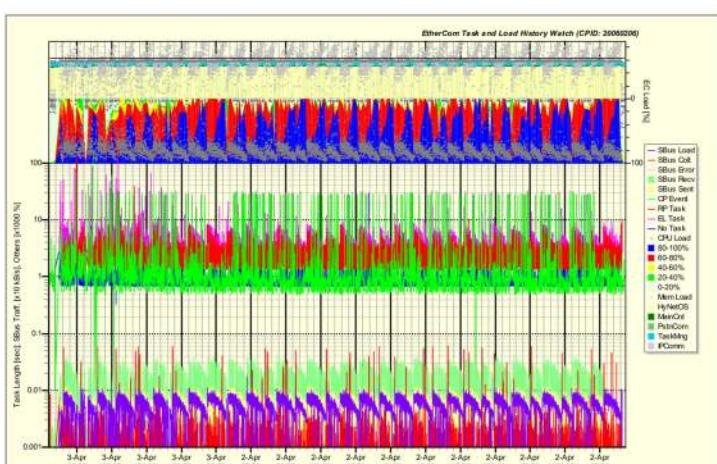
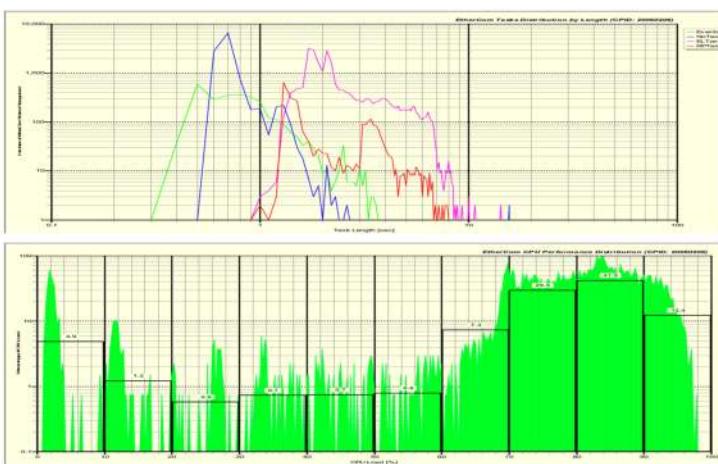
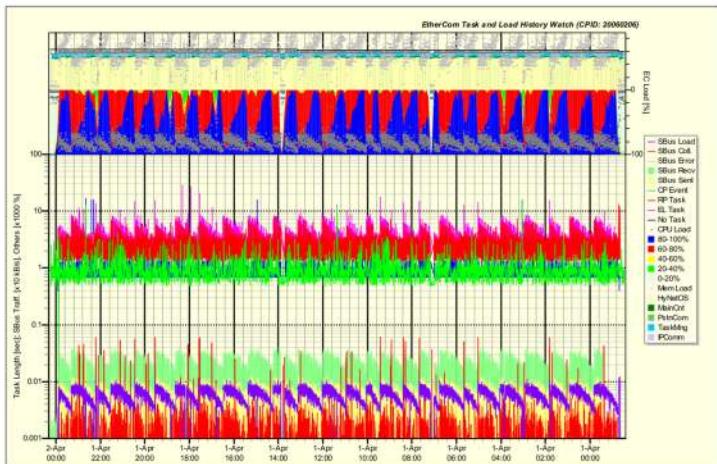
**EtherCom Task and Load History Observation**

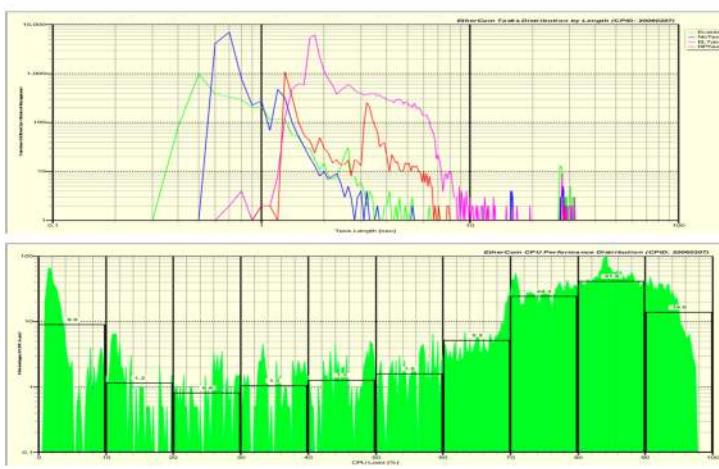
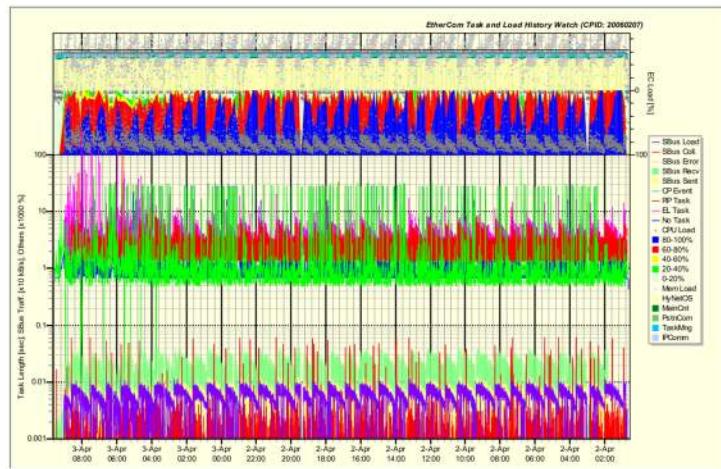
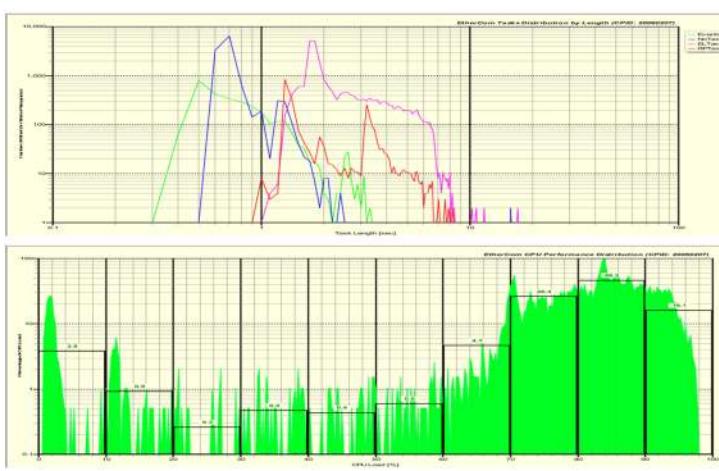
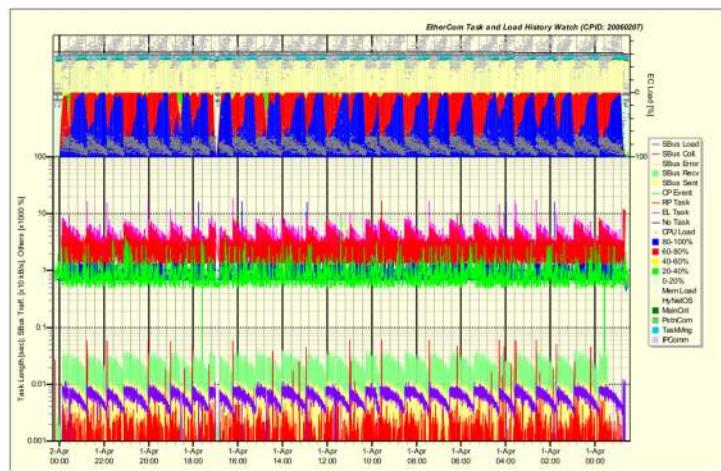






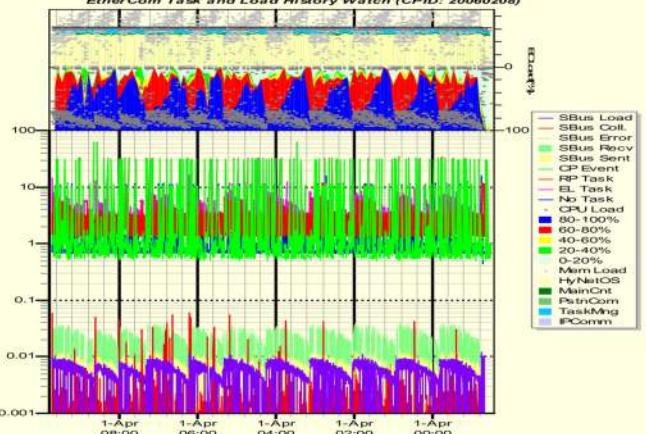




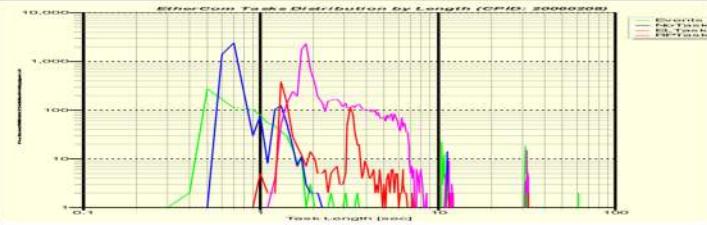


EtherCom Task and Load History Watch (CPID: 20060208)

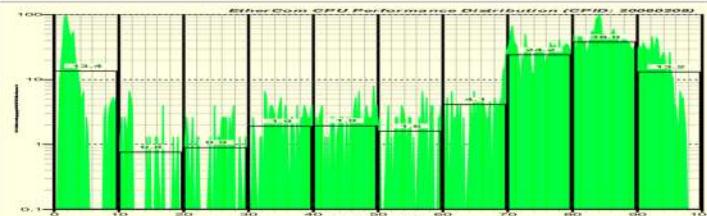
Task Length (sec) > Task & CPU Others (<10000 %)



EtherCom Tasks Distribution by Length (CPID: 20060208)

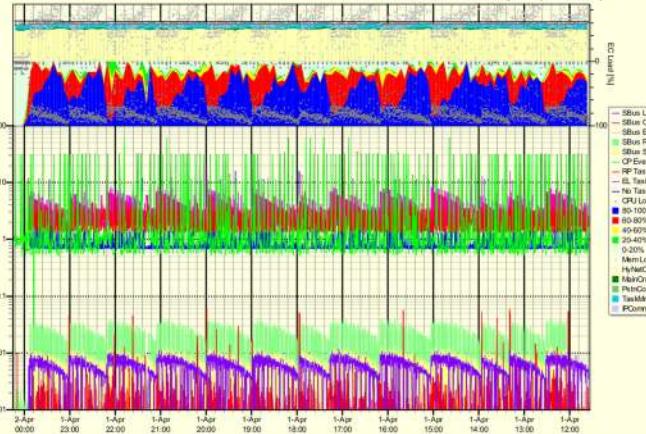


EtherCom CPU Performance Distribution (CPID: 20060208)



EtherCom Task and Load History Watch (CPID: 20060208)

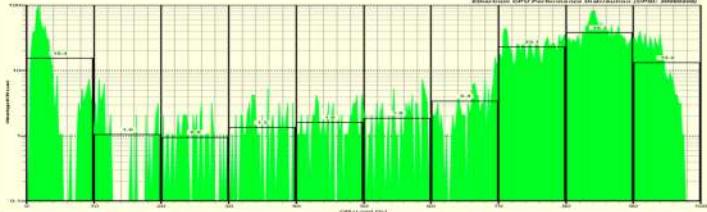
Task Length (sec) > Task & CPU Others (<10000 %)

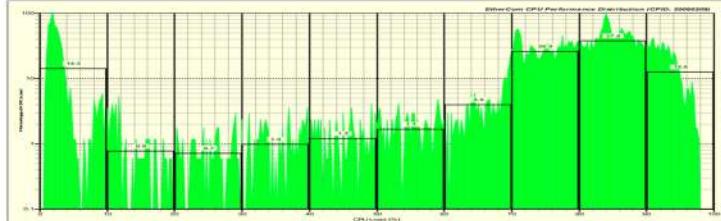
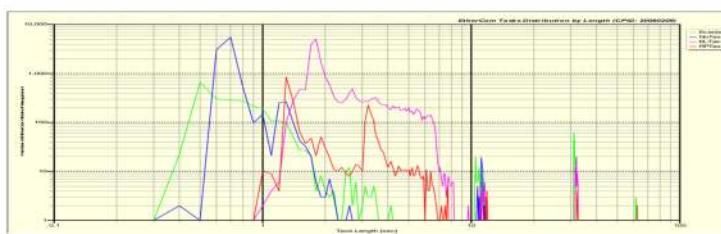
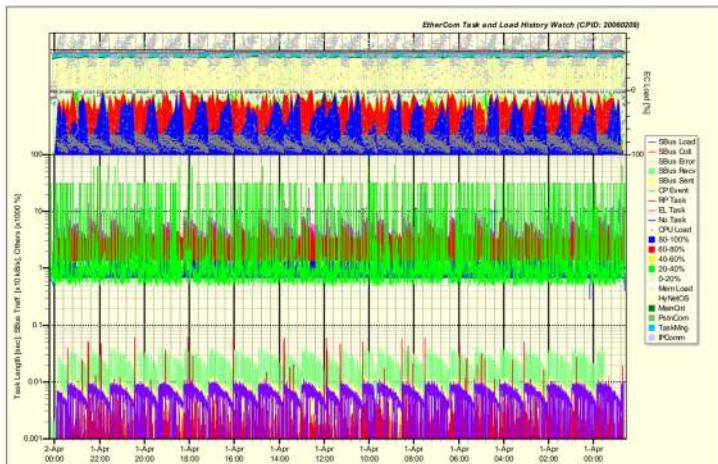
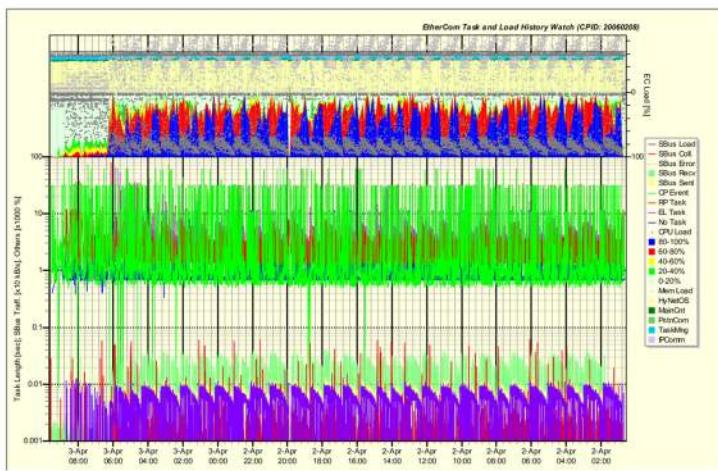


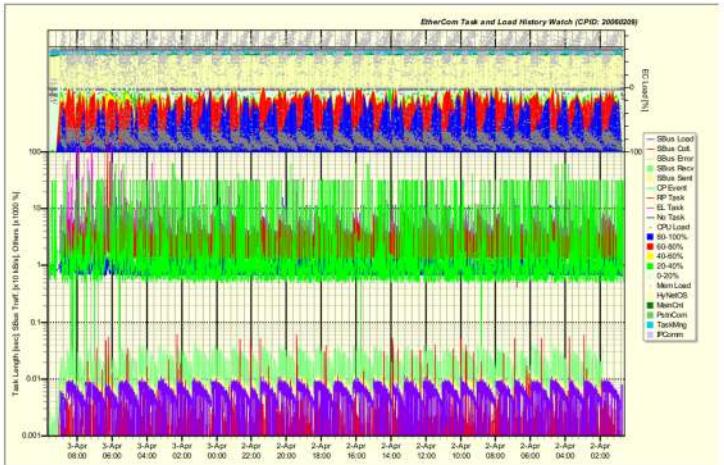
EtherCom Tasks Distribution by Length (CPID: 20060208)



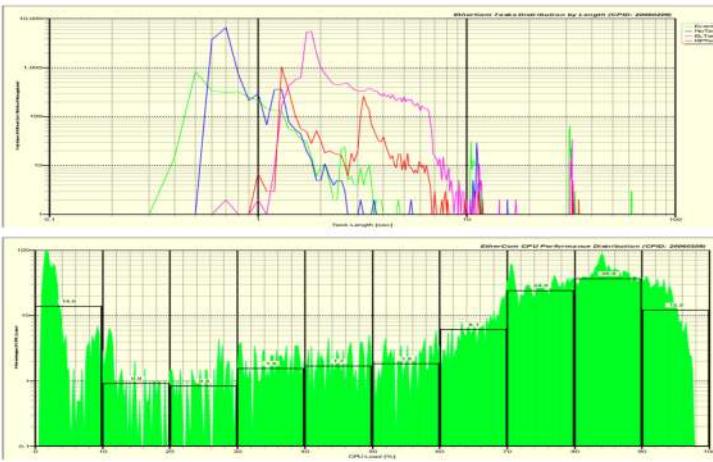
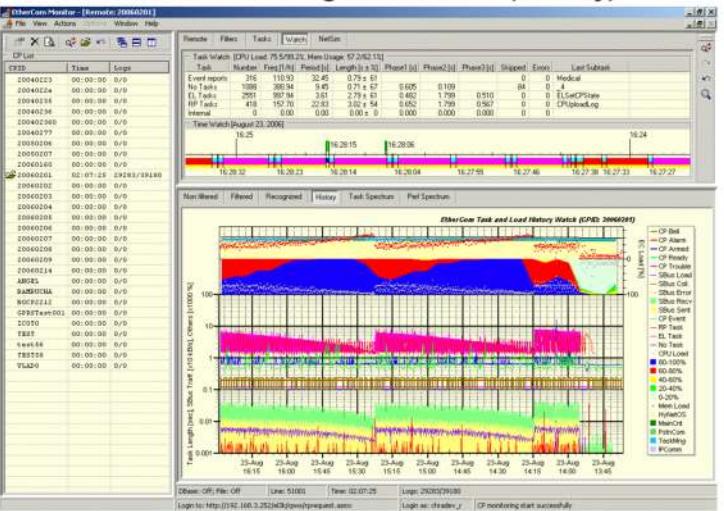
EtherCom CPU Performance Distribution (CPID: 20060208)



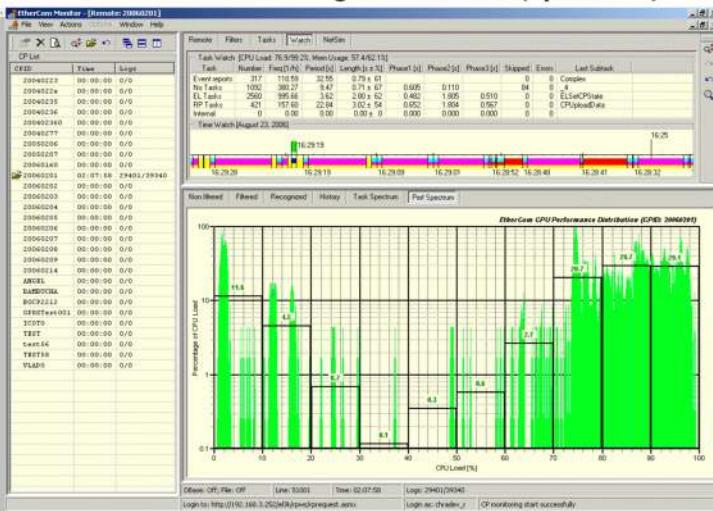




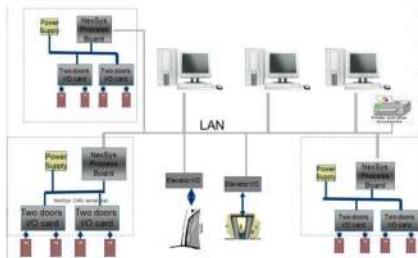
**Ethercom monitoring tool RCMon (history)**



**Ethercom monitoring tool RCMon (spectrum)**



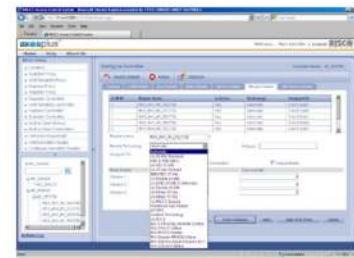
## RISCO AxesPlus Access Control System, EV1 RFID Reader and Test Suit for long term, high load functional testing



RISCO AxesPlus Architecture (3-rd party SW)



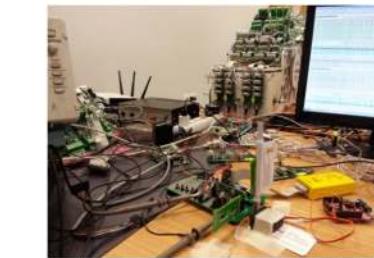
RISCO EV1 RFID Reader (FW development and testing)



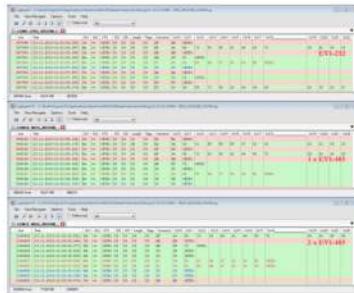
AxesPlus Web Interface (HW setup section)



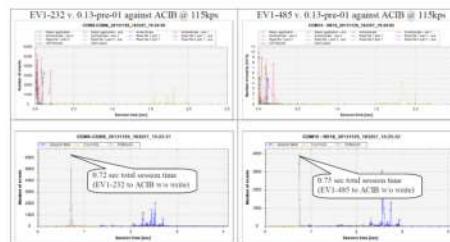
Test suit with controllable rotational speed, up to 16 EV1 Readers with RS232/RS485 interface, up to 16 RFID Desfire Cards, ACIO/HIO interface and ACCB control boards, AxesPlus Application and DB Servers on VMWare Workstation



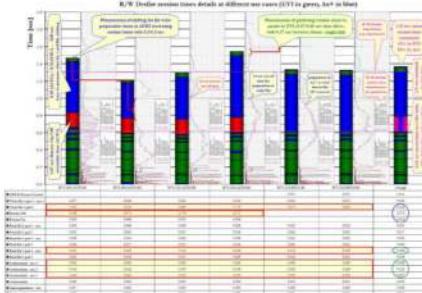
Capturing Application (via RS232/RS485 to USB adapters) written specially for testing purposes of EV1 Reader's FW



Other tools used to capture EV1 functionality



Performance tests on EV1 RS232/485 unified FW



Long term, high load functional tests on EV1 unified FW

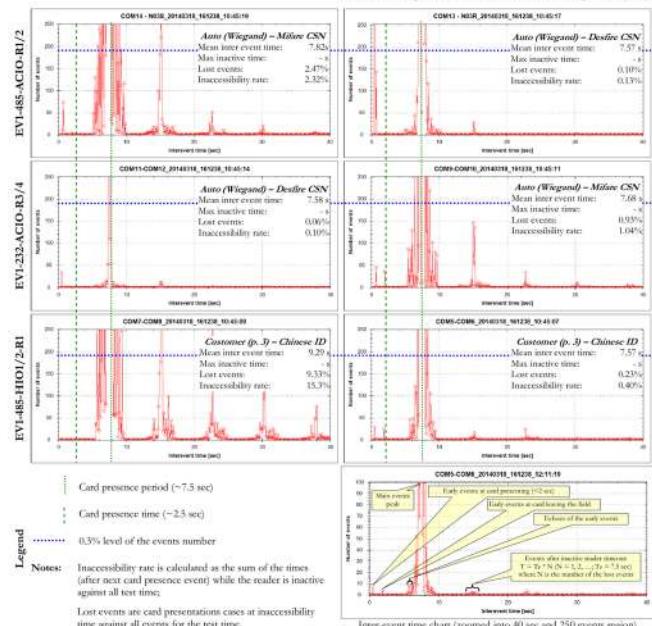
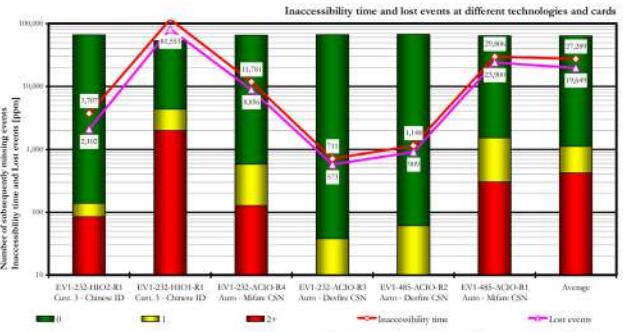
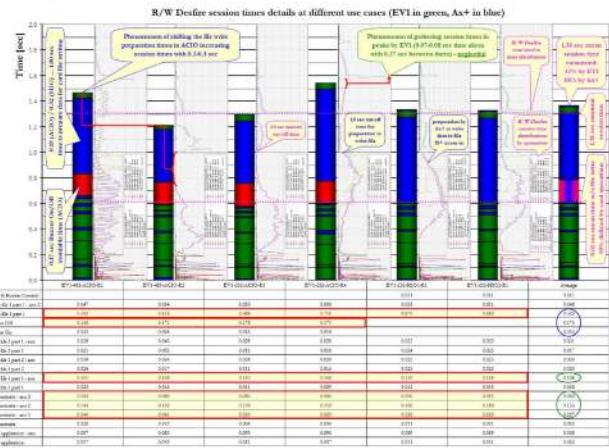
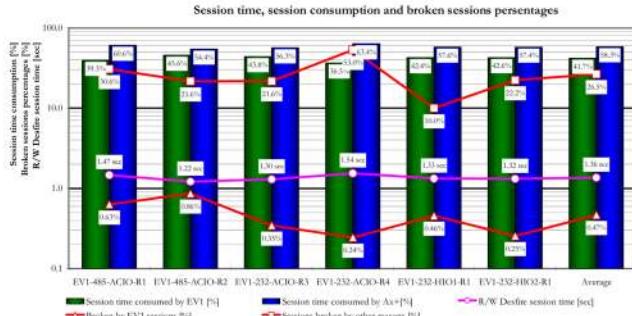
## EV1 unified FW ver. 0.13-RC2 – long term intensive in-system test results (2014-03-31)

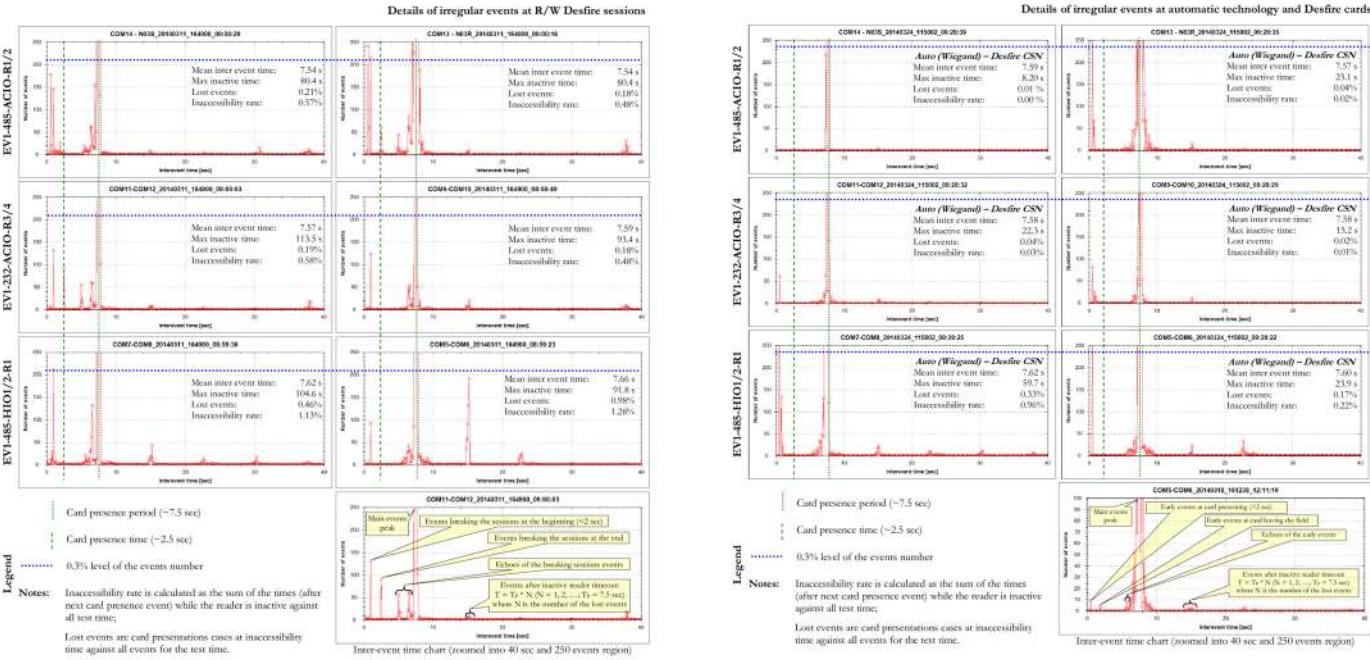
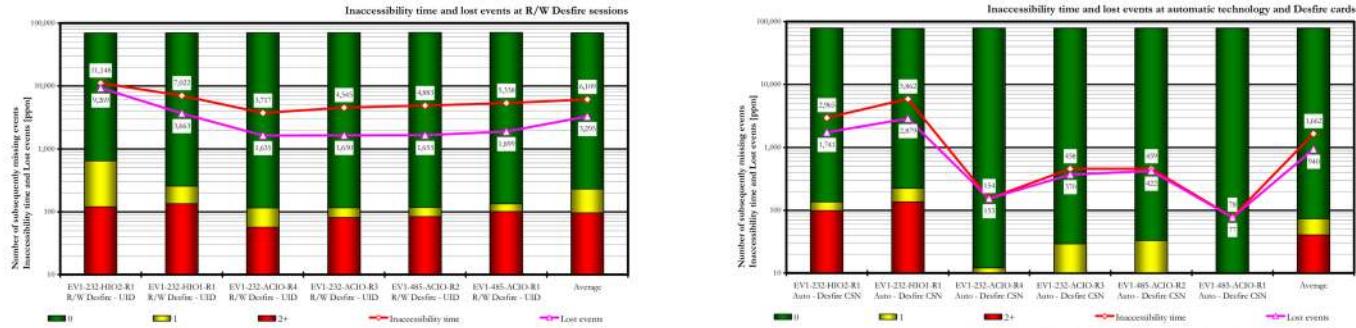
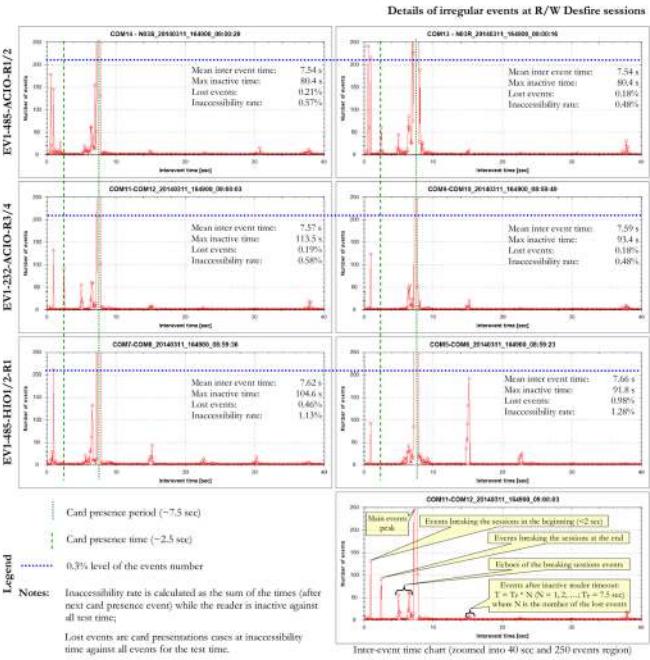
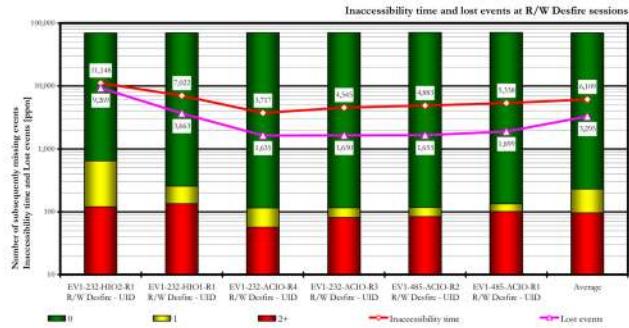
### Test conditions:

- 4 x EV1-232 and 2 x EV1-485 HW rev. C with unified FW ver. 0.13-RC2;
  - Ax+ (single server) ver. 2.0.7 with ACIB, ACIB and 2 x HIO (with EV1-232 at 57kbps);
  - All EV1 readers are set in factory default mode using Ax+/R/W RISCO Desfire® technology;
  - EV1 Reader Tester utility is used to capture and analyze reader behavior and test results.
- Notes:
- HW latency (RF off time of 0.045 sec mean, 0.09 sec max/min) will be added to the total session times below;
  - Items below marked in red have to be analyzed with care for potential problems and possible improvements.

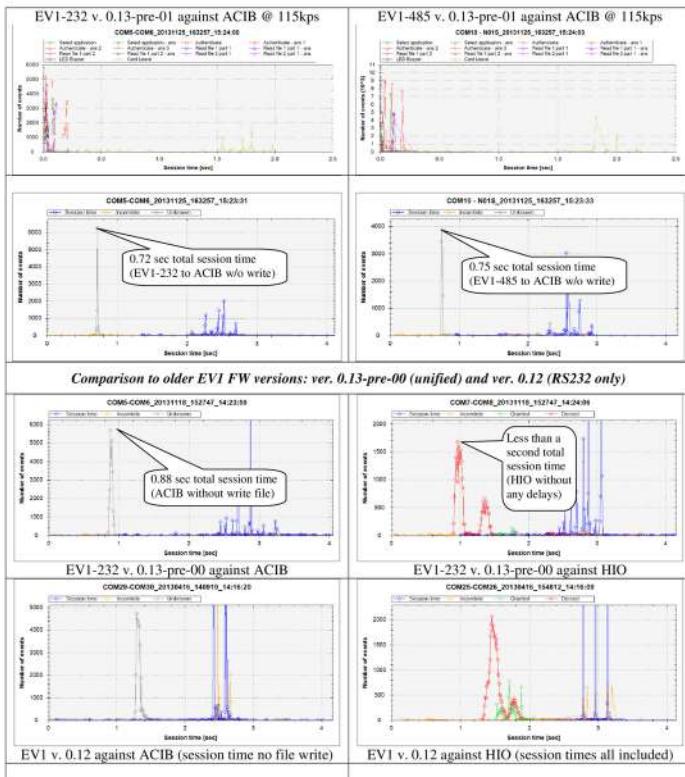
### Conclusions:

- There are no uncontrollable cases observed for more than 450h on 6 EV1 readers continuously tested in Ax+ system at 8 events/min loads;
- Inaccessibility rates and lost events in EV1 unified FW ver. 0.13 and their reasons are comparable with once observed at ver. 0.12 for EV1-232;
- The phenomenon of R/W Desfire session breaking by EV1 was not identified as reason but it was limited to 0.4% of sessions;
- Performance improvements (incl. HW latency limited by RF off time) do not influence EV1 efficiency (incl. thermal);
- 1.0 sec R/W Desfire session time with EV1 Reader is reachable after Ax+ optimization while 0.5 sec – is unfeasible;
- More tests could to be done for identifying the other reasons (some unknown) for breaking 26% of R/W Desfire sessions;
- No room for more improvements in current EV1 HW/FW framework.

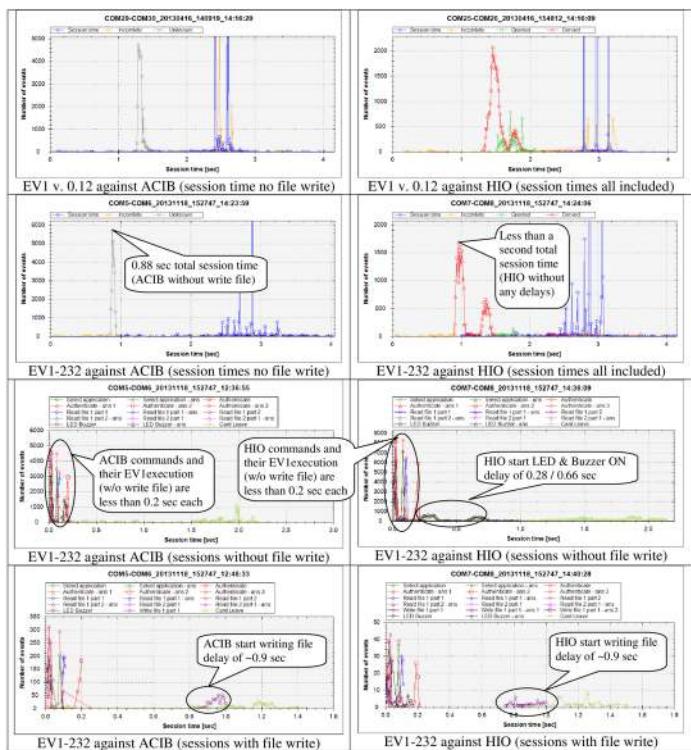




## Performance tests on EV1 unified FW ver. 0.13-pre-01 report (2013-11-26)



## Performance tests on EV1 unified FW ver. 0.13-pre-00 report (2013-11-19)



### Notes:

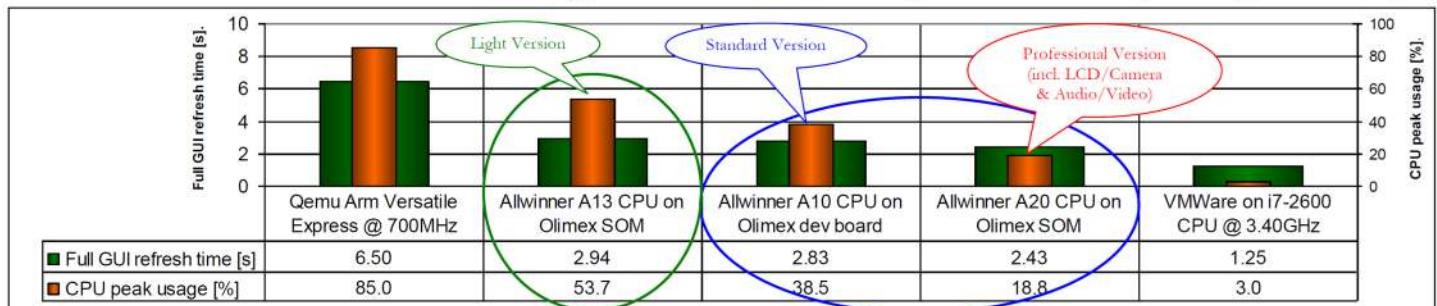
- Session times at ACIB case cannot be recognized because ACIB do not send LED ON/OFF command;
- Session times with file write at ACIB case cannot be recognized because command mismatch;
- There are some limitations of PC EV1 Reader Test utility but presented figures are representative;
- Detailed analyses are not presented in current report because of complexity.

### Conclusions:

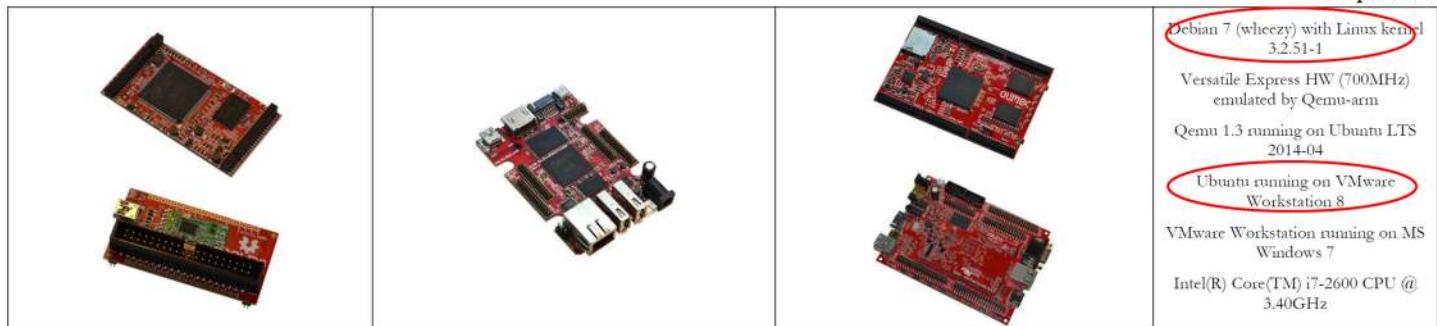
- Delay (~0.9 sec) in starting write file operation double card access time at both ACIB and HIO cases;
- There is an unaccountable delay (~0.6 sec) of LED and Buzzer ON command start at HIO case;
- There is significant performance increase in EV1 unified FW ver. 0.13-pre-00 correlated to ver. 0.12;
- Biggest EV1 reader delays at file opening and authentication are card related (visible in detailed analysis).

# Application service and Web client interface framework for RC & RR products (preliminary performance assessment on Allwinner SoC series)

## Application Service and Web Interface performance framework (preliminary performance figures)



Tested platforms



CPU Board A13-SOM-512 Size: 61 x 33 mm		Periphery Board A13-SOM-WIFI-4GB Size: 61 x 33 mm		CPU Board A10-OLinuino-LIME Size: 84 x 60 mm		USB 802.11n WiFi, 2.5" SATA HDD		CPU Board A20-SOM-4GB Size: 81 x 56 mm		Periphery Board A20-SOM-EVB Size: 135 x 103 mm						
CPU A13	512	RAM 4096	NAND 4096	uSD 100 MBit USB	LAN 100 Mbit	CPU A10	512	NAND 0	uSD 4096	LAN 100 Mbit native	CPU A20	1024	RAM 4096	uSD 4096	LAN Gigabit native	Periphery Board A20-SOM-EVB Size: 135 x 103 mm
More: RTL8188CU 802.11n						Note: Consumption is given in booting/booted pass according to <a href="http://haudreac.libre.ecp.fr/2014/06/rtl8188cu-vs-a10-olimex-powering-and-software-performance/">http://haudreac.libre.ecp.fr/2014/06/rtl8188cu-vs-a10-olimex-powering-and-software-performance/</a>										Versatile Express HW (700MHz) emulated by Qemu-arm
USB Host 0	1	USB OTG no	SATA yes	LCD no	HDMI no	Audio yes	Cam no	USB Host 2	USB OTG 1	SATA yes	LCD yes	HDMI yes	Audio yes	Cam 2 Mpix	Ubuntu running on VMWare Workstation 8	
root@a13-Olinuino-Micro-SOM:~# cat /proc/cpuinfo	Processor : ARMv7 Processor rev 2 (v7l)		Processor : ARMv7 Processor rev 2 (v7l)		Processor : ARMv7 Processor rev 4 (v7l)		Processor : ARMv7 Processor rev 4 (v7l)		Processor : ARMv7 Processor rev 0 (v7l)		Processor : ARMv7 Processor rev 0 (v7l)		Processor : ARMv7 Processor rev 0 (v7l)		root@debian-armhf:~# cat /proc/cpuinfo	
BogoMIPS : 1001.88	BogoMIPS : 1001.88		BogoMIPS : 2011.05		BogoMIPS : 2011.05		BogoMIPS : 2011.05		BogoMIPS : 680.75		BogoMIPS : 680.75		BogoMIPS : 680.75		root@debian-armhf:~# cat /proc/cpuinfo	
Features : swp half thumb fastmult vfp edsp neon vfpv3 tls	Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		Features : swp half thumb fastmult vfp edsp neon vfpv3 tls		root@debian-armhf:~# cat /proc/cpuinfo	
CPU implementer : 0x41	CPU implementer : 0x41		CPU implementer : 0x41		CPU implementer : 0x41		CPU implementer : 0x41		CPU implementer : 0x41		CPU implementer : 0x41		CPU implementer : 0x41		root@debian-armhf:~# cat /proc/cpuinfo	
CPU architecture : 7	CPU architecture : 7		CPU architecture : 7		CPU architecture : 7		CPU architecture : 7		CPU architecture : 7		CPU architecture : 7		CPU architecture : 7		root@debian-armhf:~# cat /proc/cpuinfo	
CPU variant : 0x5	CPU variant : 0x5		CPU variant : 0x5		CPU variant : 0x5		CPU variant : 0x5		CPU variant : 0x5		CPU variant : 0x5		CPU variant : 0x5		root@debian-armhf:~# cat /proc/cpuinfo	

```
CPU variant : 0x3
CPU part : 0xc08
CPU revision : 2
Hardware : sun5i
Revision : 0000
Serial : 0000000000000000
```

```
root@a13-OLinuXino-Micro-SOM:~# uname -a
Linux a13-OLinuXino-Micro-SOM 3.4.90+ #11 PREEMPT
Thu Jun 5 16:40:24 EEST 2014 armv7l GNU/Linux
```

```
root@a13-OLinuXino-Micro-SOM:~# cat /etc/os-release
PRETTY_NAME="Debian GNU/Linux 7 (wheezy)" ...
```

```
root@a13-OLinuXino-Micro-SOM:~# cat /proc/meminfo
MemTotal:      395388 kB
MemFree:       74096 kB
Buffers:        9920 kB
Cached:       138804 kB
SwapCached:      0 kB
SwapCached:      0 kB
Active:        219780 kB
Inactive:      99028 kB
Active(anon): 131432 kB
Inactive(anon): 120 kB
Active(file):   88348 kB
Inactive(file): 98908 kB ...
```

```
CPU part : 0xc08
CPU revision : 2
Hardware : sun4i
Revision : 0000
Serial : 0000000000000000
```

```
root@a10Lime:~# uname -a
Linux a10Lime 3.4.90+ #3 PREEMPT Tue Jun 10 09:17:04 EEST
2014 armv7l GNU/Linux
```

```
root@a10Lime:~# cat /etc/os-release
PRETTY_NAME="Debian GNU/Linux 7 (wheezy)" ...
```

```
root@a10Lime:~# cat /proc/meminfo
MemTotal:      378392 kB
MemFree:       36480 kB
Buffers:        2640 kB
Cached:       184840 kB
SwapCached:      0 kB
Active:        202340 kB
Inactive:     103532 kB
Active(anon): 157320 kB
Inactive(anon): 2380 kB
Active(file):  45020 kB
Inactive(file): 101152 kB ...
```

```
vfpv4 idiva idrvt
CPU implementer : 0x41
CPU architecture: 7
CPU variant : 0x0
CPU part : 0xc07
CPU revision : 4
Hardware : sun7i
Revision : 0000
Serial : 0000000000000000
```

```
root@a20-Lime2-SOM:~# uname -a
Linux a20-Lime2-SOM 3.4.79+ #8 SMP PREEMPT Fri May 9
11:13:14 EEST 2014 armv7l GNU/Linux
```

```
root@a20-Lime2-SOM:~# cat /etc/os-release
PRETTY_NAME="Debian GNU/Linux 7 (wheezy)" ...
root@a20-Lime2-SOM:~# cat /proc/meminfo
MemTotal:      895876 kB
MemFree:       620036 kB
Buffers:        9464 kB
Cached:       55888 kB
SwapCached:      0 kB
Active:        143036 kB
Inactive:     170144 kB
SwapCached:      0 kB
Active:        85532 kB
Inactive:     103368 kB
Active(anon): 92 kB
Inactive(anon): 66776 kB
Active(file): 85440 kB ...
```

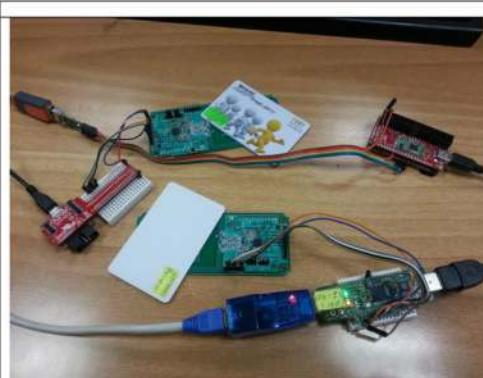
```
CPU architecture: 7
CPU variant : 0x0
CPU part : 0xc09
CPU revision : 0
Hardware : ARM-Versatile Express
Revision : 0000
Serial : 0000000000000000
```

```
root@debian-armhf:~# uname -a
Linux debian-armhf 3.2.51-1 armv7l GNU/Linux
```

```
root@debian-armhf:~# cat /etc/os-release
PRETTY_NAME="Debian GNU/Linux 7 (wheezy)" ...
```

```
root@debian-armhf:~# cat /proc/meminfo
MemTotal:      515404 kB
MemFree:       377388 kB
Buffers:        9564 kB
Cached:       55888 kB
SwapCached:      0 kB
Active:        79088 kB
Inactive:     46604 kB
Active(anon): 60280 kB
Inactive(anon): 112 kB
Active(file): 18808 kB
Inactive(file): 46492 kB ...
```

## Preliminary tests with PN532 board



PN532 board – SPI – atmega32u4 – USB (CDC) – PC Terminal (Serial)

```
Hello!
Found chip PN532
Firmware ver. 1.6
Waiting for an ISO14443A Card ...
Found an ISO14443A card
UID Length: 7 bytes
UID Value: 0x04 0x1C 0x65 0xD2 0xEA 0x22 0x80
```

```
Seems to be a Mifare Ultralight tag (7 byte UID)
Reading page 4
1C CE 00 AA ???
```

```
Found an ISO14443A card
UID Length: 4 bytes
UID Value: 0xD6 0x8A 0x75 0xC1
```

```
Seems to be a Mifare Classic card (4 byte UID)
Trying to read 16 sectors:
sector 0: D6 8A 75 C1 E8 18 02 00 8F 23 25 1A 01 11 04 00 00 adafruit.com...
sector 1: 61 64 61 66 72 75 69 74 2E 63 6F 6D 00 00 00 adafruit.com...
sector 2: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
sector E: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
15 sectors were read successfully!
```

PN532 board – serial – A13-SOM – LAN – PC Terminal (SSH)

```
Linux a13-OLinuXino-Micro-SOM 3.4.90+ #11 PREEMPT Thu Jun 5 16:40:24 EEST 2014 armv7l
Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY; to the extent
```

```
root@a13-OLinuXino-Micro-SOM:~# nfc-list
nfc-list uses libnfc 1.7.0
NFC device: pn532_uart: /dev/ttyUSB0 opened
```

```
root@a13-OLinuXino-Micro-SOM:~# nfc-poll
nfc-poll uses libnfc 1.7.0
NFC reader: pn532_uart: /dev/ttyUSB0 opened
NFC device will poll during 30000 ms (20 pollings of 300 ms for 5 modulations)
ISO/IEC 14443A (106 kbps) target:
```

```
ATQA (SENS_RES): 03 44
UID (NFCID1): 04 34 86 5a 47 21 80
SAK (SEL_RES): 20
ATS: 75 77 81 02 80
```

```
root@a13-OLinuXino-Micro-SOM:~# nfc-poll
NFC reader: pn532_uart: /dev/ttyUSB0 opened
NFC device will poll during 30000 ms (20 pollings of 300 ms for 5 modulations)
ISO/IEC 14443A (106 kbps) target:
```

```
ATQA (SENS_RES): 03 44
UID (NFCID1): 8a 75 c1
SAK (SEL_RES): 18
```

# Application's Web Interface and performance measuring staff snapshot

The image displays a 4x3 grid of screenshots illustrating the integration of a web application's user interface with performance monitoring tools.

**Left Column (Web Application Screenshots):**

- Row 1:** Shows the main company search interface with a search bar and results table.
- Row 2:** Shows a detailed view of a company record, including tabs for Company, Details, and Network.
- Row 3:** Shows another company search interface with a different set of results.
- Row 4:** Shows a third company search interface with a different set of results.

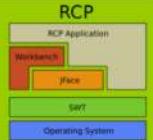
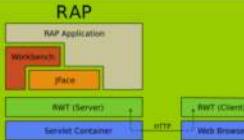
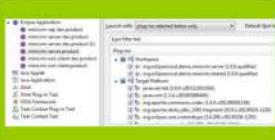
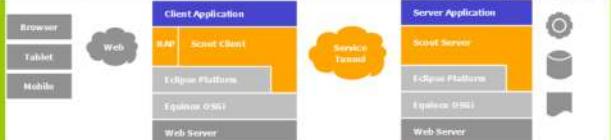
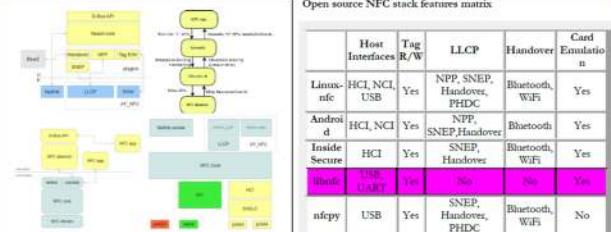
**Middle Column (Performance Monitoring - Network Tab):**

- Row 1:** Network traffic for a session starting at 2023-01-10T10:00:00Z, showing requests and responses.
- Row 2:** Network traffic for a session starting at 2023-01-10T11:00:00Z.
- Row 3:** Network traffic for a session starting at 2023-01-10T12:00:00Z.
- Row 4:** Network traffic for a session starting at 2023-01-10T13:00:00Z.

**Right Column (Performance Monitoring - CPU Usage):**

- Row 1:** CPU usage for a session starting at 2023-01-10T10:00:00Z, showing Thread Utilization and CPU Load.
- Row 2:** CPU usage for a session starting at 2023-01-10T11:00:00Z.
- Row 3:** CPU usage for a session starting at 2023-01-10T12:00:00Z.
- Row 4:** CPU usage for a session starting at 2023-01-10T13:00:00Z.

## Application service, Web clients interface and NFC framework (preliminary components overview)

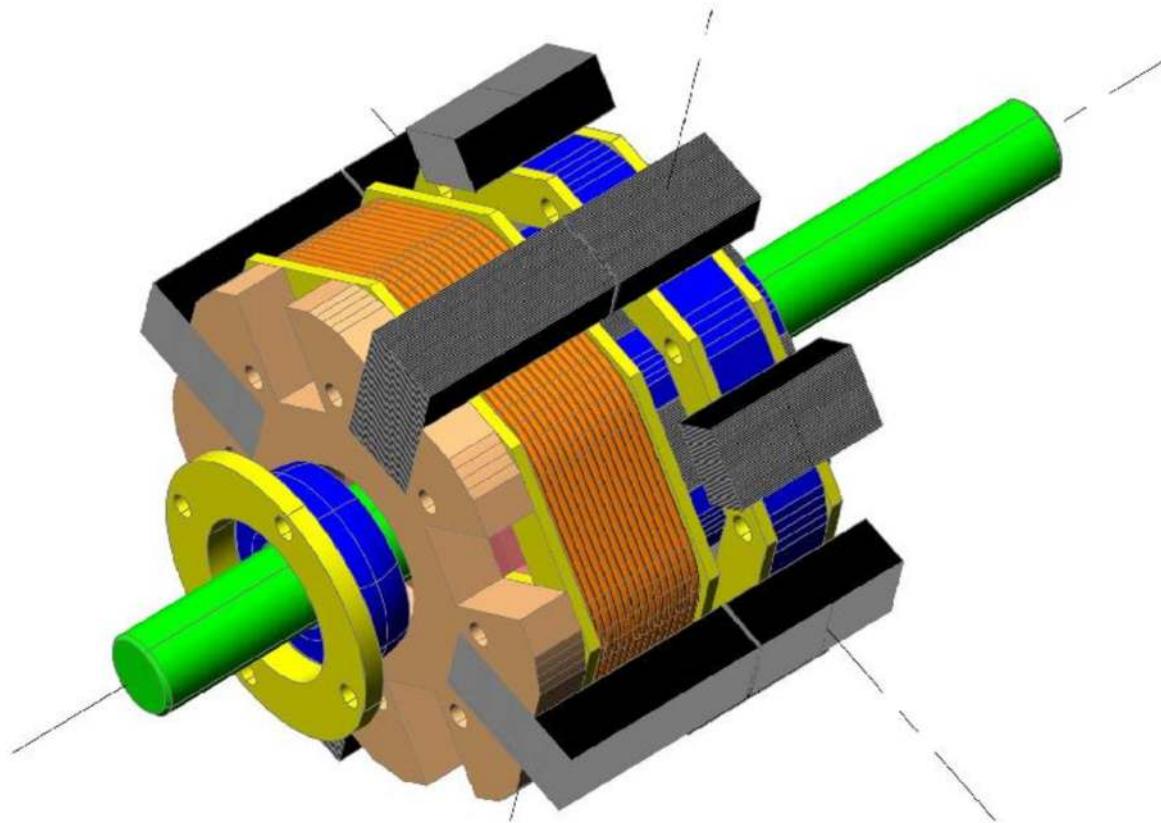
				
<b>RCP</b> 	<b>RAP</b> 	<b>Eclipse Application</b> 		
				
<b>Application Service</b> Eclipse scout framework for service oriented business applications Java, OSGI, Eclipse, Tomcat, Derby etc. staff Debian/Ubuntu/Yocto distribution/build	<b>Unified Web, Desktop, Mobile clients</b> Linux X without window manager	<b>lightweight webkit browser</b> Linux X without window manager	<b>OSGI based advertising, registration, management, access etc.</b> Eclipse Communication Framework	
Uboot, Linux kernel, drivers and modules CPU module (incl. RAM/Flash and PMU)	Standard libraries and packages Standard interfaces and built-in peripherals	Additional libraries and packages Extended/external peripherals and modules	NFC libraries or Linux NFC middleware NFC module and antenna (without MCU)	RTOS, libraries, middleware and RR FW Built-in FW and communication protocol NFC module and antenna (with MCU)
				

# Eolyc's Wind Generator

3 phase Axial Flux Ironless Generator  
with NdFeB Permanent Magnets  
R&D Process and Chronology

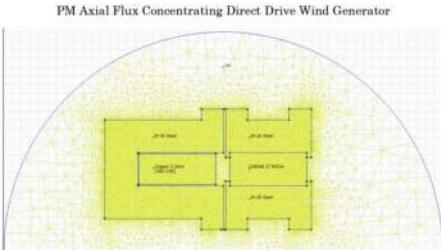
# Startup with advanced ideas

- Concentrating multiphase transverse flux topology with permanent magnet excitation

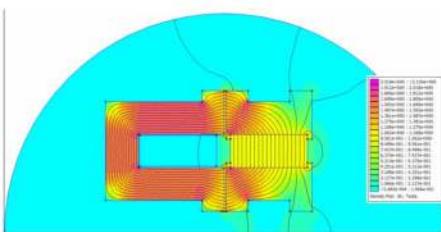


# Concentrating transverse flux topology

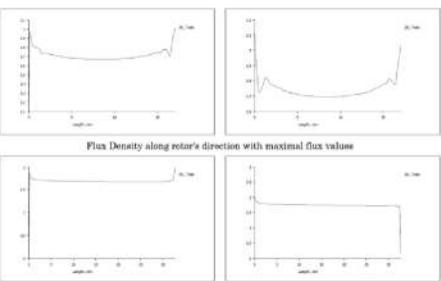
- Simulation results for elementary generator



Planar model prepared in FEMM with geometry imported from AutoCAD .dxf file



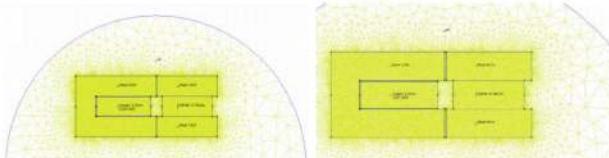
2D Magneto-static analysis result solved by Finite Element Method Magnetic package



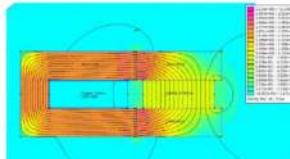
Flux Density along rotor's direction with maximal flux values

Flux Density along stator's direction with maximal flux values

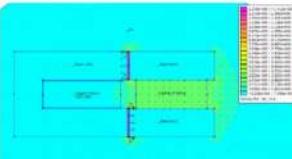
PM Axial Flux Concentrating Direct Drive Wind Generator



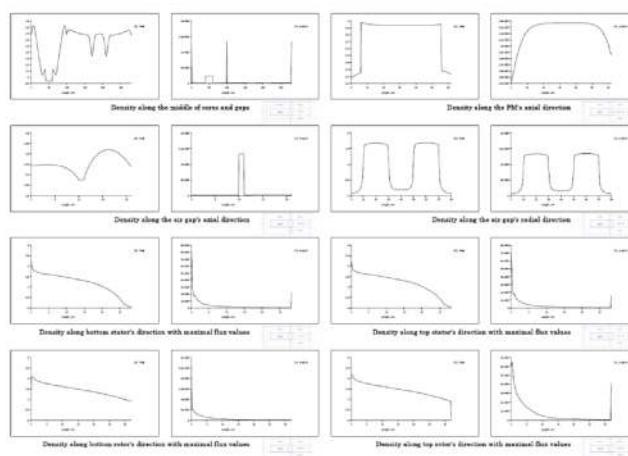
Planar model prepared in FEMM with geometry imported from AutoCAD .dxf file



2D Magnetic-static analysis result solved by FEMM package (Flux Density)

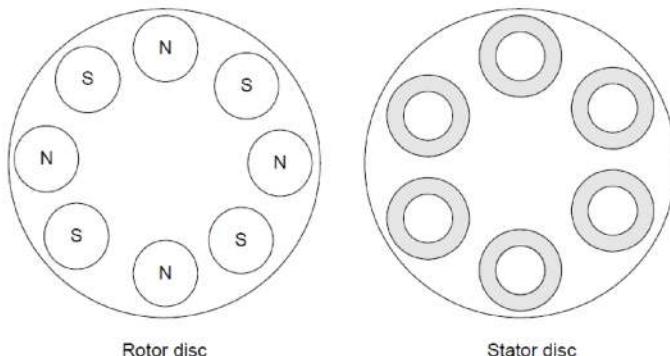
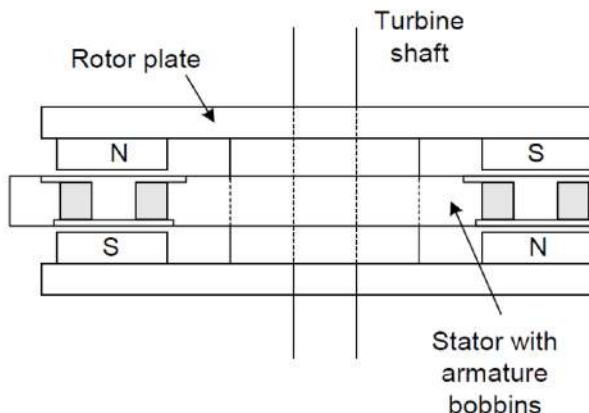


2D Magnetic-static analysis result solved by FEMM package (Field Intensity)



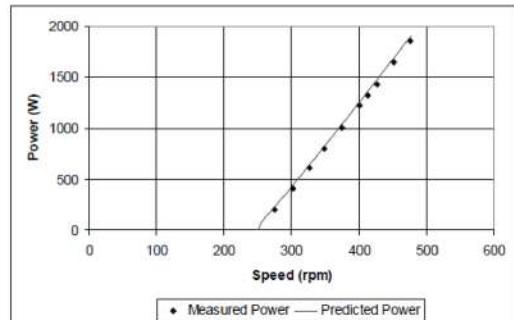
# Following traditional ideas

- Multiphase Axial Flux Ironless Generator with permanent magnet excitation



	1kW	2.5kW
Rated power	W	1000 2500
Rated speed	rpm	300 250
Rated frequency	Hz	40 33.3
Rated EMF (per coil)	V	33.6 205
Number of phases		3 3
Number of pole pairs		8 8
Number of armature coils		12 12
Generator diameter	mm	462 590
Generator length	mm	55 60

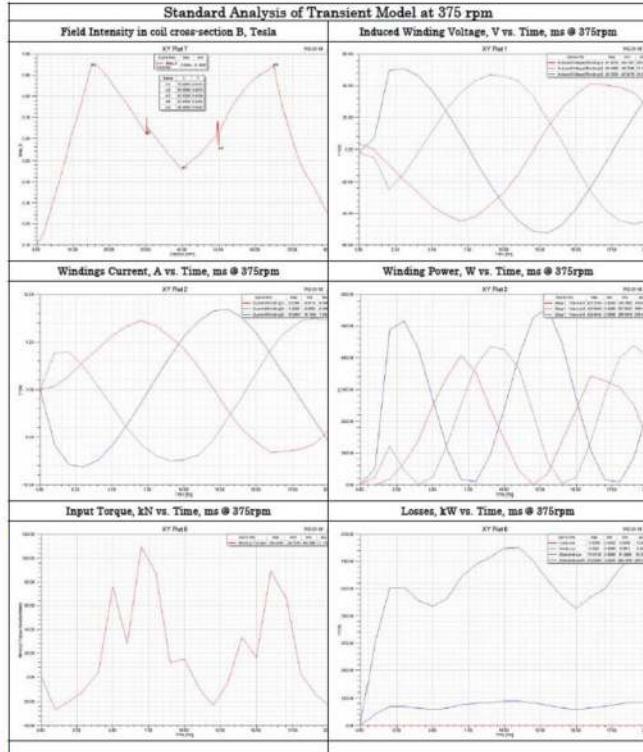
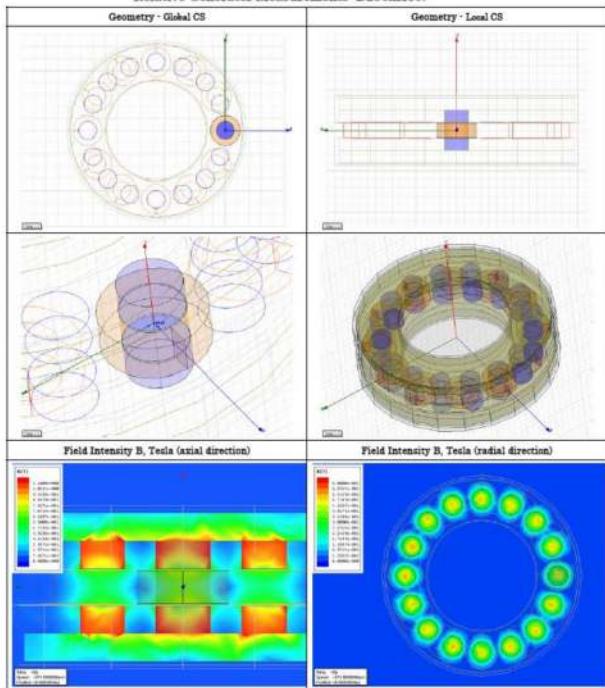
	1 kW		2.5 kW	
	Measured	Predicted	Measured	Predicted
Coil inductance (mH)	4.67	4.59	67	81
Coil resistance (ohms)	1.02	0.97	12.9	11.1
V/100rpm/coil	11.03	11.2	86.0	82.1



# Axial Flux Ironless Generator

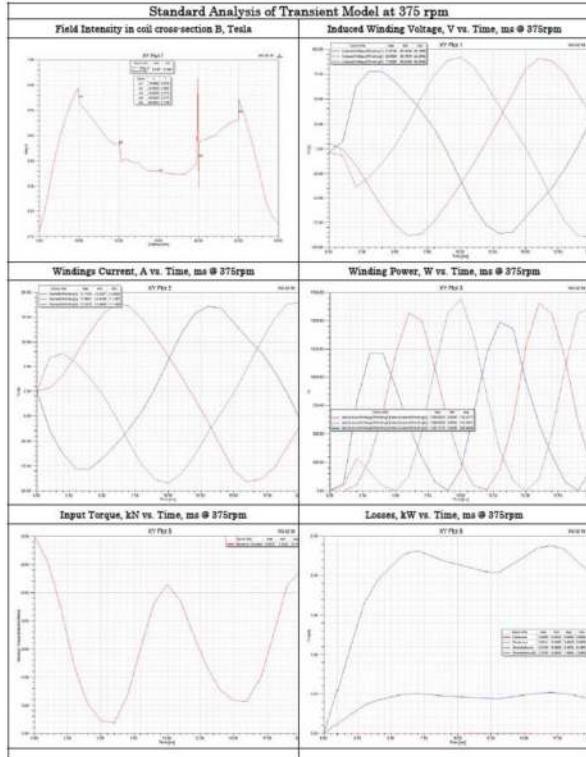
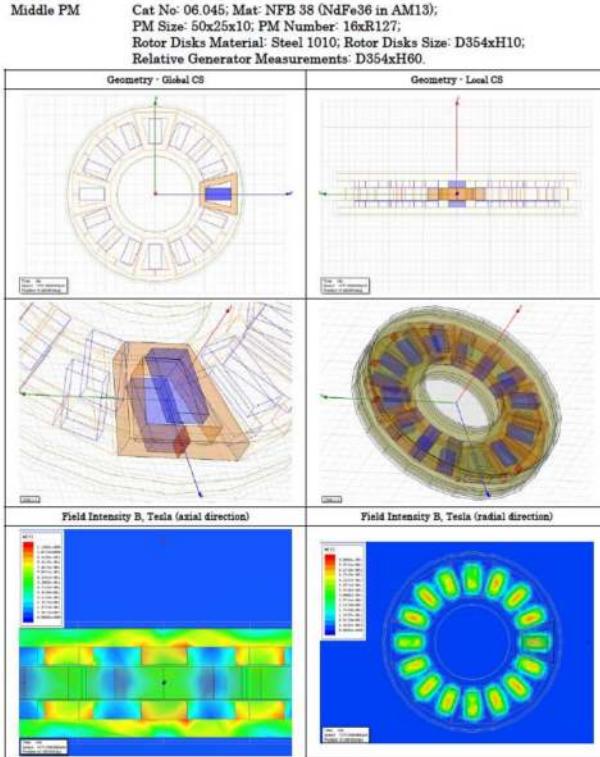
- 3D Simulation results – small cylinder magnets poles

Small PM  
Cat No: 06.028; Mat: NFB 38 (NdFe36 in AM13);  
PM Size: D30xH15; PM Num: 16 xR115;  
Rotor Disks Material: Steel 1010; Rotor Disks Size: D290xH15  
Relative Generator Measurements: D290xH80.



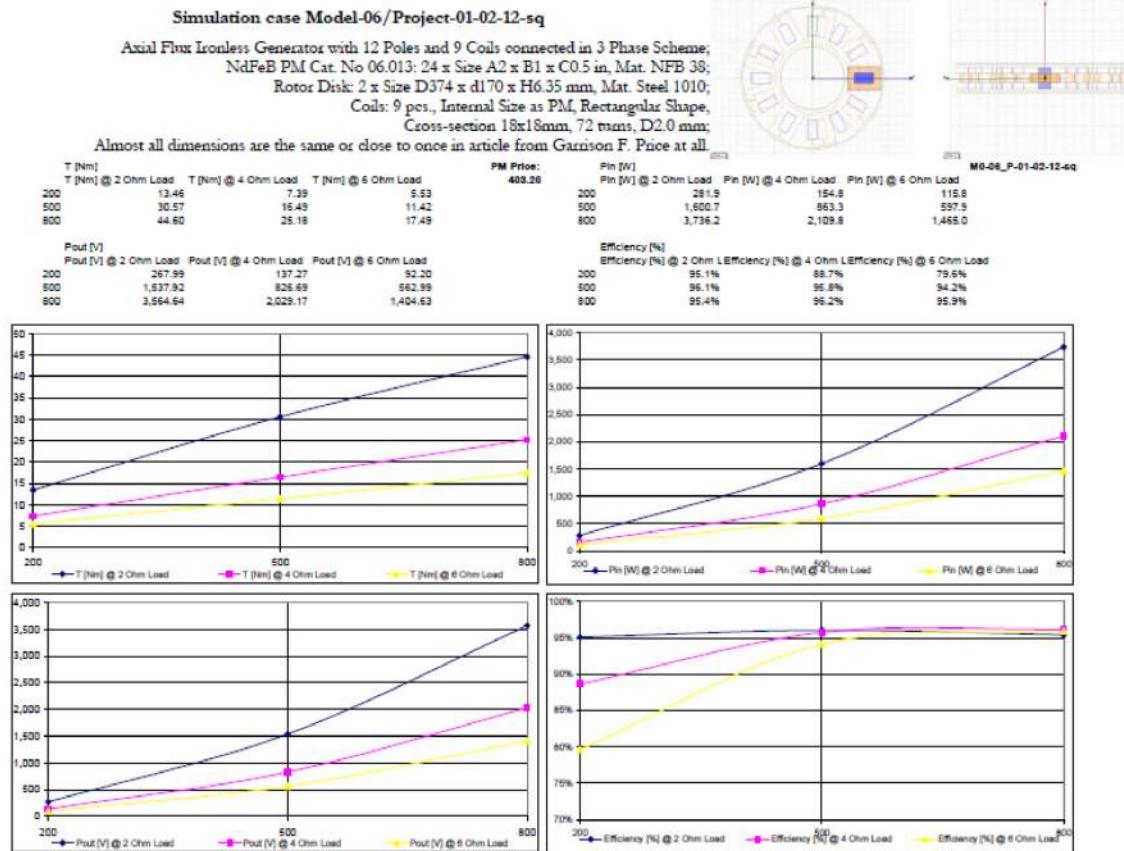
# Axial Flux Ironless Generator

- 3D Simulation results – medium parallelepiped magnet poles



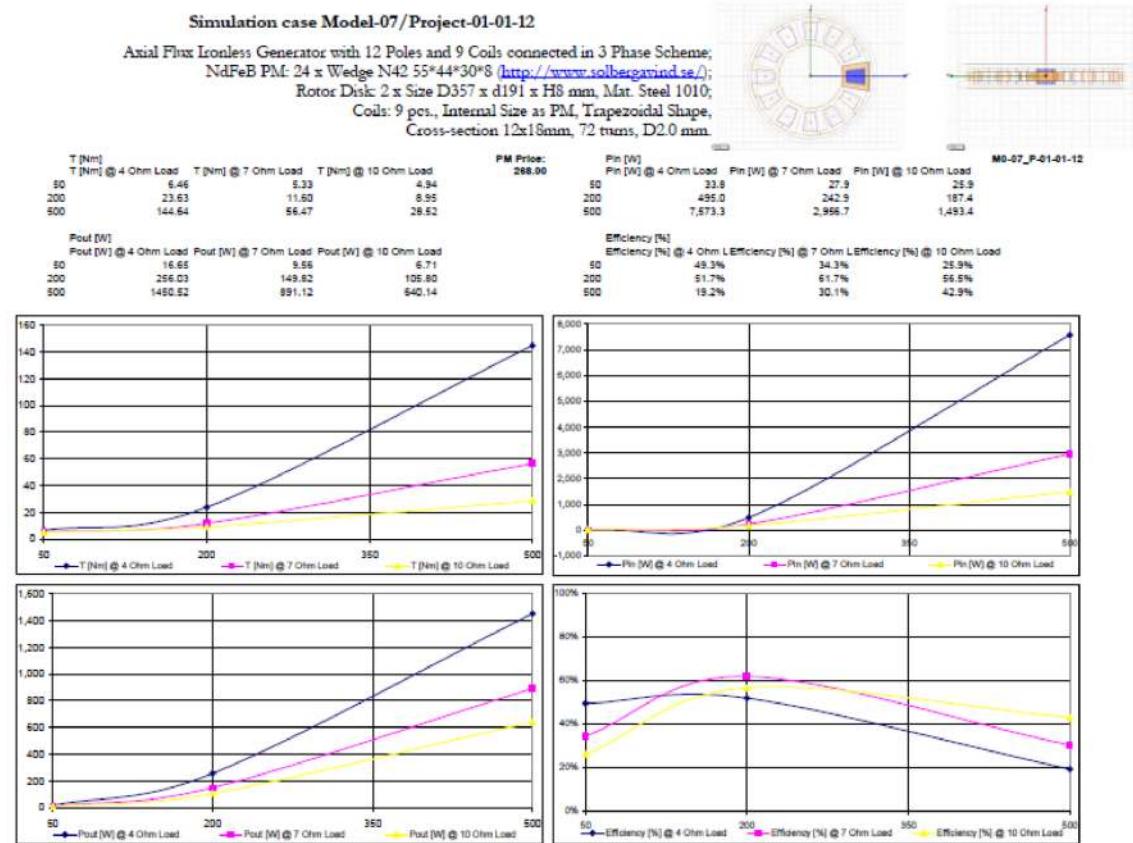
# Axial Flux Ironless Generator

- 3D Simulation results – big parallelepiped magnet poles



# Axial Flux Ironless Generator

- 3D Simulation results – medium wedge magnet poles

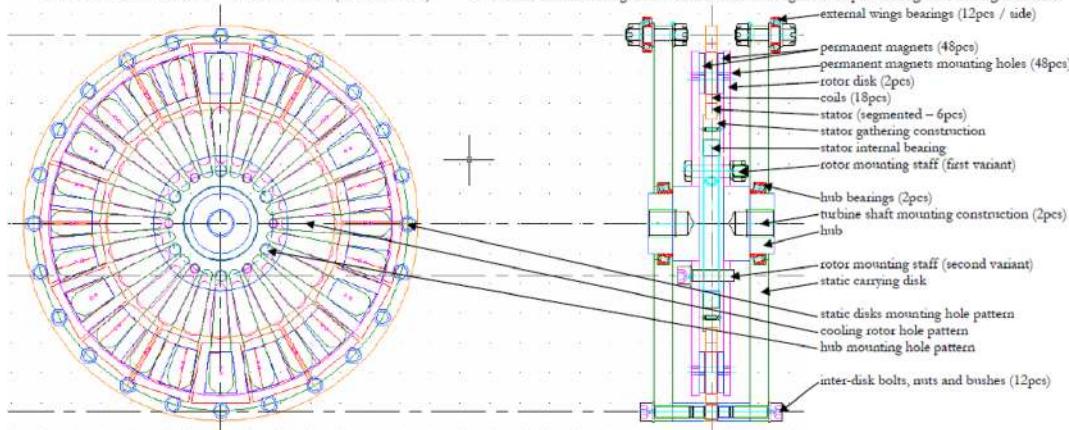


# Axial Flux Ironless Generator

- After simulation design summary – based on medium wedge magnet poles

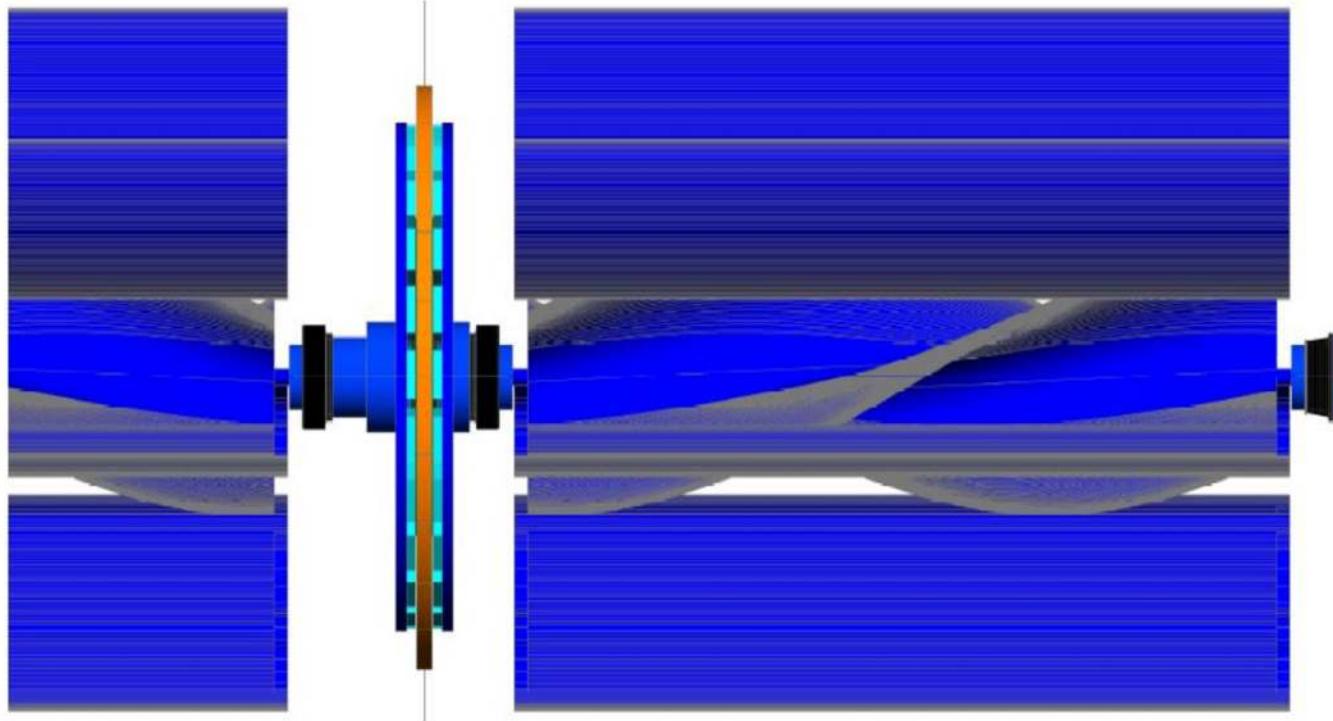
## Axial Flux Ironless (AFIL) Generator parameters and construction

PM kind	Wedge 55x44x30x8 hole d3.4 mm	Geometry	Poles 24 / Coils 18
PM pieces / Poles / Pole pairs	48 / 24 / 12	Coils / Phases / Coils per Phase	18 / 3 / 6
Radial PM repetition ratio	0.70766	Radial Coil repetition ratio	0.87718
Radial Inter PM space	15.36	Radial Inter PM space	8.31 @ 12 mm coil width
PM placement pattern	24 x R200 x d3.4 mm	Coil placement pattern	3 x 8 x R200 mm
Air gap total	16 mm	Air gap	2 x 1 mm
Steel Rotor Disk height	10 mm	Coil height	14 mm
Steel Rotor Disk External Diameter	D460 mm	Coil cross-section	12 x 14 mm
Steel Rotor Disk Internal Diameter	D100 mm	Coil turns	42 x d2.0 mm
Steel Rotor Disk Hole Pattern	24 x R200 x d3.4 mm (PM fixture) 6 x R140 x d16 mm (Hub fixture) 6 x R140 x d10.2 mm (Mount Tool)	Plastic Stator Disk Segments	D528 x d304 x H14 mm (in mounted state)
Static Carrying Disk Diameter	528 mm	Coils/Phases per Segment	3
Static Carrying Disk Hole Pattern	12 x R252 d16 mm (inter-disk bolts) 12 x R252 d16 mm (external wings)	Notes:	
Hub Bearings	2 x Roller D110xd80xB20 mm	• Construction is designed to fit both wedge 55x44x30x8 and 70x46x28x10 PMs;	
Stator Internal Bearing	Roller D180xd225xB22 (xx011836)	• Both rotor and carrying disks should be made with maximal cooling efficiency;	
External wings bearings	Roller D47xd20xB12 (DIN 615)	• Stator gathering construction should be tuned to fit all incl. 24 and 16 poles 140/6 rotor disks;	
Generator overall dimensions	D528 x B152 mm (w/o bolt heads)	• Construction has to be made in respect to turbine mounting and carrying;	
		• Construction should be designed to be tolerant to external environment;	
		• Turbine shaft mounting construction should be designed in respect to long shaft and big deviations.	



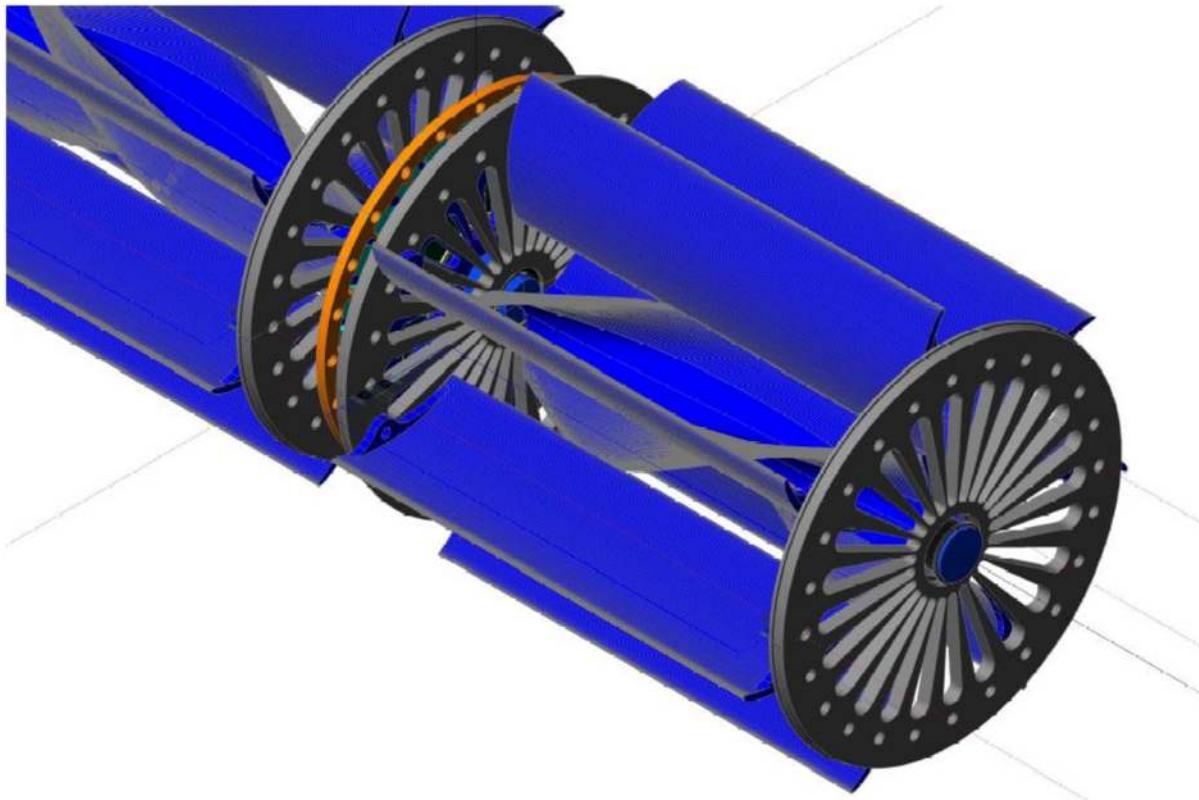
# Generator Construction

- 3D model of wind turbine, generator rotor and stator – first revision



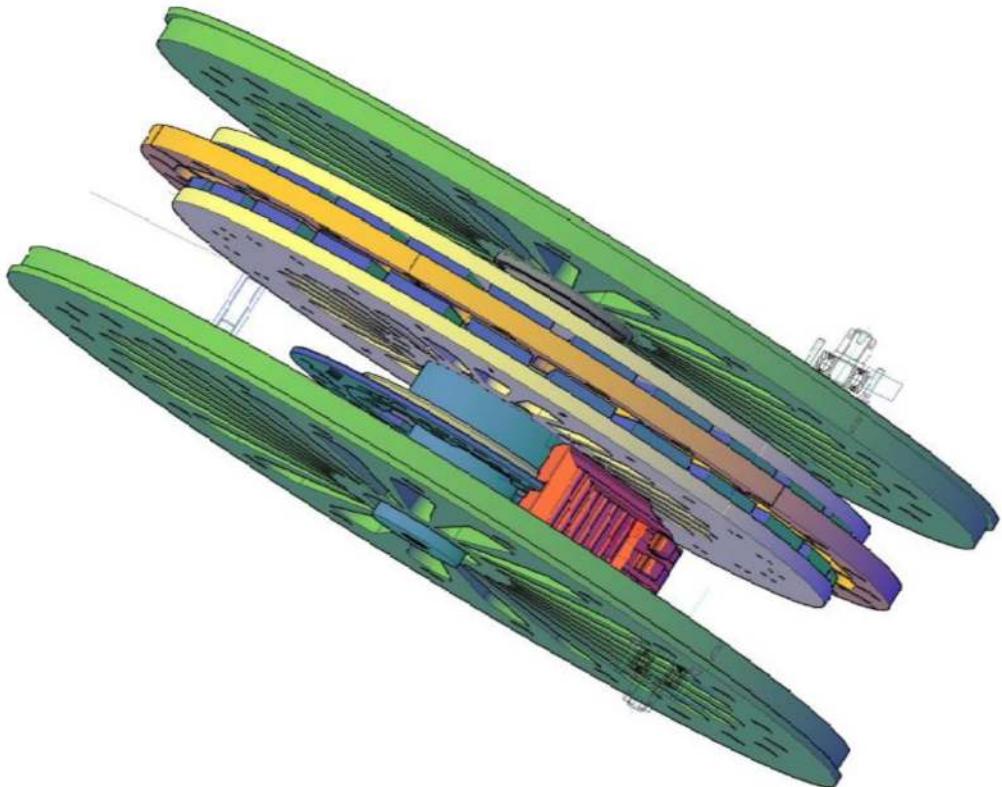
# Generator Construction

- 3D model of wind turbine, generator rotor and stator – first revision



# Generator Construction

- 3D model of wind turbine, generator rotor and stator – first revision

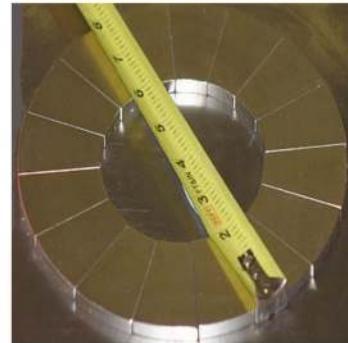


# Generator Construction

- NdFeB Permanent Magnets – supplier selection and delivery

Dailymag Magnetic Technology (Ningbo) Limited  
is a Chinese leading manufacturer and exporter  
of permanent magnets etc.

**Wind Generator NdFeB Magnets 22.5 degree**  
**8 inch OD x 4 inch ID x 0.5 inch thick**  
**Wedge Segment Shape, Grade N35~N52**  
**Nickel-Copper-Nickel triple layer coated**



# Generator Implementation

- The rotor disk



# Generator Implementation

- The startup staff



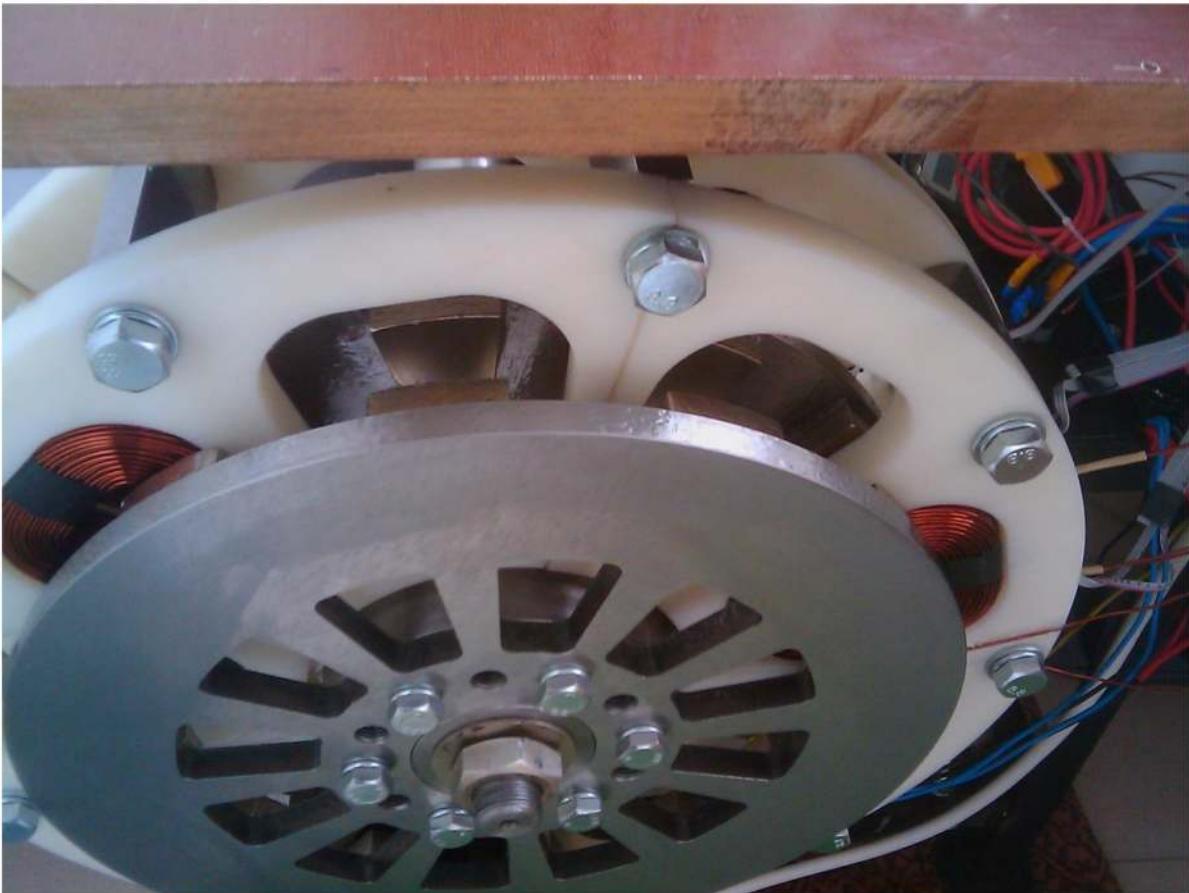
# Generator Implementation

- The stator segment



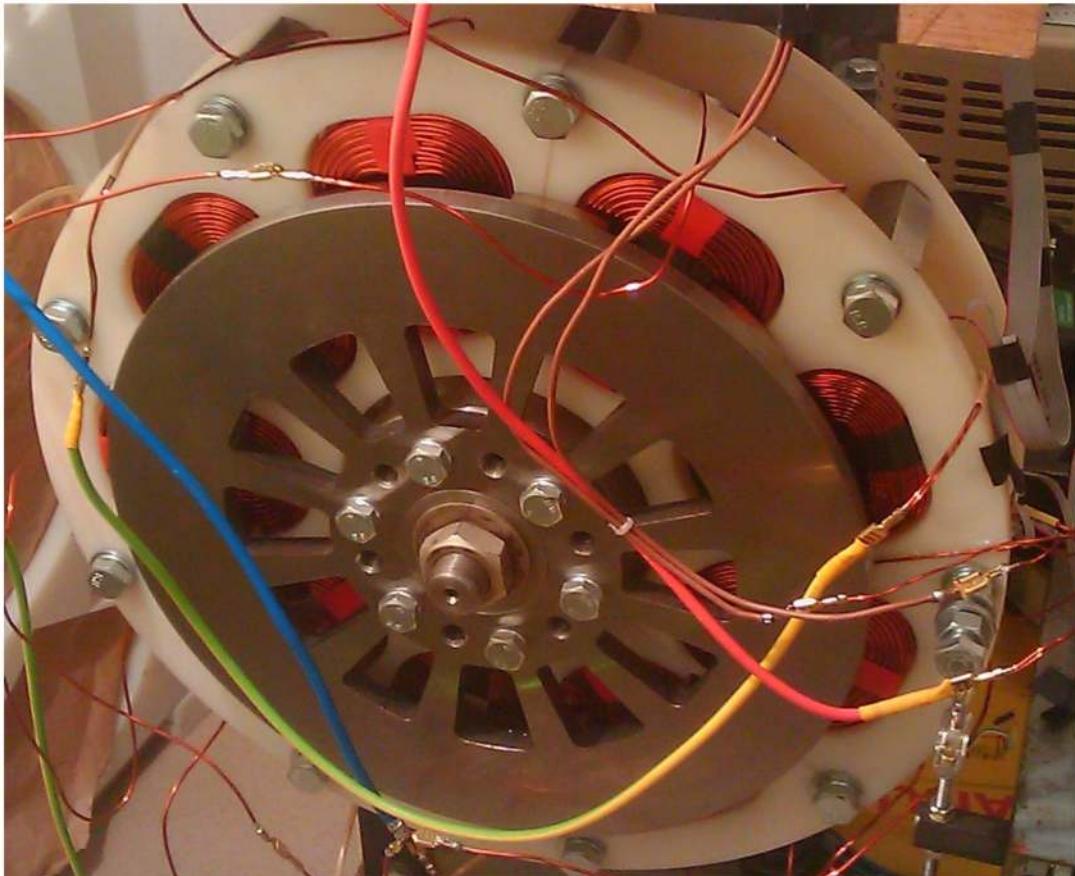
# Generator Implementation

- The first assembling together



# Generator Implementation

- Generator mounted on the test bed – (both first revision)



# Test Bed Implementation

- Test bed – first revision



# Generator Testing

- Generator mounted on the test bed – energy production

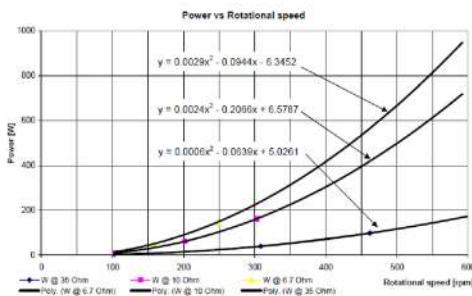
First Light



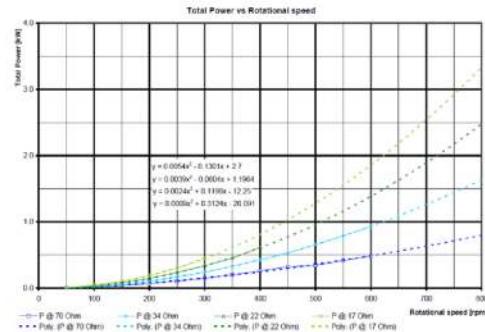
First Watts



First measured 100ths of Watts

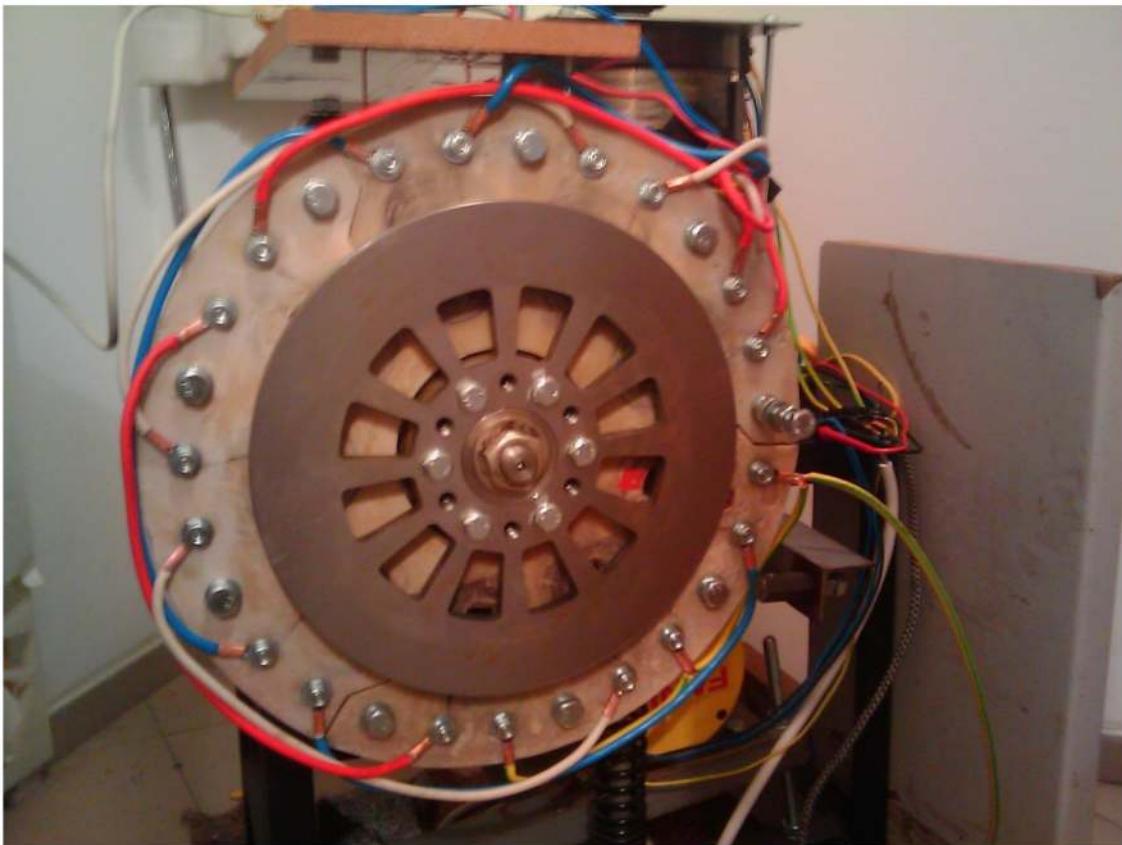


First measured 1000 Watts



# Generator Improvements

- Wind Generator – first revision with modified stator (molding technology)



# Generator and Turbine

- First assembling of the generator and the turbine



# Generator and Turbine

- Rotational test of the generator and the turbine



# Generator, Turbine and Wings

- The generator, the turbine and the wings

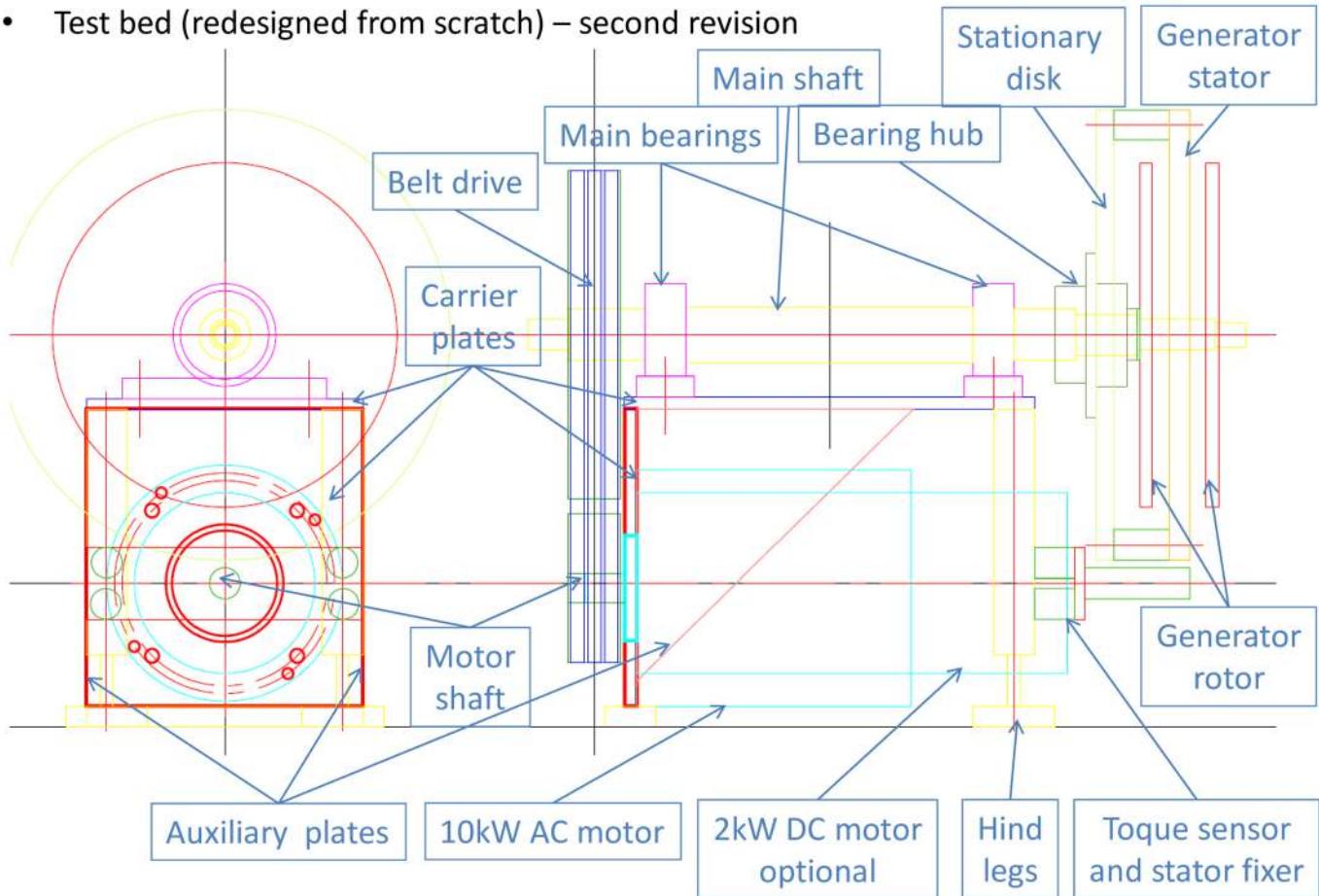


# The field test suite (Belmeken)



# Test Bed Improvements

- Test bed (redesigned from scratch) – second revision



# Mechanical System Improvement

- Test bed – belt drive is using V-Belts pulleys for taper bushes by Bea Ing. S.P.A.



## PULEGGE A GOLE TRAPEZOIDALI PER BUSSOLA CONICA V-BELTS PULLEYS FOR TAPER BUSHES

### Descrizione e caratteristiche - Description and features

Le pulleggi per cinghie trapezoidali sono costruite secondo le specifiche ISO 4183 / DIN 2211.  
Our V-belt pulleys are manufactured according to International Standard ISO 4183 / DIN 2211.

### Materiale - Material

Ghisa EN-GJL-200 (G20 - UNI 5007)  
Cast iron EN-GJL-200(G20 - UNI 5007)



### Tratamento e Bilanciatura Protective treatment and Balancing

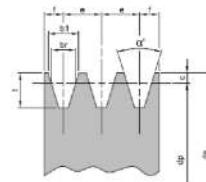
Tutte le pulleggi standard sono protette con un trattamento superficiale di POSFATAZIONE e BILANCIAZIONE STATICAMENTE per essere idonee ad un funzionamento fino alla velocità periferica di 35 m/sec.

The surface of all our standard pulleys is protected by phosphated treatment. All the pulleys are Statical Balanced and can be used for peripheral speed up to 35 m/sec.

### Calcolo della velocità periferica (Vp) Peripheric speed table (Vp)

$$V_p = \frac{\pi \cdot d_p \cdot n}{60 \cdot 1000} = \frac{d_p \cdot n}{19100} \text{ m/sec}$$

d<sub>p</sub> = diametro in mm - diameter/mm  
n = giri al minuto - revolutions per minute  
V<sub>p</sub> = velocità in m/sec - speed

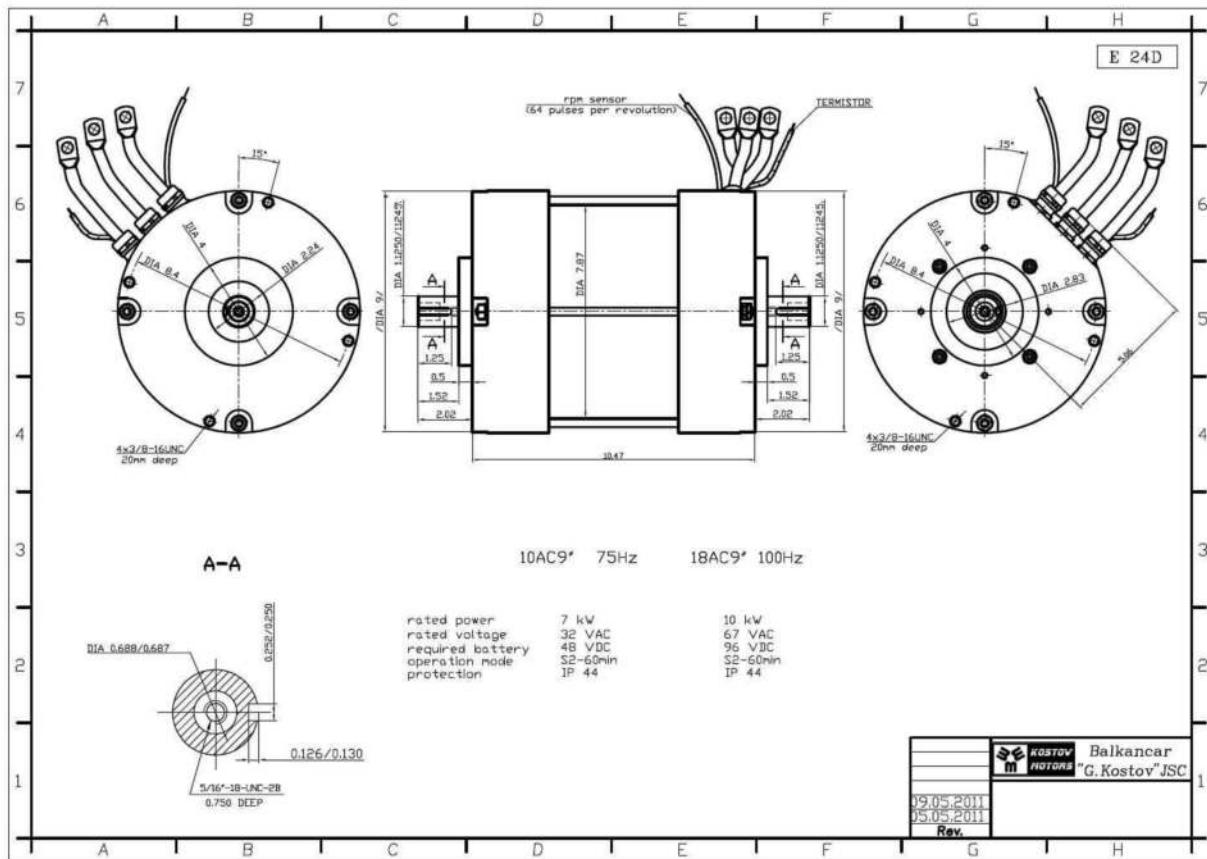


Dimensioni pulleggi  
Dimensions of Pulleys

codice	d <sub>p</sub> mm pratico	α gradi	b <sub>1</sub> mm	b <sub>r</sub> mm	o mm	f mm	c mm	l mm
SPZ (mm)	< 90	34°						
	> 90	38°	9,7	8,5	12	8	2	11
SPA (mm)	< 119	34°						
	> 119	38°	12,7	11	15	10	2,8	13,8
SPO (mm)	< 190	38°	16,3	14	19	12,5	3,5	17,5
	< 315	34°	22,0	19	25,5	17	4,8	23,8
SPC (mm)	> 315	38°						

# Electrical System Improvement

- Test bed with Kostov's AC Motor and Curtis' Controller



# Electrical System Improvement

- Test bed with Kostov's AC Motor and Curtis' Controller

ON-ROAD AC INDUCTION MOTOR CONTROLLER

MODEL 1238R



## DESCRIPTION

The Curtis Model 1238R provides energy efficient control of AC induction motors performing on-vehicle traction drive duties. It offers vehicle developers a highly cost-effective combination of power, performance and functionality.

## APPLICATION

Designed for use as a traction controller for on-road electric and hybrid passenger vehicles using 72-96V system voltage, and other similar applications with low or medium duty cycles.

Patents Pending

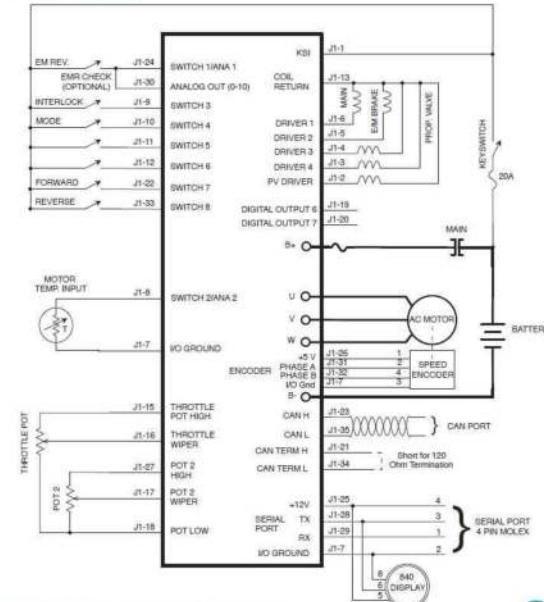
[www.curtisinstruments.com](http://www.curtisinstruments.com)



CURTIS

MODEL 1238R

## TYPICAL WIRING



**WARRANTY** Two year limited warranty from time of delivery.

 is a trademark of Curtis Instruments, Inc.

Specifications subject to change without notice.

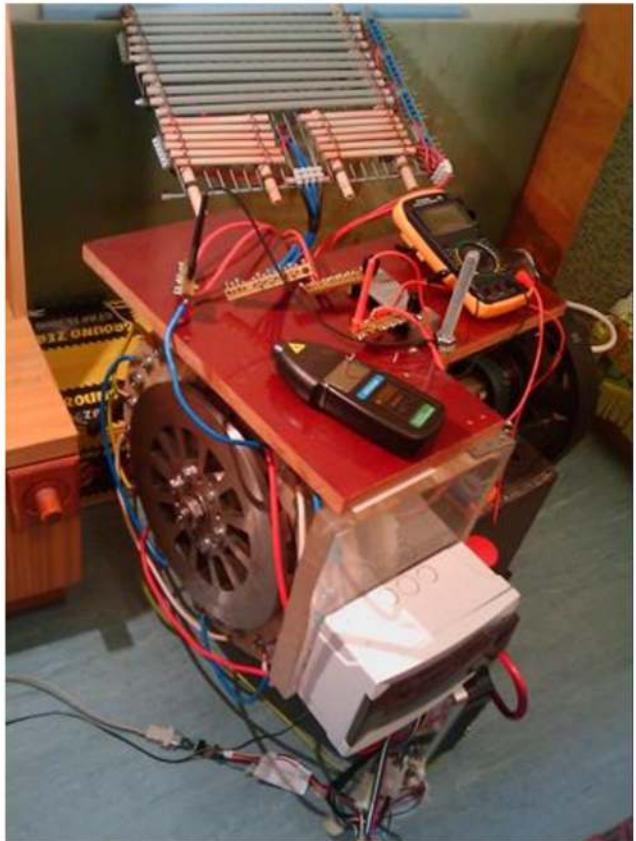
©2010 Curtis Instruments, Inc.



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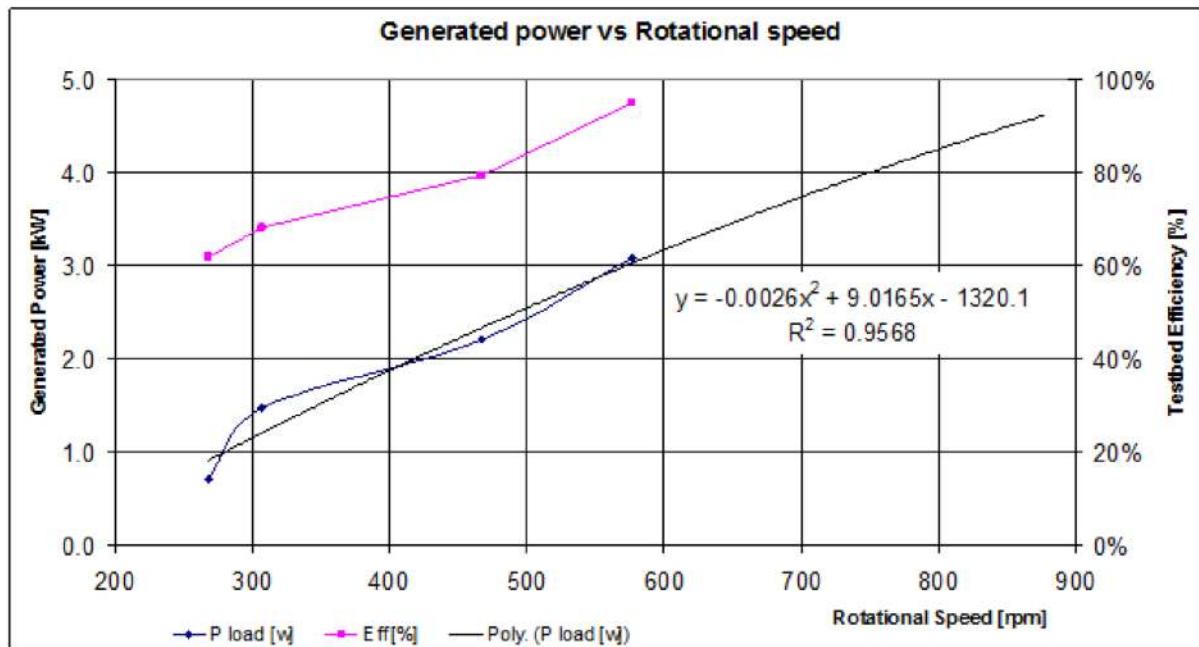
# Test Bed Improvements

- Test bed (redesigned from scratch) – second revision



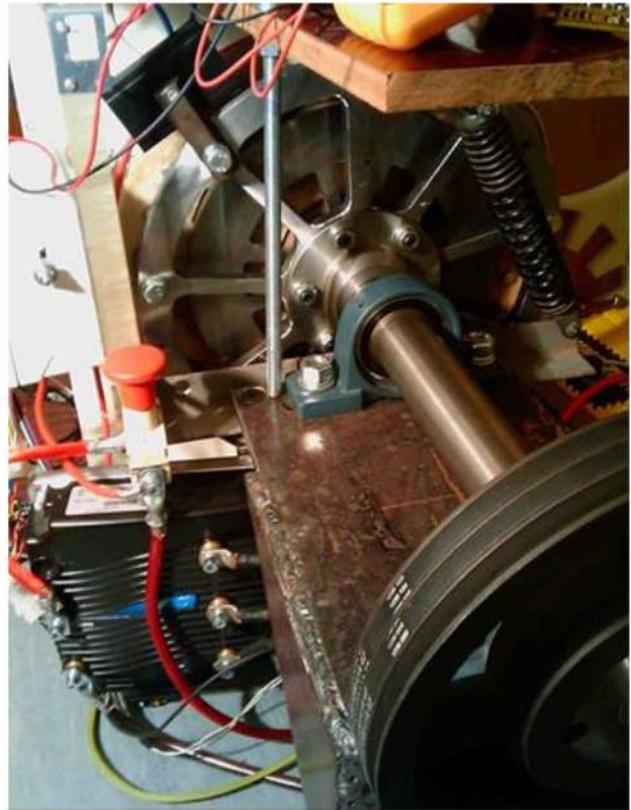
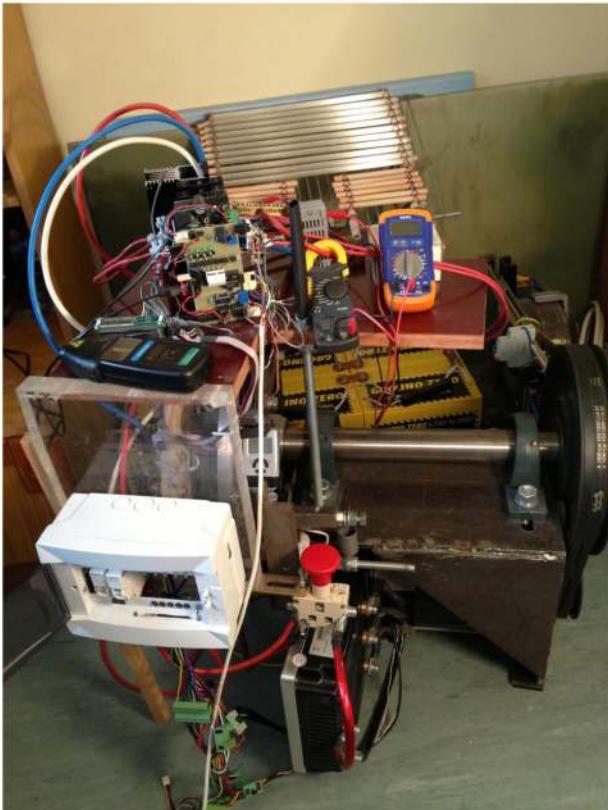
# Generator Testing

- Generator mounted on the second revision test bed – energy production



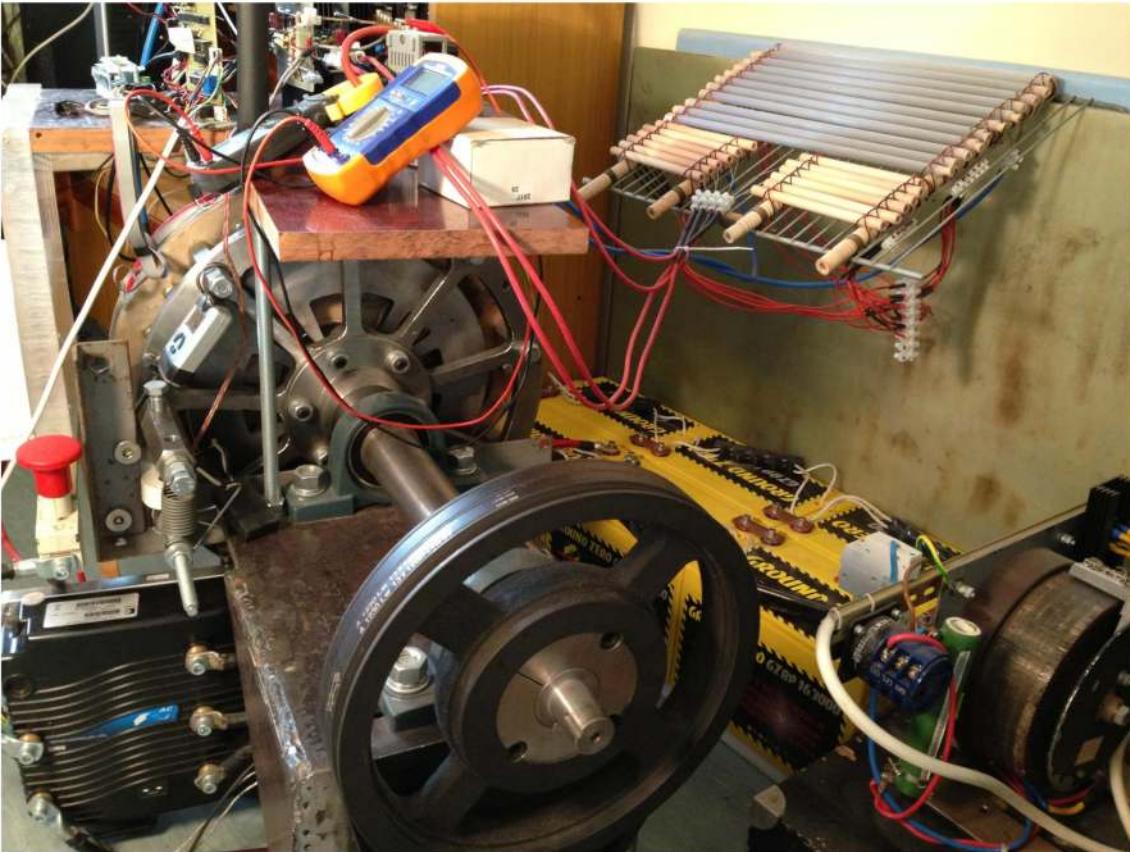
# Test Bed Improvements

- Test bed – modified second revision



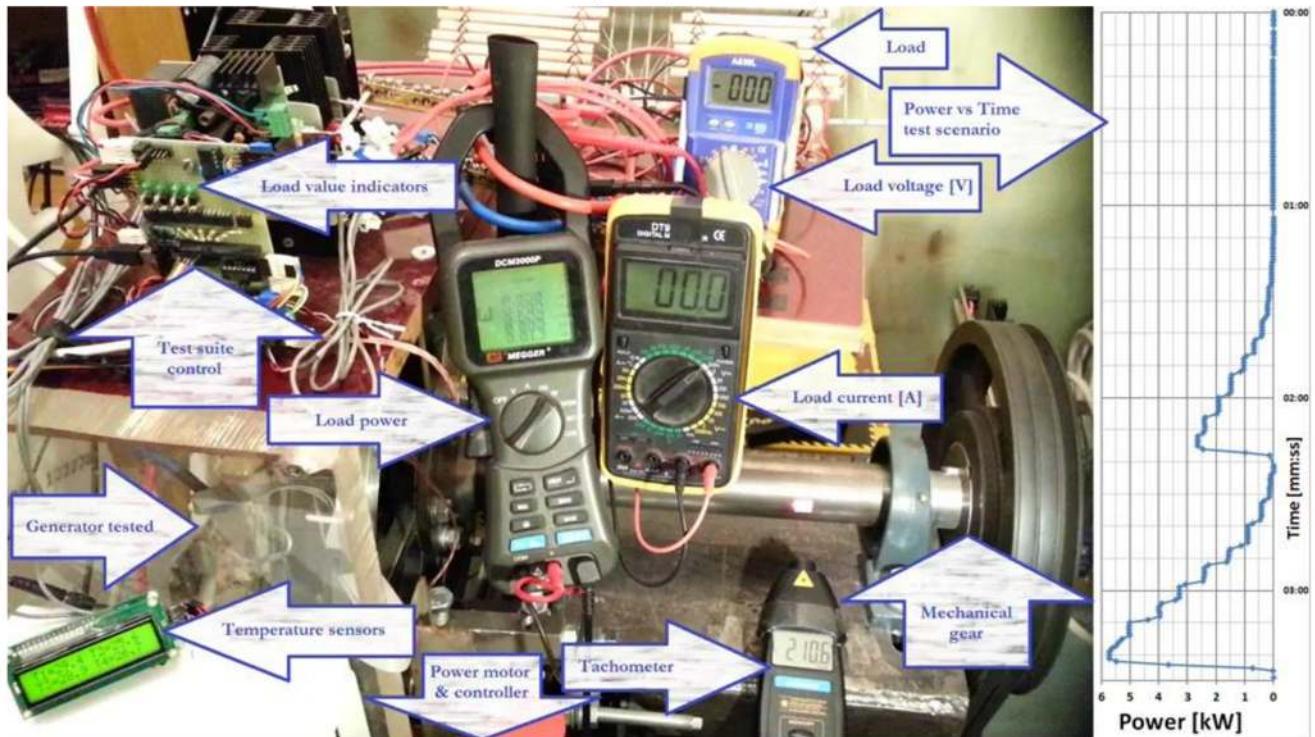
# Test Bed Improvements

- Test bed – modified second revision



# Test Bed Improvements

- Test bed – modified second revision (complete staff)

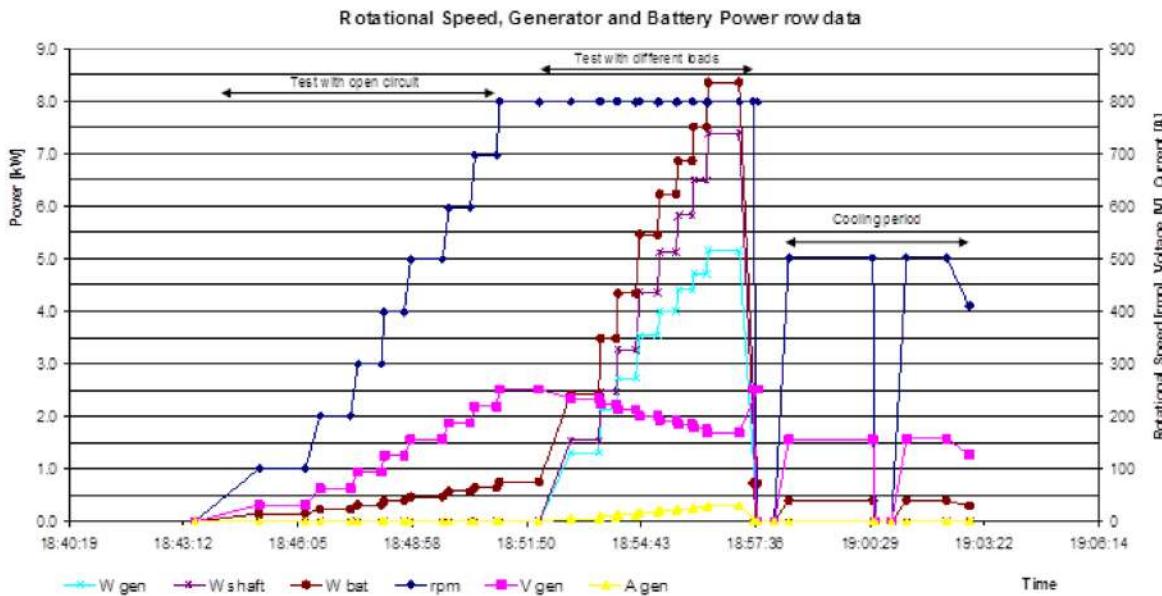


# Generator Testing

- Generator mounted on the second revision test bed – energy production

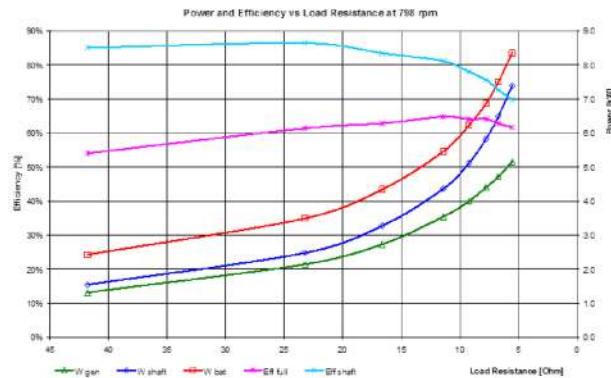
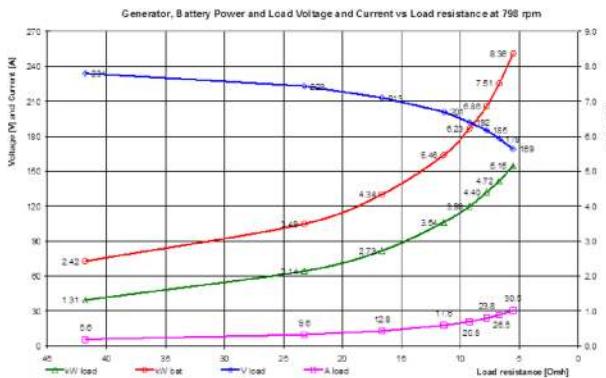
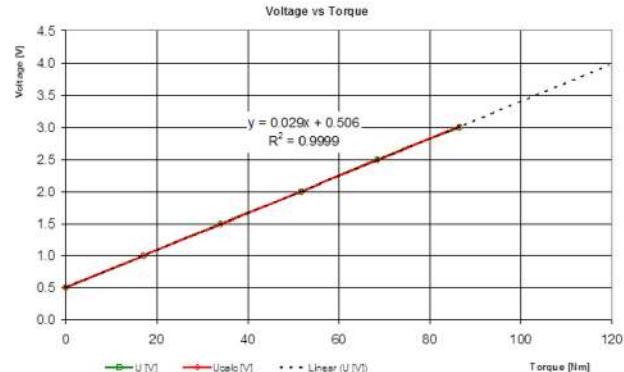
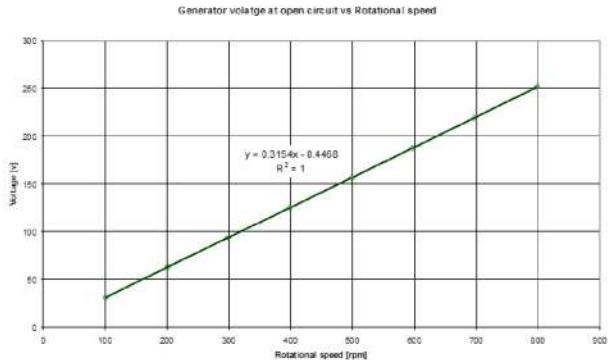
## Tests after mounting torque and temperature sensors

- Short time max power measured on 18 March – 5150 W ( $30.5\text{A} \times 169\text{V}$ ) @ 798 rpm and 5.5 Ohm load;
- Long time max power measured on 17 March – 4860 W ( $28.5\text{A} \times 171.1\text{V}$ ) @ 806 rpm and 6.2 Ohm load;
- Short time max power measured on 14 March – 4200 W ( $26.1\text{A} \times 161.4\text{V}$ ) @ 725 rpm and 6.2 Ohm load;
- Long term max power measured on 12 March – 3300 W ( $21.6\text{A} \times 152.5\text{V}$ ) @ 650 rpm and 7.1 Ohm load;
- More power output at rpm above 800 and load current above 30 A can be reached with better mechanical balancing and stator cooling.



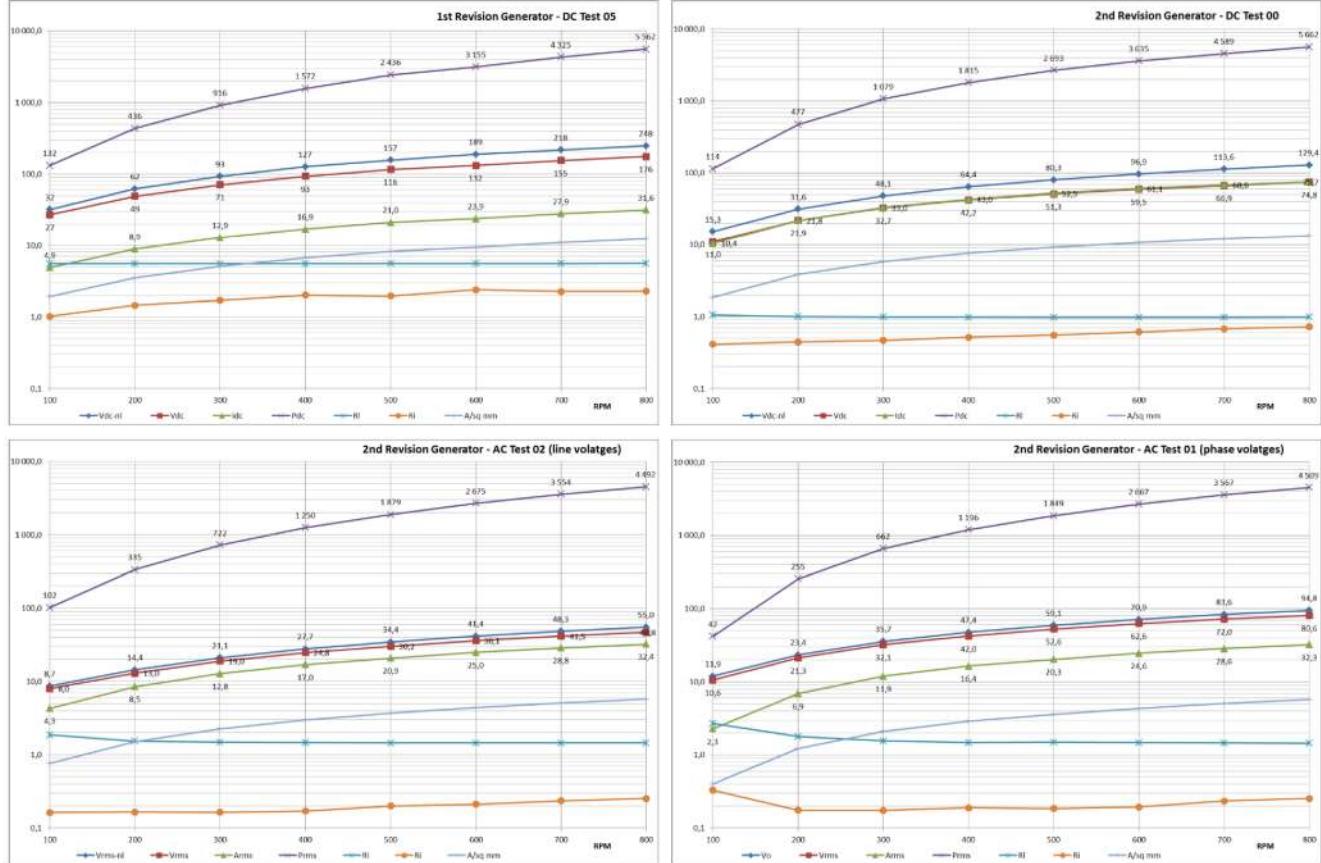
# Generator Testing

- Generator mounted on the second revision test bed – measured power up to 5 kW



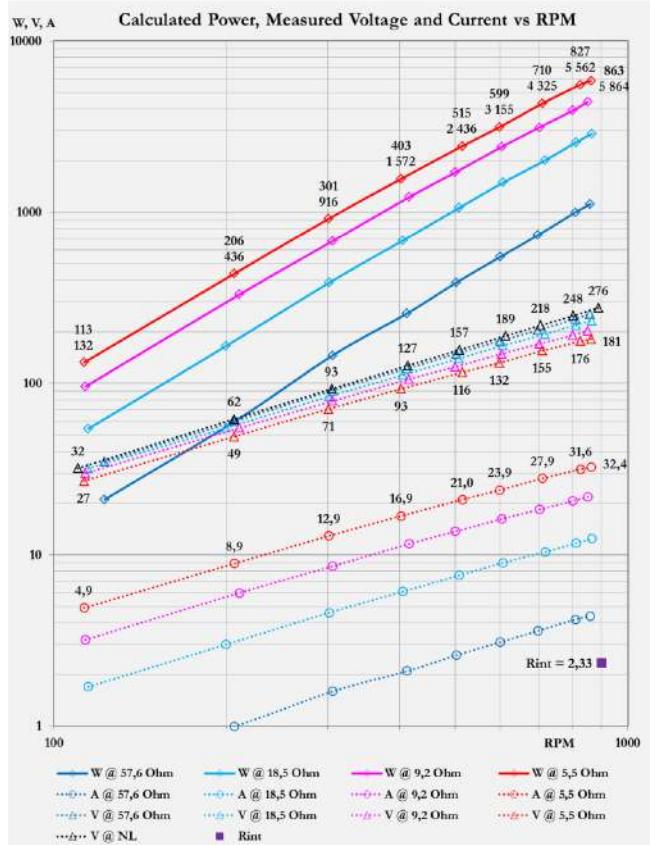
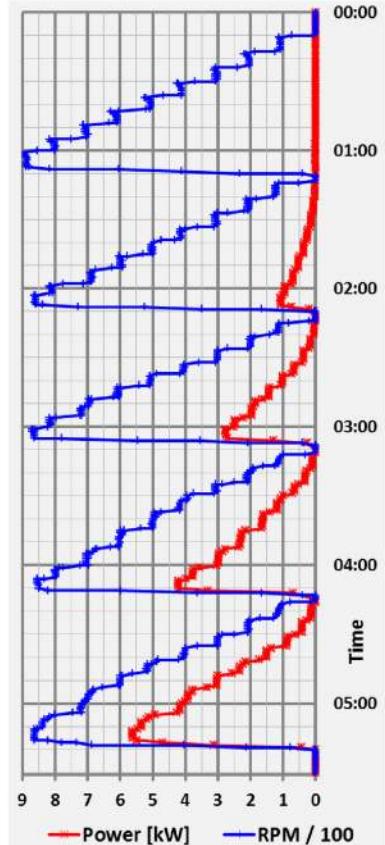
# Generator Testing

- Generator mounted on the second revision test bed (AC/DC Load comparison)



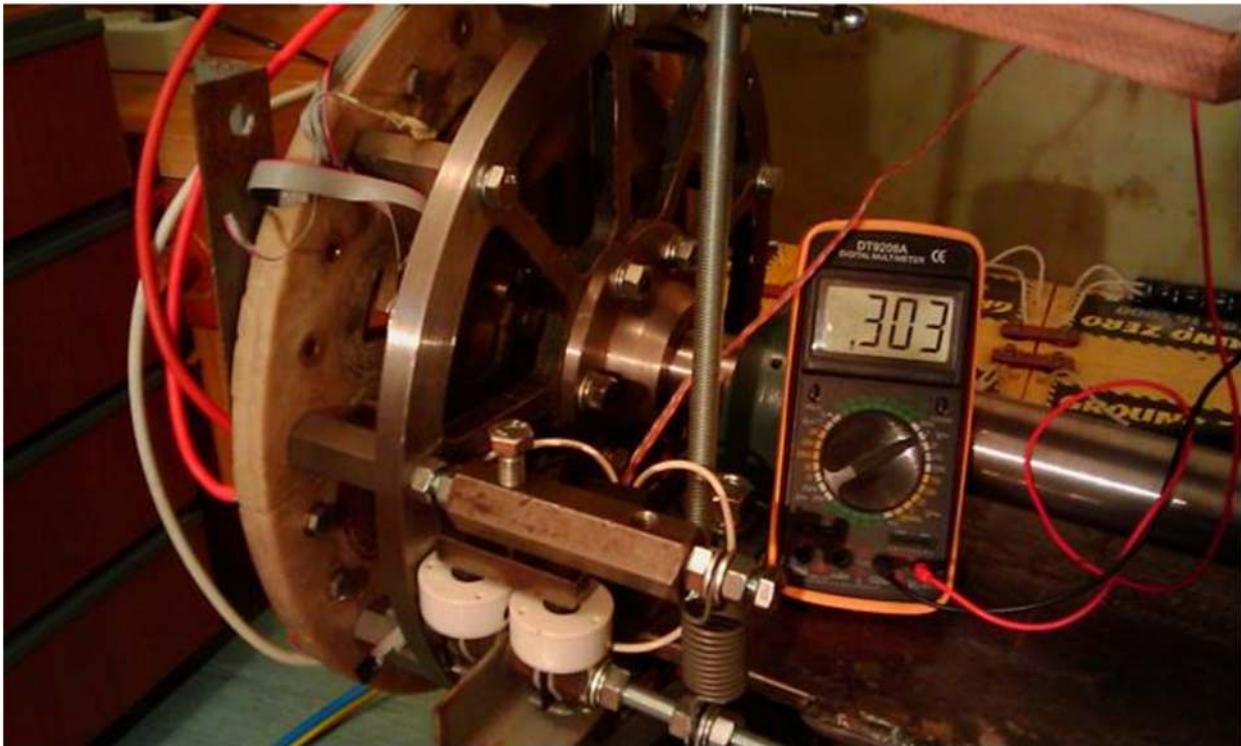
# Generator Testing

- Generator mounted on the second revision test bed (long test)



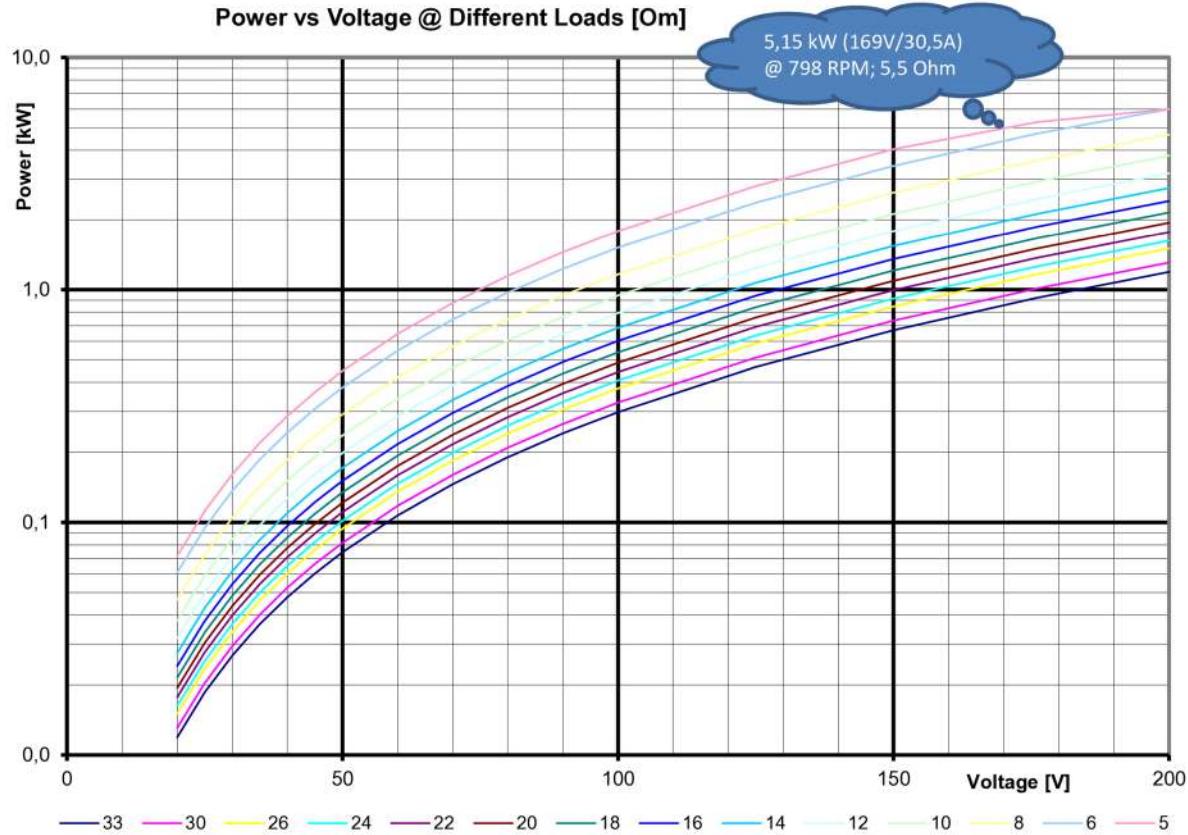
# Test Bed Improvements

- Test bed – modified second revision with torque and temperature sensors



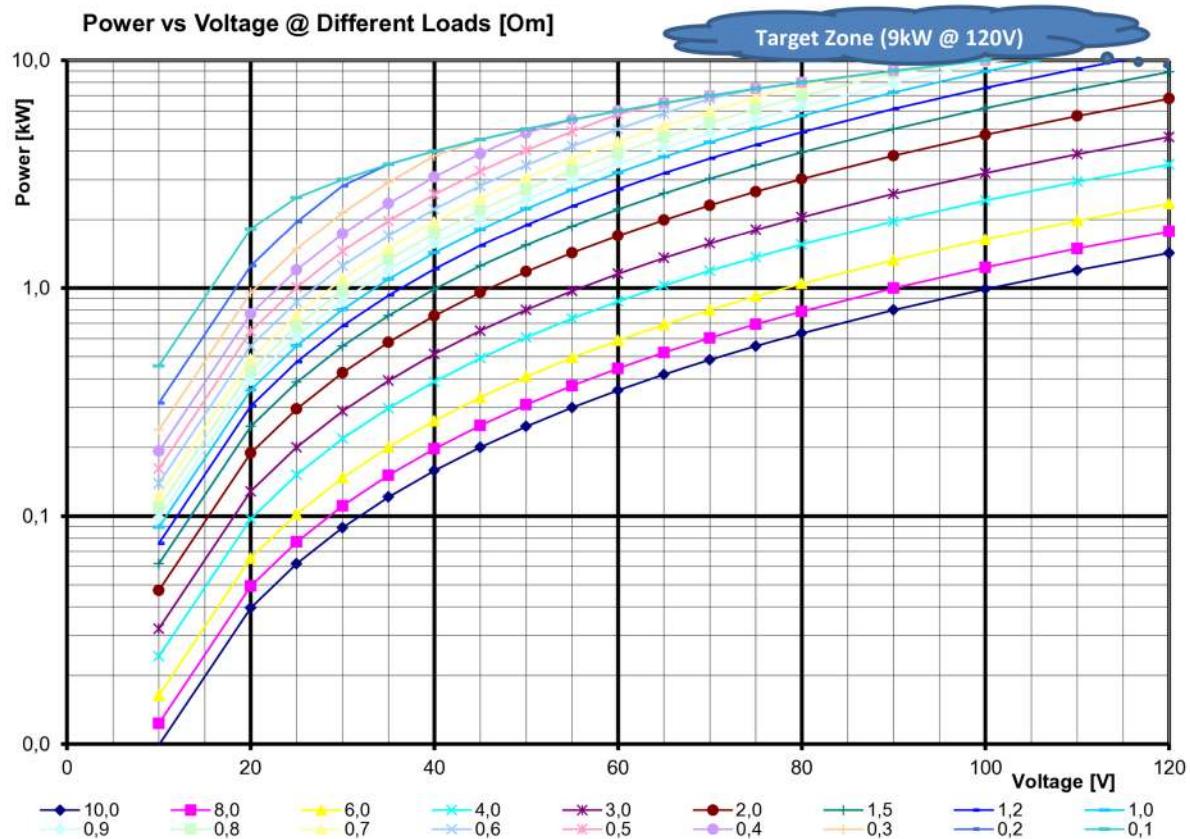
# Next Generator Improvements

- Current Stator Base – wire size: D1.8 mm, 2.54 mm<sup>2</sup>; coil: 120 windings



# Stator Redesign (Coil)

- Next Stator Base – wire size:  $1.8 \times 3.15 \text{ mm}$ ,  $5.67 \text{ mm}^2$ ; coil: 60 windings



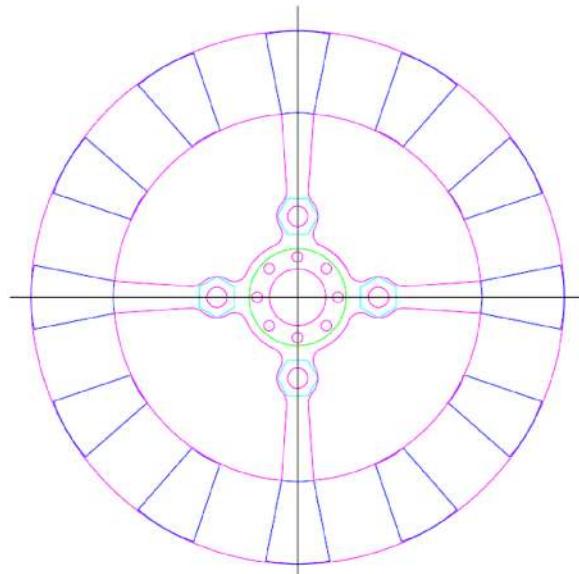
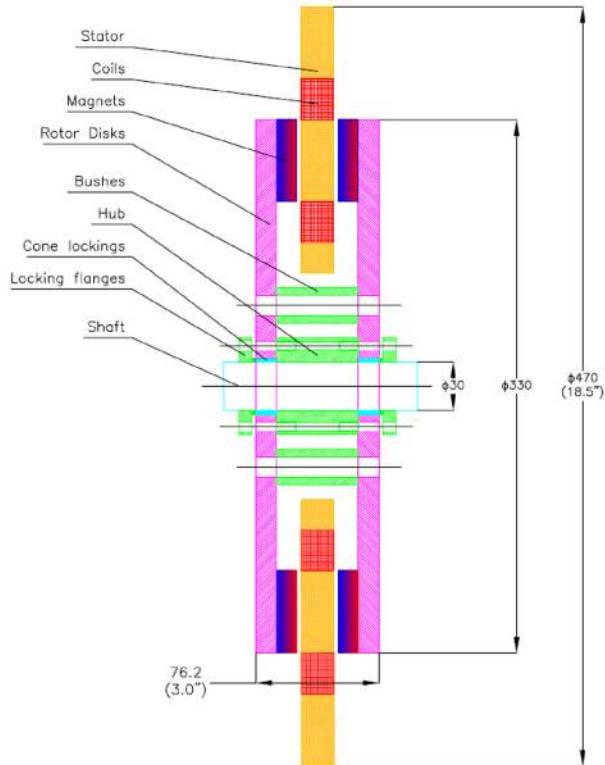
# Stator Redesign (Coil)

- *Production of the new coils*



# Generator Redesign

- *Rotor design with light hub and centered cone bushes and plotted stator*



# Generator Redesign

- *Modified to use centered cone bushes by Bea Ing. S.P.A. for mounting to the shaft*

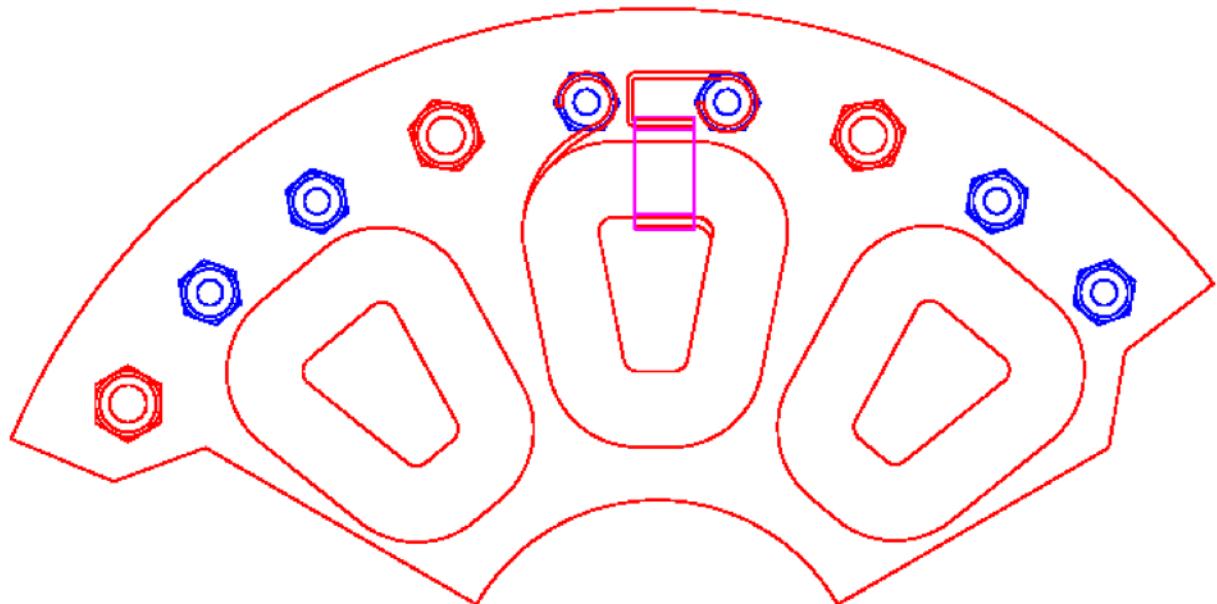
# Stator Redesign (Segment)

- *Stator template for molding technology*



# Stator Redesign (Segment)

- *New stator geometry for plotting technology*



# Stator Redesign (All segments)

- *New stator after plotting and ready for coil mounting*



# Stator Redesign (Complete staff)

- *New stator produced by plotting technology and Cu plate wires*



# Rotor Redesign (Assembled)

- *Assembled rotor with light hub, spacers and centered cone bushes*



# Rotor Redesign (Painted)

- *Assembled and painted rotor, stator carrier disk both mounted on the field*

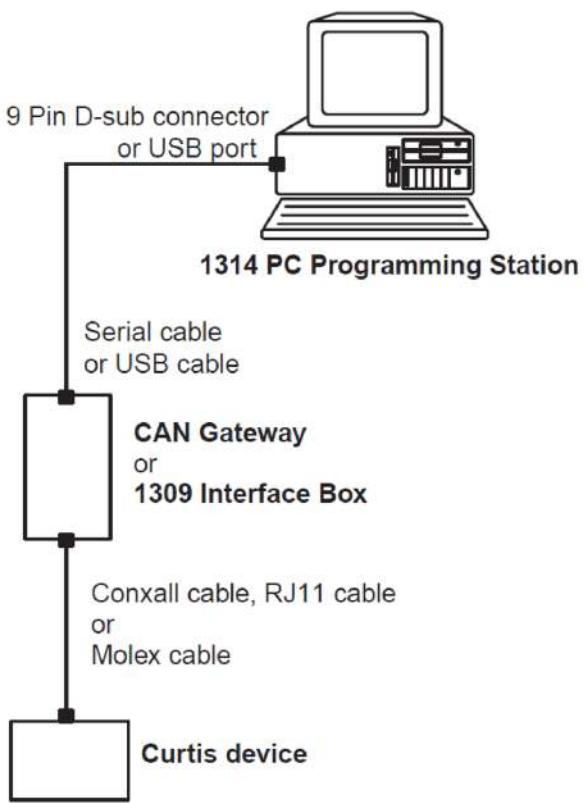


# The field test suite (Shabla)

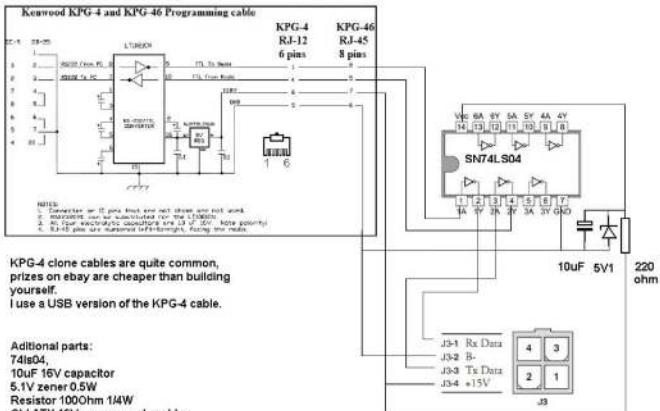


# Electrical System Improvement

- Test bed – rev. 3 with PC Station interconnection and Cooler for Curtis' Controller



Using a standard programming cable found on ebay to program your curtis motor controller.



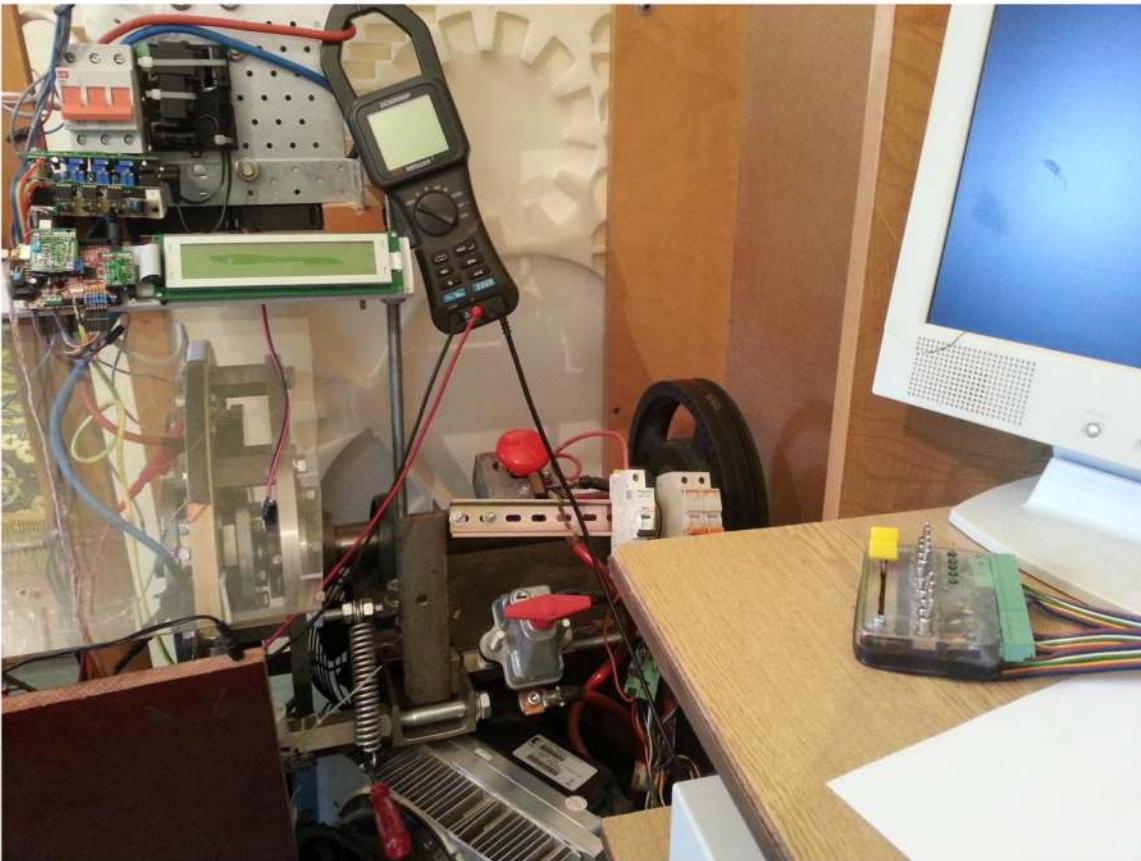
# Electrical System Improvement

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 1-st rev.



# Electrical System Improvement

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 1-st rev.



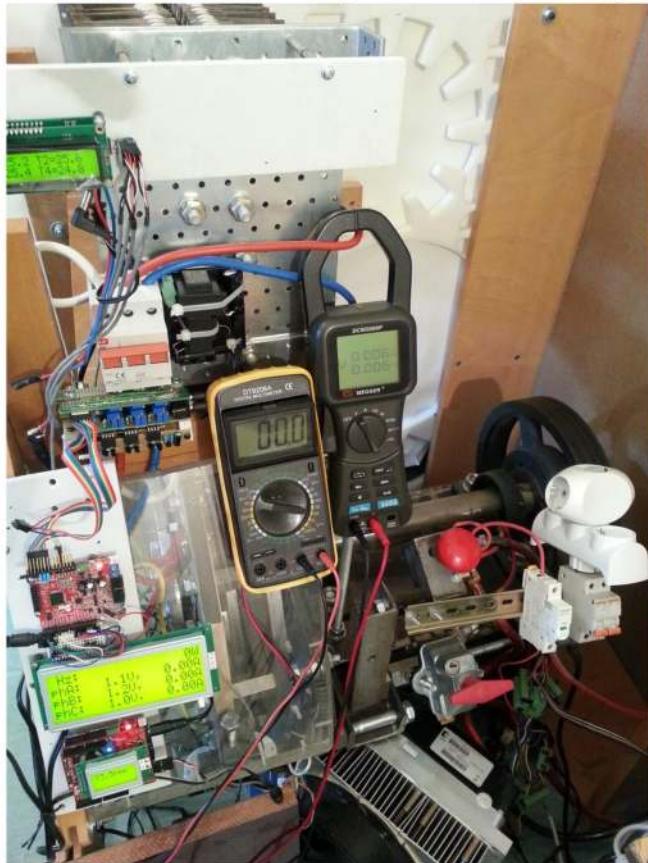
# Electrical System Improvement

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



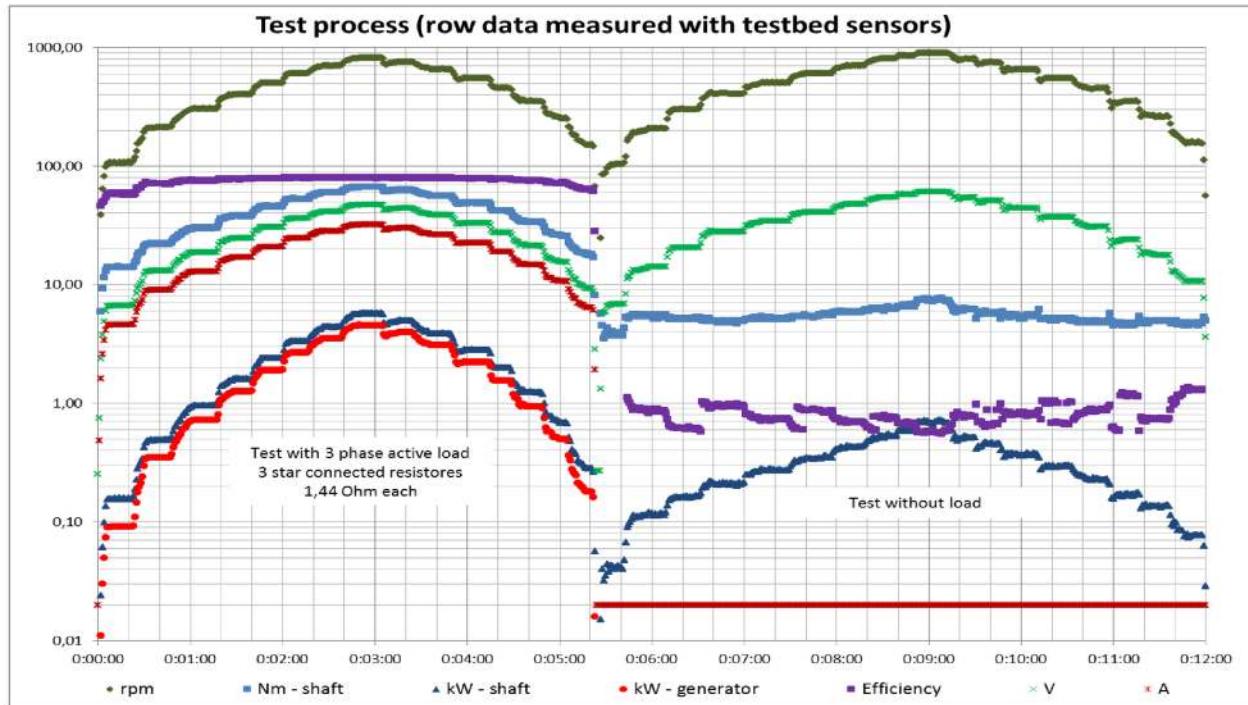
# Electrical System Improvement

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



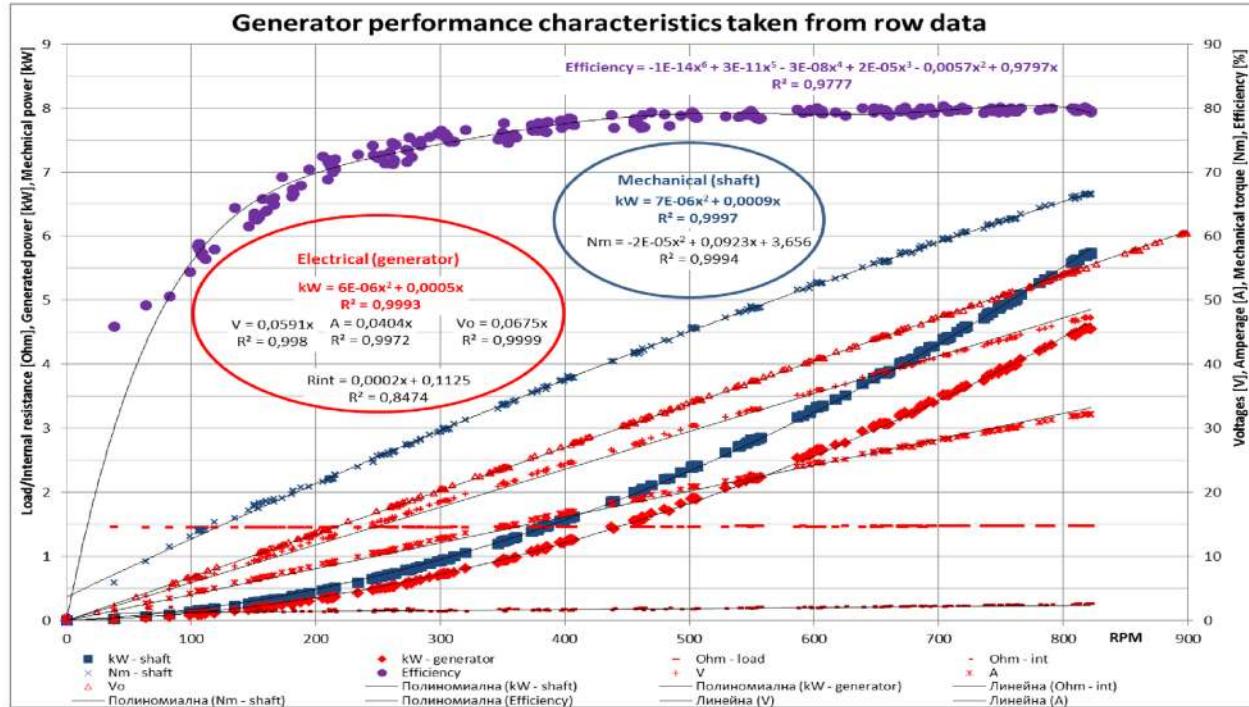
# Measurement Results

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



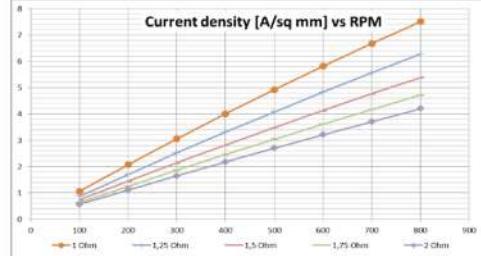
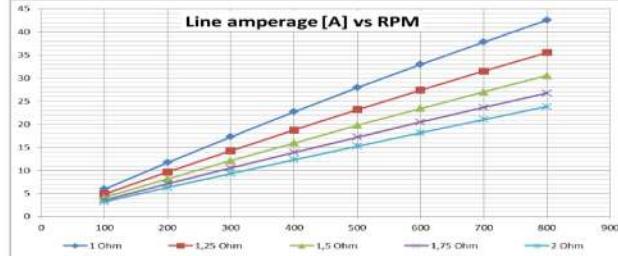
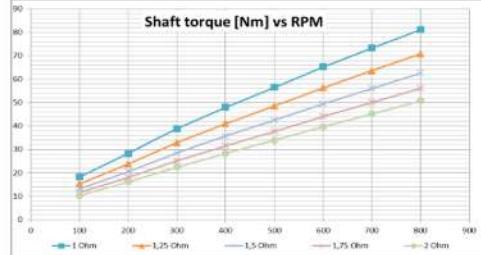
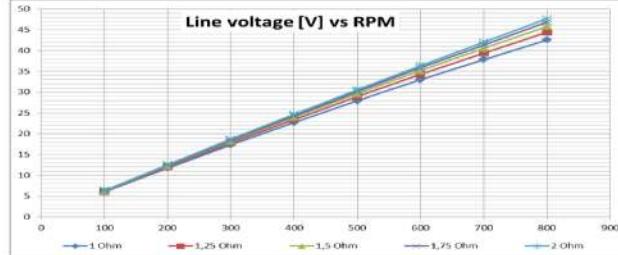
# Measurement Results

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



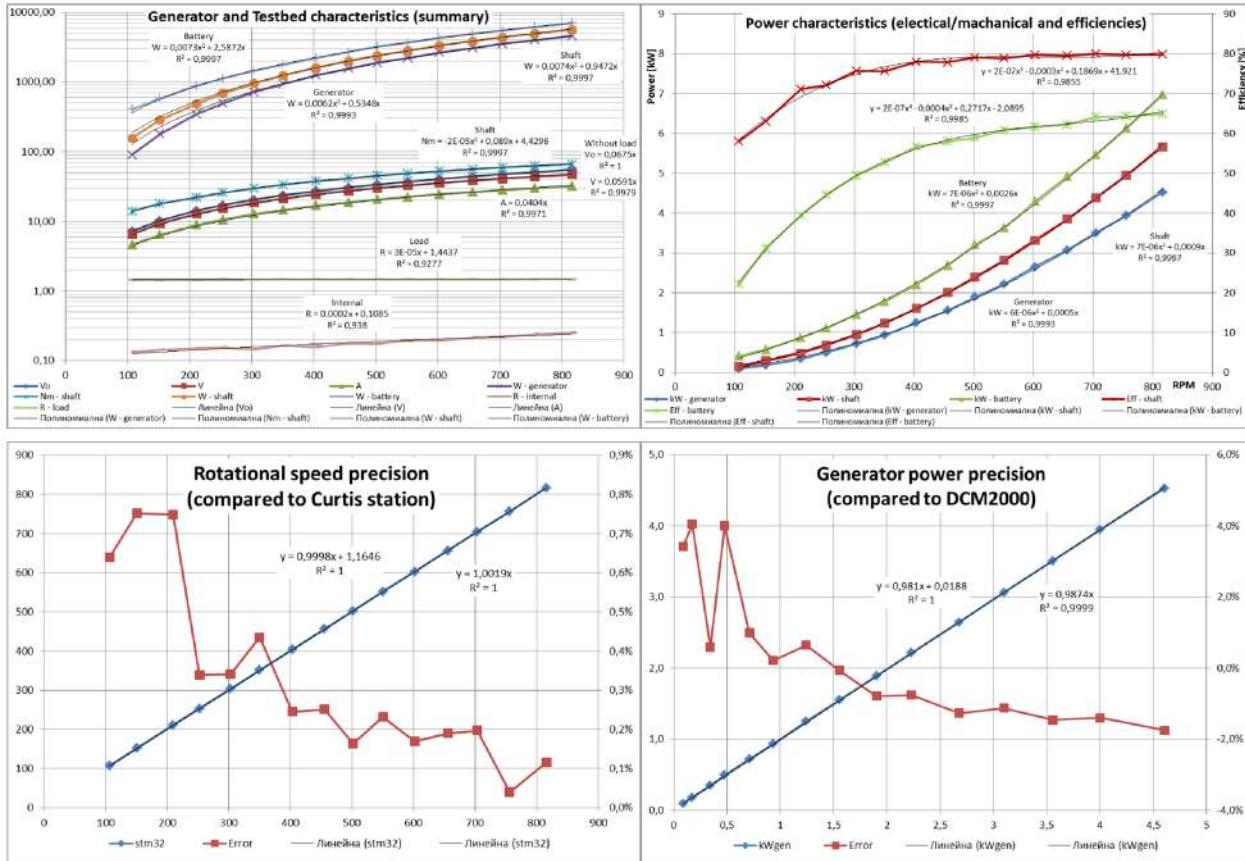
# Measurement Results

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



# Measurement Results

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



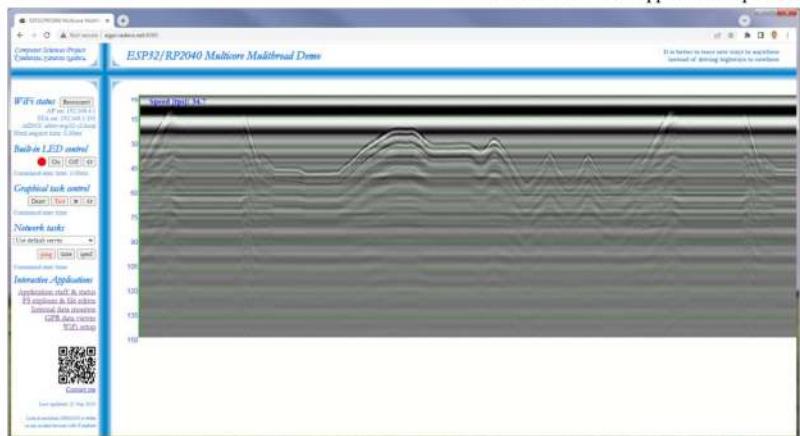
## Modified multicore application as the proof-of-concept for local and remote visualization of GPR data via ESP32-S3 board with TFT SPI 240x320 display

The modified multicore application is modification of the unified multicore application for ESP32 and RP2040 with 3.2" TFT SPI 240x320 display to run on RP2040, ESP32-WROOM and ESP32-S3-WROOM based boards. The main bug (impossibility to display and edit SPIFFS files in the file browser in case of compiling application against Espressif ESP32 core 2.0 or later) is fixed by own code instead of using SPIFFSEditor library component (part of the core ESPAsyncWebServer library). SPIFFS structure is changed to separate private and public files. The development process was eased thanks to using USB OTG JTAG/Serial (USBSerial) and UART0 (Serial) interfaces for uploading the program and printing of debug messages respectively. Serial ports on UART1 (Serial1) and UART2 (Serial2) are used to connect GPR and GPS devices.

It is also added a code to read GPR data via serial port and display them on local TFT display. A code based on AsyncEventSource is also added to send GPR data to all registered remote clients. Demo version of remote GPR data viewer is developed as web application to prove the concept. As it is visible from the photo below 5x remote clients are served in addition to the local display. There is no disturbance in any of the served local and remote viewers at more than 30 tps (tracks per second). For the moment GPR data are sourced by written in JavaScript simulator reading them from a SEGY file. At the first tests application can run on all Pi Pico W, ESP32-WROOM and ESP32-S3-WROOM based boards but only on ESP32-S3-WROOM one it is working without problems and stable enough.

In the final application for GPR data visualization some of the components in current application will be removed or modified and others will be added. The control of the GPR device by the local and remote viewers is under discussion. In case of remote control of the GPR device the concurrence may cause problems so it has to be assessed its usefulness. There are following alternatives for the local control: touch screen, rotational encoder or buttons. It is cleaner remote viewers to control visualization only. Saving of GPR data to file locally and/or remotely has to be discussed as well.

### Modified multicore application in pictures



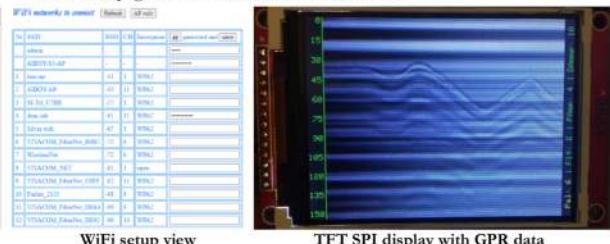
Test suit photo



SPIFFS browser

Internal data monitor

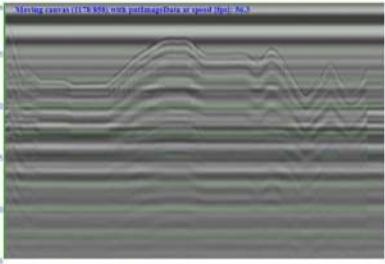
Main web page view with remote GPR data viewer



TFT SPI display with GPR data

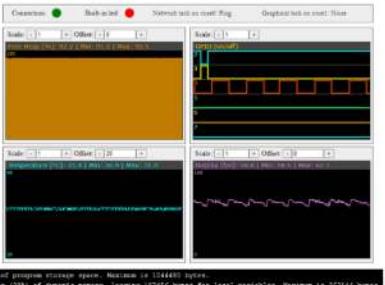
Modified multicore application for ESP32-S3-WROOM-1, RP2040 & CYW43439 and ESP32-WROOM with 3.2" TFT SPI 240x320 display – summary in pictures

ESP32-S3-WROOM-1 (Olimex  
ESP32-S3-DevKit-Lipo board)



56 tps @ 460800 bps

RP2040 & CYW43439  
(Raspberry Pi Pico W board)



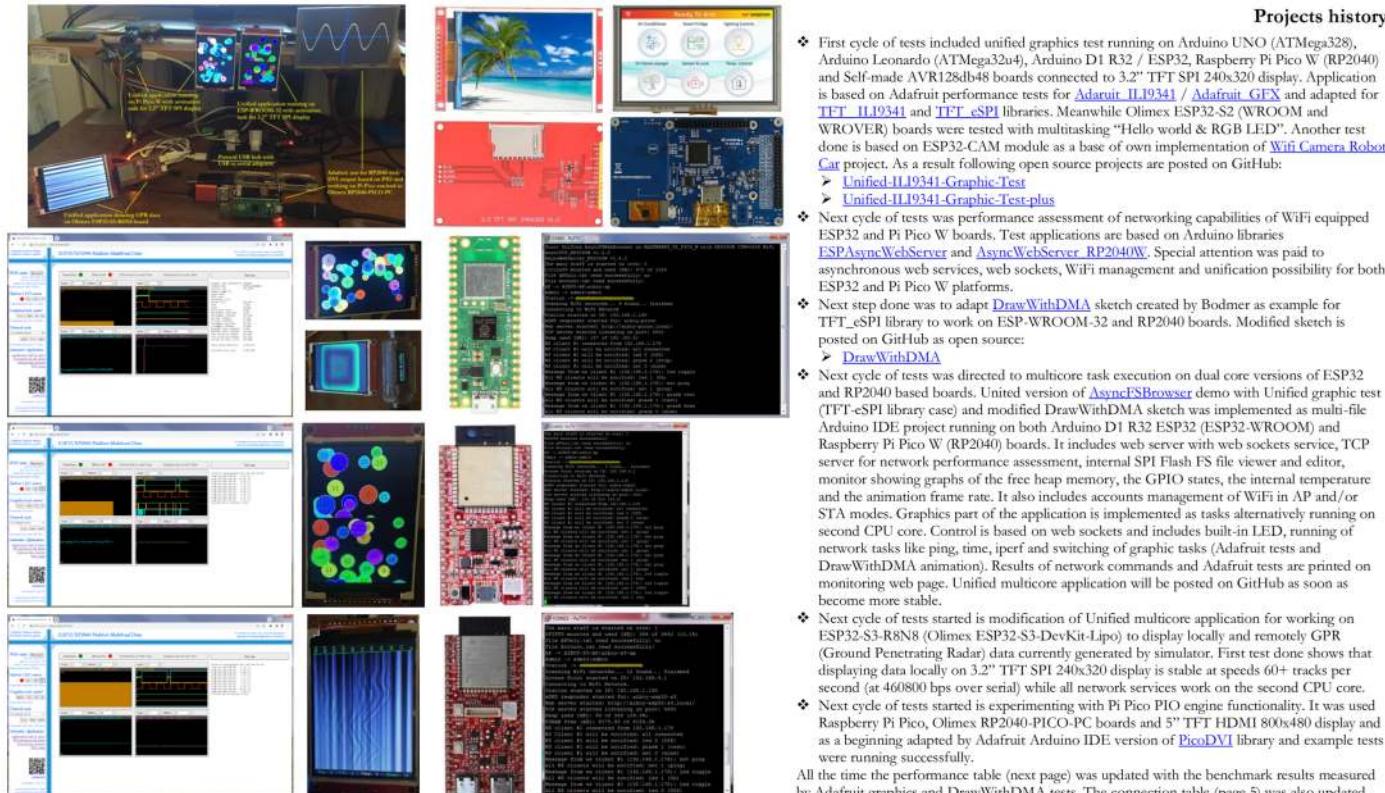
67 tps @ 460800 bps

ESP32-WROOM (Olimex  
ESP32-DevKit-Lipo board)



16 tps @ 115200 bps

## Unified multicore application for ESP32, RP2040 with 3.2" TFT SPI 240x320 display – summary in pictures and projects history



Full color PicoDVI test on Raspberry Pi Pico, RP2040-PICO-PC and 5" TFT HDMI 800x480 display



## Benchmark of unified graphic and scroll tests built on Adafruit\_ILI9341, TFT\_ILI9341 and TFT\_eSPI libraries

Arduino board / MCU	UNO / ATMega328		Leonardo / ATMega32u4		D1 R32 / ESP32			Pi Pico / RP2040			Pi Pico / RP2040 (Overclocked)			Unified App		AVR128db48	ESP32-S3			
ILI9341 Library used (SPI clock)	Adafruit	TFT	Spec'd up	Adafruit	TFT	Spec'd up	Adafruit (3MHz)	TFT_eSPI	Speed up	Adafruit	TFT_eSPI (27MHz)	Speed up	Adafruit	TFT_eSPI (62.5MHz)	Speed up	TFT_eSPI with DMA	Adafruit	Adafruit (27MHz)		
<b>Memory usage [B]</b>																				
<b>Flash used:</b>	23,736 of 32,256 (73.59%)	21,870 of 32,256 (67.80%)		25,874 of 32,256 (90.24%)	23,992 of 28,672 (83.68%)		237,600 of 1,310,720 (18.13%)	295,261 of 1,310,720 (22.52%)		327,772 of 2,093,056 (15.65%)	372,092 of 2,093,056 (17.78%)		327,868 of 1,568,768 (20%)	372,180 of 1,568,768 (23%)		505,232 of 1,044,480 (48%)	24,354 of 1,044,480 (18.65%)	295,261 of 1,310,720 (22.52%)		
	950 of 2,048 (46.39%)	746 of 2,048 (36.43%)		915 of 2,560 (35.74%)	711 of 2,560 (27.77%)		37,264 of 327,680	19,480 of 327,680		71,324 of 262,144 (11.37%)	71,768 of 262,144 (5.94%)		71,324 of 262,144 (27.21%)	71,768 of 262,144 (27.38%)		74,912 of 262,144 (27%)	1,087 of 16,384 (28%)	19,480 of 327,680 (6.63%)		
<b>Benchmarks [us]</b>					<b>~42°C</b>					<b>~32°C</b>					<b>~34°C</b>		<b>~36°C</b>		<b>~50°C</b>	
Screen fill	1,496,456	870,220	1,720	1,503,900	874,600	1,720	2,120,993	274,575	9,097	604,056	281,577	2,145	497,451	107,972	4,607	107,567	1,603,604	274,575		
Text	147,068	60,416	2,435	147,820	60,724	2,434	99,610	32,599	6,491	45,452	18,831	2,414	30,599	8,085	3,785	8,070	114,885	32,599		
Lines	1,172,116	242,732	4,829	1,178,004	243,988	4,828	986,748	339,491	10,975	454,856	101,897	4,464	304,234	42,741	7,118	43,648	946,199	339,491		
Horiz/Vert Lines	125,064	71,336	1,753	125,656	71,696	1,753	173,171	24,171	8,603	50,042	23,541	2,126	40,853	9,078	4,500	8,880	132,637	24,171		
Rectangles (outline)	82,228	45,844	1,794	82,632	46,076	1,793	110,682	15,996	8,697	32,657	14,932	2,187	26,417	5,773	4,576	5,686	85,703	15,996		
Rectangles (filled)	3,107,060	1,807,436	1,719	3,122,844	1,816,740	1,719	4,402,687	570,510	9,096	1,253,856	584,372	2,146	1,032,576	224,086	4,608	223,506	3,329,307	570,510		
Circles (filled)	452,728	284,064	1,594	454,916	285,536	1,593	492,735	95,809	7,704	167,914	71,149	2,360	126,969	28,025	4,531	27,896	423,221	95,809		
Circles (outline)	497,252	135,580	3,668	499,604	136,149	3,670	432,728	150,143	12,978	199,626	37,258	5,358	133,263	15,561	8,564	15,743	404,412	150,143		
Triangles (outline)	261,056	59,496	4,388	262,392	59,808	4,387	225,959	74,819	10,265	101,400	23,636	4,290	68,473	10,319	6,636	10,463	213,681	74,819		
Triangles (filled)	1,330,720	694,456	1,916	1,337,200	698,032	1,916	1,432,757	209,558	8,691	429,998	195,995	2,194	345,244	75,450	4,576	75,102	1,279,412	209,558		
Rounded rects (outline)	228,892	100,004	2,289	230,024	100,532	2,288	230,767	62,675	11,013	92,280	23,635	3,904	65,233	9,576	6,812	9,602	200,582	62,675		
Rounded rects (filled)	3,127,968	1,976,936	1,582	3,143,588	1,987,180	1,582	4,384,111	578,880	8,995	1,257,871	586,292	2,145	1,032,024	225,027	4,586	224,252	3,330,751	578,880		
Fill screen by pixels	3,369,992	918,732	3,668	3,387,308	923,492	3,668	2,783,609	1,591,181	3,331	1,255,234	504,753	2,487	805,373	229,258	3,513	159,327	2,964,859	1,591,181		
Fill screen by bitmaps	528,576	855,088	0,618	531,112	859,520	0,618	435,203	62,752	0,518	66,438	520,180	0,128	70,363	234,904	0,300	166,092	453,099	62,752		
Scroll and fill screen	532,988	855,696	0,623	535,808	860,132	0,623	439,860	67,668	0,520	69,357	521,011	0,133	71,933	235,385	0,306	166,606	457,946	67,668		
Min	82,228	45,844		82,632	46,076		99,610	15,996		32,657	14,932		26,417	5,773		5,686	85,703	15,996		
Avg	1,097,346	598,536	1,833	1,102,854	601,614	1,833	1,250,108	276,722	4,497	405,402	233,937	1,733	310,067	97,416	3,183	83,496	1,062,687	276,722		
Max	3,369,992	1,976,936		3,387,308	1,987,180		4,402,687	1,591,181		1,257,871	586,292		1,032,576	235,385		224,252	3,330,751	1,591,181		
Sum	16,460,184	8,978,036		16,542,808	9,024,204		18,751,620	4,150,827		6,081,037	3,509,059		4,651,005	1,461,240		1,252,440	15,940,298	4,150,827		
DrawWithDMA test (bouncing of 42 colored and numbered circles)								36fps (Unified App)			17.8fps at CPU 133MHz SPI 27MHz			46.5fps at CPU 250MHz SPI 62.5MHz	2.6	46.5fps at CPU 250MHz SPI 62.5MHz		60+fps at GPR data visualisation		

### Notes:

- Memory usage numbers are as reported in runtime and slightly different than one reported by the compiler;
- Preparing of the data for filling the screen by pixels or bitmaps are made to be as fast as possible;
- Numbers for "Scroll and fill screen" tests at TFT\_ILI9341 and TFT\_eSPI libraries should be revised;
- At combination ESP32 and Adafruit\_ILI9341 library SPI frequency was lowered to 3MHz while in case of ESP32 S3 SPI frequency can be increased up to 27MHz but in unified application with WiFi networking TFT\_eSPI library has some problems especially at using DMA;
- Numbers in "Speed up" column means the operation is that many times faster;
- Overclocking in case of Pi Pico includes increasing of SPI and CPU speeds up to 62.5MHz and 250MHz respectively and application of suggested solution by Bodemar in his Github issue 1460 (working reliably even with 30cm long wires);

• Cases with ESP32 (Unified App), overclocked RP2040 (Unified App) and ESP32-S3 (colored in light violet) were measured by Unified multicore application (in combination with AsyncFSWebBrowser).

### Useful links for display of animation with DMA and speed assessment:

[Raspberry Pi Pico with ILI9341 TFT and TFT\\_eSPI Arduino library using RAM & DMA](https://github.com/adafruit/ILI9341_TFT_and_TFT_eSPI_Arduino_library_using_RAM_and_DMA)

[https://forum.arduino.cc/t/tft\\_eSPI-support-for-raspberry-pi-pico-added/70251](https://forum.arduino.cc/t/tft_eSPI-support-for-raspberry-pi-pico-added/70251)

[https://www.youtube.com/watch?v=mlENzCTQ\\_Q](https://www.youtube.com/watch?v=mlENzCTQ_Q)

[https://github.com/Bodemar/TFT\\_eSPI/issues/1460#issuecomment-100661452](https://github.com/Bodemar/TFT_eSPI/issues/1460#issuecomment-100661452)

This application uses two sprites in RAM and DMA for filling display half buffer while updating the other half. The ILI9341 display operates reliably on Pi Pico up to 62.5MHz so frame rate up to ~43fps is possible with DMA. Overclocking CPU to 250MHz and applying Bodmire notes makes it possible frame rates to go up to 46.5fps. The total consumption in overclocked mode of both Pi Pico and SPI TFT is 110mA. The application is unified to run on both RP2040 and ESP-WROOM-32 boards. In case of ESP32 frame rate was lower (~36fps).

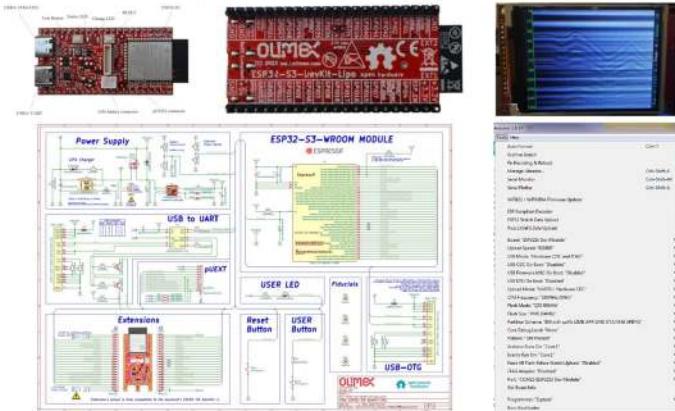
## Modified multicore application for ESP32-S3, RP2040 and ESP32 to display GPR data locally and remotely

Modified multicore application is based on Unified multicore application which is combination of AsyncFSWebBrowser demo application, Unified graphic test (TFT-eSPI library) and DrawWithDMA sketches. It is targeted to ESP32-S3 based Olimex ESP32-S3-DevKit-Lipo board.

ESP32-S3 is a dual-core Xtensa LX7 core, capable of running at 240 MHz. It also comes with integrated 2.4 GHz, 80.11 b/g/n Wi-Fi and Bluetooth 5 (LE) connectivity that provides long-range support. It has 45 programmable GPIOs and supports a rich set of peripherals. ESP32-S3 supports larger, high-speed SPI flash, and PSRAM and PSRAM with configurable data and instruction cache.

Olimex ESP32-S3-DevKit-Lipo board with ESP32-S3-WROOM-1-R8R has 8MB PSRAM and 8MB SPI Flash. It also has pU-EXT and 2x USB C connectors (via CH340 USB-to-Serial adapter and native OTG) (T)AG Serial with串口 PHY), LiPo battery charger and connector, user and reset buttons and user and charge LEDs. All GPIO pins are routed to 2x22 pins connectors compatible to the Expressif ESP32-S3-DPFL-1C.

Development is made on Windows 7 / 10 using Arduino IDE (ver. 1.8.9), the latest Expressif system version 2.0.14, AsyncWebServer, Adafruit\_ILI9341, Adafruit\_GFX etc. libraries (all latest versions). Node.js (ver. 12.22.7) with serialport library (ver. 8.0.5) is used to develop and use "gpr-simulator" application. To power and connect the board to the computer may use powered 4+ USB Host, 2x USB A to USB C cables and 2x CP2102 USB-to-Serial adapters. Install CH340 and CP210x drivers for Windows if required.



For user configuration of internal SPI flash do following changes:

at esp32-S3 based files in \hardware\esp32\esp32\partition-tables\user\esp32\partitions\user\esp32\_0\_1\rp2040\users.txt:  
# User partition table for RP2040

esp32-S3\user\partition-tables\user\esp32\partitions\user\esp32\_0\_1\rp2040\users.txt:  
# User partition table for RP2040

At file C:\Users\Boris\Documents\Arduino\local\hardware\esp32\esp32\partition-tables\user\esp32\_0\_1\rp2040\users.txt:  
# User partition table for RP2040

# Name, Type, offset, size, Flag  
root, data, mnt, 0x0000, 0x0000,  
sdcard, data, mnt, 0x0000, 0x0000,  
appfs, data, mnt, 0x0000, 0x0000,  
app, data, mnt, 0x0000, 0x0000,  
spiffs, data, spiffs, 0x1000, 0x0000,  
coring, data, coring, 0x0000, 0x0000,

and at esp32-S3 based files in \hardware\esp32\esp32\partition-tables\user\esp32\partitions\user\esp32\_0\_1\rp2040\users.txt:  
# User partition table for RP2040

esp32-S3\user\partition-tables\user\esp32\partitions\user\esp32\_0\_1\rp2040\users.txt:  
# User partition table for RP2040

At file C:\Users\Boris\Documents\Arduino\local\hardware\esp32\esp32\partition-tables\user\esp32\_0\_1\rp2040\users.txt:  
# User partition table for RP2040

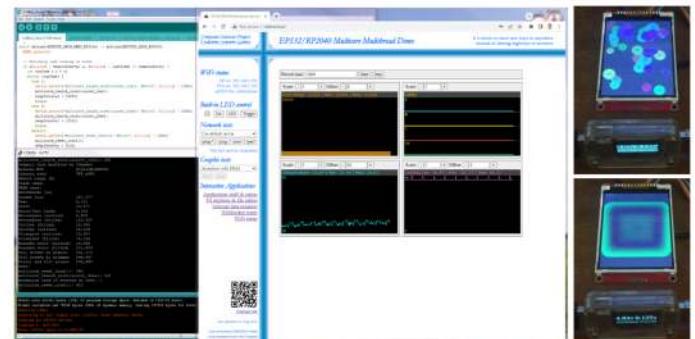
Save new copy of Unified multicore application under other name (like GPR\_Display) and remove not relevant components like TCPServer.ino, DrawWithDMA.ino, Unified\_Ar9340\_Graphic\_Task\_physics and create new components GPR\_Task.ho and GPS\_Task.ho. Additional component SPIFFS based FSDirectory.h is added instead of SPIFFSEditor to overcome its problem if ESP32 core ver. 2.0 and later is used. Restructure SPIFFS file stuff to separate private and public files. Restart Arduino IDE and re-flash SPIFFS changes to take effect. Modify the staff in GPR\_Display.ho and WebSockets.ho according to changes made. Write required staff in GPR\_Task.ho to read data from Serial2 and display them on 3.2" TFT SPI 240x320 display. GPR\_Task has to be set to run on CPU core0 (not running main application). Use board configuration in Arduino -> Tools as shown above. ESP32-S3 may be programmed via native USB OTG JTAG/Serail port (COM23); Serial port via CH340 USB-to-Serial adapter (COM20) is used for debug information printing and as a spare channel for application programming. ESP32-S3 Serial port is used to connect GPR module later on.

Web files are located in project subfolder named "data". They can be flashed to internal SPI Flash using Atmel tool "ESP32 Sketch Data Upload". Application "esp\_tool\_gfx" may also be used to check ESP32-S3 information and configuration. For testing purposes JavaScript simulator is written to read GPR data from SEGY file and send them via ESP32-S3 Serial port (via CP2102 USB-to-Serial adapter on COM22). In future is planned JavaScript GPS simulator to be developed to read data from GPS file and send them to ESP32-S3 Serial port (via CP2102 USB-to-Serial adapter on COM22).

Notes:

- In future both USB OTG JTAG/Serail and CH340 USB to Serial port may be used as host for storing of archive data files) and CDC device (for connecting to other computer) respectively but some pins have to be soled so currently they will be used for development purposes only;
- In case of more space needed SPIFlash partition scheme can be changed or ESP32-S3 module with more flash (16/32MB) can be used;
- Usage of SPI SD card slot located at 3.2" TFT SPI 240x320 display board for storing of archive files is also possible;
- Lack of ESP32-S3 reset after application flashing via USB OTG JTAG/Serail port bug is not observed;

## Unified multicore application for ESP32 and RP2040 – more than combination of AsyncFSWebBrowser and graphic tests



Unified multicore application is based on AsyncFSWebBrowser, Unified graphic test (TFT-eSPI library) and DrawWithDMA sketches. It is Arduino IDE multicore application for esp32-S3 and RP2040 boards. It is running on both boards (ESP32-S3 based on Olimex ESP32-S3-DevKit-Lipo board and RP2040 based on Adafruit TTG Test Board) and controlled by Adafruit TFT library and lot of memory graphical tasks to work on the other core, web application with internal monitor showing graphs of the free heap memory, the GPIO states, the internal temperature sensor and the animation frame rate. On the right are shown pictures of graphical tasks (animation and graphical tests) and all Adafruit TFT tests adapted to work with the eTFT library.

The most attractive application feature is almost complete independency of the performance of tasks running on different CPU cores. Other impressive result is graphical performance of animation task (46 frames per second at 42 bouncing circles) and all Adafruit TFT tests adapted to work with the eTFT library (especially scrolling 320x240 graphics at speed of 0.8ms per 240 pixels line). Next pictures represent final version of unified multicore application in action.



On the left most pictures are shown views with graphs of the internal system and application parameters (left) and WiFi setup page (right). It is evident that the results of the invoked commands and monitors (as well as other clients) are synchronized and ESP32 WiFi works in AP+STA mode (top-left WiFi icon). Graphical task log in the monitor view is showing the best results ever achieved (look at the table on page 7). This snapshot is taken after complete unification of the application for PI\_Pico\_W (left) and ESP32 (top-right) platforms and adding network tasks control bar (only ping is implemented for the moment).

On the right most pictures are shown TFT displays in action connected to PI\_Pico\_W (top-left) and ESP32 (top-right) boards while running unified application. The current state of the application is not stable and has some bugs especially for ESP32 where bouncing circles are only moving at the bottom half of the screen, but crosses form time to time at exchanging of the graphic tasks.

In the special modification of the unified multicore application running on ESP32-S3-R8NR (rightmost bottom) is implemented preliminary test for displaying of data from GPR (Ground Penetration Radar) received via serial link and shown as 320x240 pixels scrolling graphics with up to 18 tracks per second speed.

## Network performance using AsyncWebServer and AsyncTCP libraries on Pi Pico W and ESP32 series of boards

Startup projects working on ESP32-S2 Olimexino boards and based on [ESPAsyncWebServer library for Arduino](#):



• [ESP32 Create a WiFi Manager \(AsyncWebServer Example\)](#)

Application uses SPIFS on ESP32 memory to hold web configuration files which have to be uploaded manually by "ESP32 Sketch Data Upload" tool of Arduino IDE. The application runs in AP mode using connection credentials of the local router. After storing them in FS files and restart it runs in STA mode. Main web page allows controlling built-in LED.



• [ESP32 WebSocket Server: Control Outputs \(Arduino IDE\)](#)



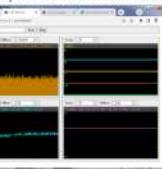
Application on ESP32 runs in STA mode with credentials defined in the sketch and open WebSocket server to control the LED. Its status can be changed by any client and will be updated at all clients.

It was used Adafruit NeoPixel library to run above projects on Olimexino S2 series of boards with RGB instead of regular LED.

DrawWithDMA TFT\_eSPI library test was compiled and run successfully on Raspberry Pi Pico W. Later on AsyncFSWebServer and DrawWithDMA combined multithread application was done by simply putting both files in a single project, renaming setup and loop functions in the second file to setup1 and loop1 and commenting the line Serial.begin(115200). Display drawing (42 circles) speed was the same (17.85fps) without appreciable change in the web access. Temperature measured by internal sensor is increased from 50MHz up to 150MHz. CPU overclocking to 250MHz did not affect display drawing and web access but increase the temperature with approximately 10% (up to 34°C). SPI pins can be changed in UserConfig.h of TFT\_eSPI library. Change of SPI pins from 53 to 54 or 55 to 56 did not result in any display drawing problem. Clock generation and CPU clocking at 125MHz (SPI clock @ 62.5MHz) display drawing can be up to 43.45fps @ 62 circles and 46.3fps @ 36 circles. Overclocking CPU to 250MHz (possibly SPI clock in again 62.5MHz) increase display drawing speed up to 46.5fps @ 42 circles (2.6x) while working smoothly and reliably. Total consumption is increased from 110mA in case of overclocked DrawWithDMA single core application up to 144mA for combined multicores application.



Remote file manager and editor



On-line monitor



SPI/TFT display

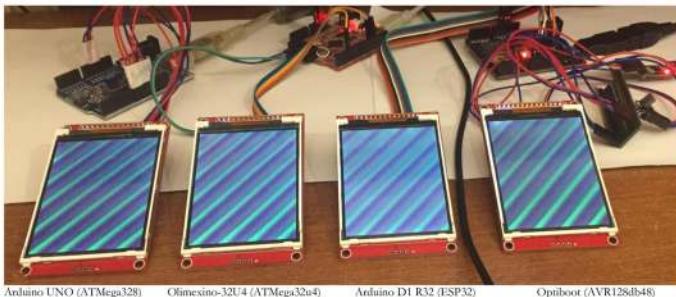
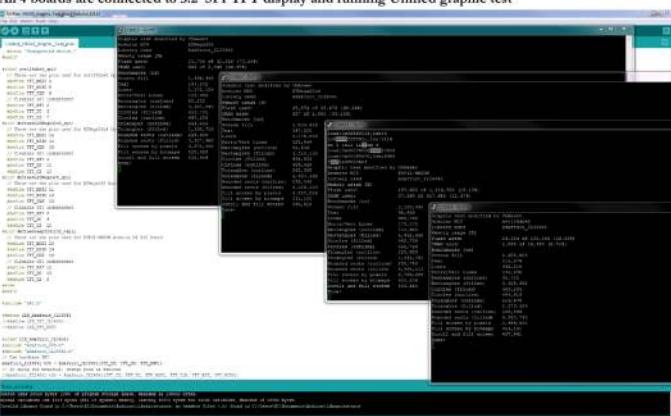
[AsyncWebServer for RP2040W](#) library built by Khoi Hoang is based on and modified from [ESPAsyncWebServer](#) library support of ESP32 and ESP8266 on Arduino cores. Next steps to be done for building of unified multithread application:

- Check of the code compatibility for both ESP32 and Pi Pico W boards;
- Dynamically running of different tasks on the second CPU core;
- Build unified web server application with WiFi working in AP and/or STA modes including its management, mDNS, LittleFS, WebSockets etc.

## Connection setup for 3.2" 240x320 pixels TFT display with SPI interface

	3.2" TFT SPI LCD Display	Arduino UNO ATmega328	Olimexino-32U4 ATMega32U4	Opitboot AVR128db48	Arduino R32 ESP-WROOM-32	Raspberry Pi Picos RP2040	ESP32-S3-WROOM	Signal description (3.2" TFT SPI LCD Display)
1	VCC	VCC-3.3V	VCC-3.3V	VCC-3.3V	VCC-3.3V	VCC-3.3V	3.3V	3.3V power input (do not connect to 5V)
2	GND	GND	GND	GND	GND	GND	GND	GND
3	CS	D10	D13	0.08S, PA7	I005	GPIO17	GPIO10	LCD chip select signal, low level enable
4	RESET	D8	D4	PA2 (0.05I)	I012	GPIO24	GPIO9	LCD reset signal, low level reset
5	DC/RS	D9	D11	PA3 (0.05I)	I013	GP20	GPIO14	LCD register / data selection signal, high level: register, low level: data
6	SDI(MOSI)	D11	D16	0.MOSI, PA4	I025	GP16	GPIO11	SPI bus write data
7	SCK	D13	D15	0.SCK, PA6	I016	GP18	GPIO10	SPI bus clock signal
8	LED	VCC-5V	VCC-5V	VCC-5V	VCC-5V	3V	Backlight control, high level lighting, if not connected, connect 5V for always bright	SPI bus enable signal
9	SDO(MISO)	D12	D14	0.MISO, PA5	I019	GP19	GPIO3	SPI bus read data signal, if you do not need to the read function, you cannot connect it

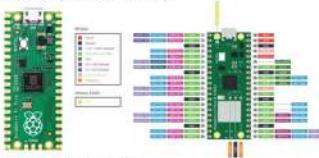
All 4 boards are connected to 3.2"SPI TFT display and running Unified graphic test



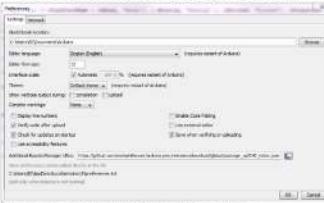
Arduino Uno (ATmega328)    Olimexino-32U4 (ATmega32U4)    Arduino R32 (ESP32)    Opitboot (AVR128db48)

## Arduino Pi Pico (W) boards

- For using Pi Pico (W) boards



- In Preferences add URLs:  
[https://github.com/earlghillhower/arduino-pico/releases/download/global/package\\_ip2040\\_index.json](https://github.com/earlghillhower/arduino-pico/releases/download/global/package_ip2040_index.json)



- Install Pi Pico / RP2040 in board manager



- Install "Raspberry Pi Pico" or "Raspberry Pi Pico W" board



- Connect the board to Windows PC while BOOTSEL button is pushed - "RPI-RP2" mass storage device should be appeared
- After uploading the sketch "Pico" or "Pico W" device will be appeared in "Device Manager"
- Update its device driver using Atmel USB to serial IMF file. Download DevKit-Lipo driver from [www.ESP32-S2-WHOVER-DevKit-Lipo.com](http://www.ESP32-S2-WHOVER-DevKit-Lipo.com)
- Change [Strings] sections also to appropriate once

## Multicore version of "Hello World and Blinking LED" common test for Pi Pico

```

• Open from File -> Examples -> {Examples for Raspberry Pi Pico} -> FreeRTOS -> Multicore FreeRTOS sketch and save it to your Arduino sketch folder;

#include <FreeRTOS.h>
#include <task.h>
#include <nop>
#include <EEPROM.h>
std::map<TaskState, Const Char *> eTaskStateName {
    {eIDLE, "IDLE"}, {eRunning, "Running"}, {eBlocked, "Blocked"}, {eSuspended, "Suspended"}, {eDeleted, "Deleted"}, {eNone, "None"}};
void pd()
{
    int tasks = uxTaskGetNumberOfTasks();
    TaskStatus_t pxTaskStatusArray[ new ];
    TaskStatus_t *pxTaskStatusArray;
    unsigned long runtime;
    pxTaskGetSystematic(pxTaskStatusArray, tasks, &runtime);
    Serial.printf("# Tasks %d\n", tasks);
    Serial.println("ID, NAME, STATE, PRIO, CYCLE");
    for (int i=0; i < tasks; i++) {
        pxTaskStatusArray[i].eCurrentPriority,
        pxTaskStatusArray[i].eCurrentPriority,
        pxTaskStatusArray[i].ulRunTimeCounter);
        delete[] pxTaskStatusArray;
    }
}

void blink(void) param {
    (void)param;
    pinMode(LED_BUILTIN, OUTPUT);
    while(1)
    {
        digitalWrite(LED_BUILTIN, LOW);
        delay(500);
        digitalWrite(LED_BUILTIN, HIGH);
        delay(500);
    }
}

void setup() {
    Serial.begin(115200);
    xTaskCreate(blink, "BLINK", 128, NULLptr, 1, multipr);
    delay(5000);
}

volatile int val= 0;
void loop() {
    Serial.printf("*C0: Blue Leader standing by...\r\n");
    pause();
    Serial.printf("*val: %d\r\n", val);
    delay(1000);
}

// Running on core1
void setup() {
    delay(5000);
    Serial.printf("C1: Red leader standing by...\r\n");
}

void loop() {
    static int x = 0;
    Serial.printf("C1: Stay on target...\r\n");
    val++;
    if (i+x < 10) {
        EEPROM.write(i+12);
        EEPROM.write(0,x);
        EEPROM.commit();
    }
    delay(1000);
}

• It demonstrates a simple use of the setup() /loop() functions for a multiprocessor run and following will be printed on the serial port while LED is blinking:
```

C1: Stay on target...

C0: Blue leader standing by...

C1: Tasks: 9

ID, NAME, STATE, PRIO, CYCLE

0: CORE0	Running	4	191473164
1: IDLE0	Running	0	36220232404
2: IDLE0	Ready	0	3371562651
3: BLINK	Blocked	1	1032697338
4: CORE1	Blocked	4	1032697388
5: OSB	Blocked	6	3826967365
6: TMR SW	Blocked	2	21071
7: IdleCore0	Suspended	7	17213
8: IdleCore0	Suspended	8	89886622
		val:	603

## ESP32-S2/3 boards on Arduino IDE

- For using ESP32-S2 boards like:

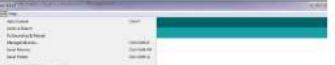


- Install the ESP32-S2 support for Arduino IDE
- In "File" -> "Preferences" add URL:  
[https://espresif.github.io/arduino-esp32/package\\_esp32\\_index.json](https://espresif.github.io/arduino-esp32/package_esp32_index.json)
- In "Tools" -> "Boards" -> "Board Managers" search for the esp32 platform and install ver. 2.0.0 or later

- Restart IDE and select board in "Tools" -> "Board":  
o "ESP32S2 Dev Module" for ESP32-S2-DevKit-Lipo



- "ESP32S2 Native USB" for ESP32-S2-WHOVER-DevKit-Lipo-USB



- "ESP32S3 Dev Module" for ESP32-S3-DevKit-Lipo



- Connect ESP32-S2/3-DevKit-Lipo and install driver for USB-Serial CH340 adapter if needed

- Connect ESP32-S2-WHOVER-DevKit-Lipo and put it in boot loader's mode (hold GND low while reset)
- Install driver with [Radicig software](#) if needed
- Enable in "options" -> "list all devices"
- Choose device "ESP32-S2 (Interface 2)"
- And option "USB Serial (CDC)"
- Any time for programming ESP32-S2-WHOVER-DevKit-Lipo-USB has to be put in boot loader's mode and reset manually after uploading the sketch

## Multitasking "Hello World & RGB LED" test

```

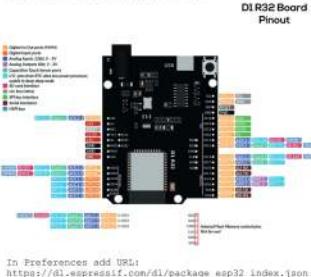
/* 
 * Requires Adafruit NeoPixel library
 */
#include <Adafruit_NeoPixel.h>
#define PIN 11
#define NUMPIXELS 1
#define PERIOD 10 //ms
Adafruit_NeoPixel pixels(NUMPIXELS, PIN,
                        NEO_GRB + NEO_KHZ800);

int colors[3];
void setup() {
    pixels.begin();
    for (int i = 1; i < 3; i++) colors[i] = 0;
    #if 1
    Serial.begin(115200); // ESP32-S2-DevKit-Lipo
    #endif
    #if 0
    Serial.begin(115200); // ESP32-S2-WHOVER-DevKit-Lipo-USB
    // Wait for serial port to connect.
    #endif
    #if 1
    // Needed for native USB port only.
    while (!Serial)
    {
        if (Serial.available())
            Serial.print("Hello World!");
        vTaskDelay(1000 / portTICK_PERIOD_MS);
        xTaskCreate(loop2, "loop2", 2048, NULL, 1, NULL);
    }
    int n = 0;
    void loop2(void * parameter) {
        while(1) {
            Serial.print("Hello World - ");
            vTaskDelay(1000 / portTICK_PERIOD_MS);
        }
    }
    void loop() {
        for (int i = 0; i < 3; i++) {
            for (j = 0; j < 256; j++) {
                colors[i] = j;
                pixels.setPixelColor(0, pixels.Color(colors[0]));
                pixels.setPixelColor(1, pixels.Color(colors[1]));
                pixels.setPixelColor(2, pixels.Color(colors[2]));
                pixels.show(); delay(PERIOD);
            }
            for (j = 255; j >= 0; j--) {
                colors[i] = j;
                pixels.setPixelColor(0, pixels.Color(colors[0]));
                pixels.setPixelColor(1, pixels.Color(colors[1]));
                pixels.setPixelColor(2, pixels.Color(colors[2]));
                pixels.show(); delay(PERIOD);
            }
        }
    }
}
• Compiler messages for ESP32-S2-WHOVER-DevKit-Lipo-USB
    size 29152 bytes (22%) of program storage space.
    Maximum is 1310720 bytes.
    Global variables use 27596 bytes (8%) of dynamic memory,
    leaving 300040 bytes for local variables. Maximum is
    327680 bytes.
• After running sketch on ESP32-S2-WHOVER-DevKit-Lipo-
    USB composite device will be installed with TinyUSB
    DFU_P7, CDC and ESP32-S2 Firmware MSC devices.
• Terminal connected to USB-Serial CH340 following
    commands will be sent from ESP32-S2-DevKit-Lipo:
ESP32-S2-DevKitLipo> AT&F&P25 2019
System messages
rst@Wk1: (PROMCR0).boot0x08 (S8E_FAST_FLASH_BOOT)
GPIN0@P0
clock div1
Load@0x3ffe6100, len=0x524
Load@0x00400c00, len=0x2070
Load@0x00500000, len=0x2959
entry@0x4004180
Send from loop task and will count every 2 sec
Hello World - 0
Hello World - 1
Send from loop task and will count every 2 sec

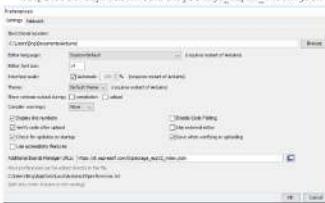
```

## Arduino D1 R32 ESP32 board

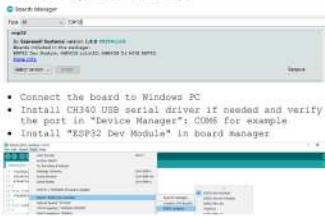
- For using ESP32 boards like D1 R32



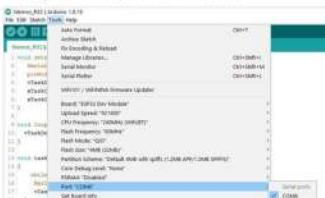
- In Preferences add URL:  
[https://dl.espressif.com/dl/package\\_esp32\\_index.json](https://dl.espressif.com/dl/package_esp32_index.json)



- Install esp32 in board manager



- Setup USB serial port as verified above



## Multitasking version of "Hello World & Blinking LED" test for ESP32

```

• Create new project "HelloWorld" and put the sketch:
void setup() {
    Serial.begin(115200);
    // This will print default SPI pins
    Serial.print("Default SPI pins:");
    Serial.print("MOSI: "); Serial.println(MOSI);
    Serial.print("MISO: "); Serial.println(MISO);
    Serial.print("SCK: "); Serial.println(SCK);
    Serial.print("SS: "); Serial.println(SS);
    vTaskDelay(1000 / portTICK_PERIOD_MS);
    xTaskCreate(task1, "task1", 2048, NULL, 1, NULL);
    xTaskCreate(task2, "task2", 2048, NULL, 1, NULL);
}

void loop() {
    vTaskDelay(1000 / portTICK_PERIOD_MS);
}

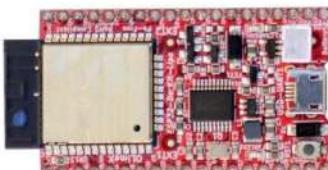
void task1(void * parameter) {
    while(1) {
        digitalWrite(2, HIGH);
        vTaskDelay(1000 / portTICK_PERIOD_MS);
        digitalWrite(2, LOW);
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
}

void task2(void * parameter) {
    while(1) {
        digitalWrite(3, HIGH);
        vTaskDelay(1000 / portTICK_PERIOD_MS);
        digitalWrite(3, LOW);
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
}

• After compilation will see:
Sketch uses 204926 bytes (15%) of program storage space.
Maximum is 1310720 bytes.
Global variables use 13416 bytes (4%) of dynamic memory,
leaving 314284 bytes for local variables. Maximum is
327680 bytes.

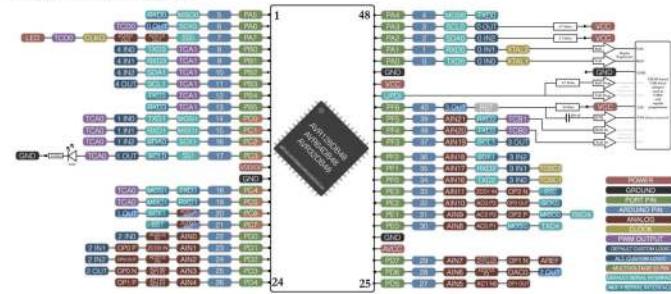
• After uploading sketch will see fast blinking LED and
following messages in terminal to USB serial port:
rst:00 (PWRUP), boot:0x13 (SPI_FAST_FLASH_BOOT)
os:ESP32
cp:1.10
os:1.10
clk_drv:0x0, q_drv:0x0, d_drv:0x0, cso_drv:0x0, hd_drv:0x0
D0,wp_drv:0x0
mode:DIO, clock:div1
load:0x3f001c, len:1216
ho 0 tail 12 room 4
load:0x40070000, len:10944
load:0x40080400, len:6388
load:0x40080504, len:6504
Default SPI pins: Default settings to VSPI
MOSI: 23
MISO: 19
SCK: 18
SS: 16
Hello World! Will be repeated every 2 sec
Hello World!
```

Alternative ESP32 development boards from Olimex based on ESP32-WROOM-32 or ESP32-WROOM WiFi/BLE modules



Variants compatible with Arduino D1 R32 ESP32 board:  
ESP32-devKit-LiPo and ESP32-DewinLiPo-EA

## AVR128db48 Arduino boards



Self-made AVR128db48 Arduino like board based on QFP adapter board

### Other boards notes:

- Arduino UNO – install windows driver for USB-Serial CH340 adapter,
- Olimex Nano – install windows driver for Arduino Leonardo compatible boards,
- Set in Tools → Board → Arduino AVR Boards → Arduino UNO or Arduino Leonardo respectively,
- Set in Tools → Port → corresponding COM port,
- LED pin may be different for different boards - change it in "Blinking LED" test sketch.

- For using AVR128db48 boards from Anton doi,

- Add URL in Preferences:  
[http://drazzy.com/package\\_drazzy\\_com\\_index.json](http://drazzy.com/package_drazzy_com_index.json)
- Install EsCore ver. 1.3.2 in board manager



- Connect CP2102 USB to UART Bridge to Windows PC
- Install CP2102 USB driver if needed and verify the port COM10 for example

### UDFI programmer (to burn bootloader)

- Connect CP2102 USB to UART Bridge to the board
- Rx = 4.7k res. - Tx - AVR128db48 UPIO (pin 4),  
o DTR = 200nF - RST (p. 40), GND, VCC (3.3V)
- Programmer: Serial Port + 4.7k Resistor (pyupdi style)\*
- Usage: Tools → Burn Bootloader
- Usage: Sketch → Upload Using Programmer

### Regular serial programmer

- Connect CP2102 USB to UART Bridge to the board
- o Rx = 4.7k res. - Tx - AVR128db48 Rx0 (p. 45)
- o CP2102/TTL-232R Rx - AVR128db48 Tx0 (p. 44)
- o DTR = 200nF - RST (p. 40), GND, VCC (3.3V)
- Usage: Sketch → Upload

Bootloader serial port could be USBARD2 (alt), but using USART9 the FTDI COM port for both programming and serial communication with the sketch will be the same.

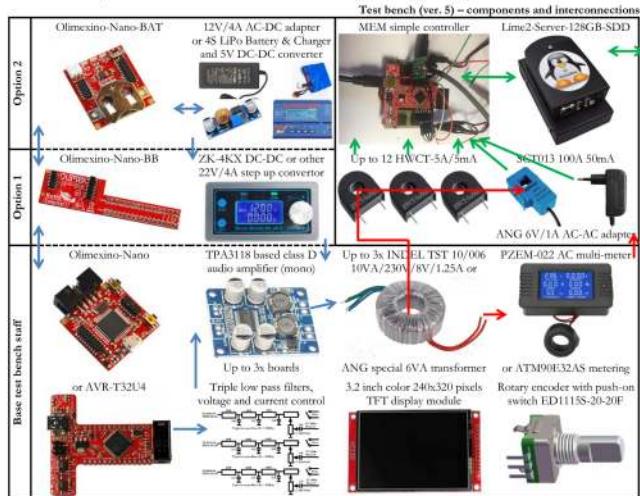
### "Blinking LED" test for avr128db48

```

void setup() {
    // PIN PC3 for avr128db48
    // may be different for other boards!
    pinMode(17, OUTPUT);
}
void loop() {
    digitalWrite(17, 1);
    delay(1000);
    digitalWrite(17, 0);
    delay(1000);
}
```

## MEM system test bench – 5<sup>th</sup> version planning and development

After measuring of some transformers parameters and waiting for a special ANG transformer production the test bench software was extended in following directions: PWM outputs of timer 4 were increased to 3s for implementing of 3-phase voltage and current source. In case of using it as a single phase 2s PWM outputs were used for separate voltage and current generating with controllable phase difference in the range of [0°, 180°]. In 3-phase variant voltage and current for each phase will be generated by a single transformer without phase difference between them. The main interface was added and tested with optoisolator switch ED1115S-20-20F (Code for Router with interrupt), 16x2 character LCD with I2C interface (LiquidCrystal\_I2C library for Arduino) and 3.2" 240x320 pixels TFT display with SPI interface. In case of TFT display Arduino UGlib color graphics library was used for low memory footprint. For better level control of voltages and currents digital potentiometer of Microchip MCP4261 was added and Arduino library available from <https://github.com/dreamer/Mcp4261> was used. After all above staff the sketch uses 92% flash and 34% RAM of Atmega32u4 memories resources and some of them will be freed after application optimization.



It is planned none monolithic design in the latest test bench (ver. 5). MCU controller staff and power supply components will be mounted in a single plastic box produced by 3D printing. Transformers and probably audio amplifiers will be mounted in separate adapter like plastic boxes. All transformers will be identical with 6V (6VA w-shaped) or 8V (10VA toroidal) primary and 230V secondary coils and a special single turn current coil. Current coil will be a copper wire with tunable length for producing currents up to 20A. In such a design the test could be used as a single or three-phase voltage and current source with up to 3 transformer units. In case of single phase usage with at least 2 transformer units phase difference between voltage and current could be controlled. The only scenario to control phase difference between voltage and current is to use the test bench as a single phase source with at least 2 transformer units. In such a case phase A will be used as voltage source and phase B as current one.

It is planned in future if have enough memory resources in Atmega32u4 AC multi-meter to be replaced by built-in metering part based on Microchip's [ATM90E32AS IC](#). In such a case voltage transformers will be replaced by resistive dividers. Other possible feature could be added is serial connection to tested MEM system for sending data and command for calibration.

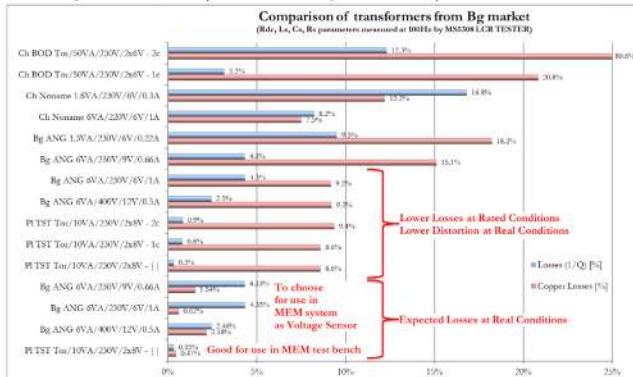
## MEM system test bench – 5<sup>th</sup> version planning and development

While trying to finish 3<sup>rd</sup> test bench version (putting it in a box) a number of new problems were found (mainly amplifier excitation because of noise coming from the potentiometer). The idea to replace it with a digital one was considered and extended with the idea to add secondary even third simulation channel. In such a way the voltage and current can be simulated separately and it will be possible to implement a phase difference between both. It will also be possible in case of 3 channels to simulate 3-phase mains. The software was successfully modified and 16x2 character LCD and rotary encoder were added for parameters setup. While adding the second channel for separate current simulation Mastech MS3308 LCR tester was found and some transformers offered on Bg market was measured and compared. The difference in measured and calculated Q is not investigated. The results are shown on the next table.

Parameters of transformers from Bg market ( $R_{dc}$ ,  $L_s$ ,  $C_s$  and  $R_s$  parameters measured at 100Hz by MS3308 LCR tester)

	$R_{dc}$ [mΩ]	$L_s$ [nH]	$C_s$ [pF]	$R_s$ [mΩ]	$\Delta R_s$ [%]	$\Delta L_s$ [%]	$\Delta C_s$ [%]	$\Delta Q$ [%]	$\Delta \omega$ [%]
Ch BOD Tm/50VA/230V - 2e	0.13	1.18	0.01	0.13	0.00	2.44	0.03	0.45	-1.44
Ch BOD Tm/50VA/230V - 1e	0.15	1.14	0.01	0.15	0.00	2.30	0.03	0.38	-0.00
Ch Nonres 1.5VA/230V/8V/1A	0.16	1.10	0.01	0.16	0.00	2.15	0.03	0.34	0.37
Ch Nonres 6VA/230V/8V/1A	0.16	1.10	0.01	0.16	0.00	2.15	0.03	0.34	0.37
Bg ANG 6VA/230V/8V/0.66A	0.16	1.05	0.01	0.16	0.00	2.00	0.03	0.30	0.37
Bg ANG 6VA/230V/8V/1A	0.16	1.05	0.01	0.16	0.00	2.00	0.03	0.30	0.37
Bg ANG 6VA/400V/12V/0.5A	0.16	1.05	0.01	0.16	0.00	2.00	0.03	0.30	0.37
P1 TST Tm/10VA/230V/2kW - 2e	0.17	1.05	0.01	0.17	0.00	1.95	0.03	0.28	0.37
P1 TST Tm/10VA/230V/2kW - 1e	0.17	1.05	0.01	0.17	0.00	1.95	0.03	0.28	0.37
P1 TST Tm/10VA/230V/2kW - 1+	0.17	1.05	0.01	0.17	0.00	1.95	0.03	0.28	0.37
Bg ANG 6VA/230V/8V/0.66A	0.18	1.05	0.01	0.18	0.00	1.90	0.03	0.27	0.37
Bg ANG 6VA/230V/8V/1A	0.18	1.05	0.01	0.18	0.00	1.90	0.03	0.27	0.37
Bg ANG 6VA/100V/12V/0.5A	0.18	1.05	0.01	0.18	0.00	1.90	0.03	0.27	0.37
P1 TST Tm/10VA/230V/2kW - 1+	0.19	1.05	0.01	0.19	0.00	1.85	0.03	0.26	0.37

The big difference for BOD coils was not investigated. The red colored columns present the extrapolated computations to real use case in MEM system test bench where the power and current are away from the rated. Comparison is shown on the next chart.

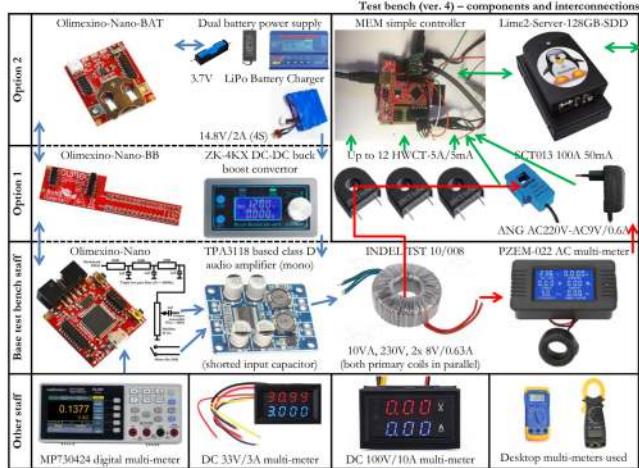


The conclusion is that the transformer TST 10/006 (toroidal, 10VA, 230V on a primary and 8Vac/0.63Aac on any of both secondary coils) produced by Polish company INDEL has the lowest losses but is relatively expensive. The transformers were tested in real conditions in which the secondary coil(s) are connected at a load to the 60W class D mono audio amplifier based on TPA3118 IC. In case of TST 10/006 both secondary coils was connected in parallel because their parameters are very close to each other.

The result of the tests is that the transformer TST 10/006 has the smallest distortion of the waveform for voltages higher than 240Vac on a primary coil and is the best candidate for usage in both voltage and current simulation channels of the test bench. Three of the transformers 6VA/230V/9V (0.66A) was used in tests of MEM system prototype and the observation is that the distortions of the waveform for voltages higher than 240Vac are relatively small. It could be replaced without any problems by ANG transformer 6VA/230V/9V/0.66A with 6VA/400V/12V/0.5A have to be ordered as a special product and the advantages must be assessed carefully especially if the price is bigger.

### MEM system and test bench – precision assessment

Before precision assessment some changes were made in test bench. DC-DC converter was changed to ZK-4KX DC-DC buck boost one with precise tuning and measurement features. Peacefairy's PZEM-022 AC digital multi-meter was added for precise measurement of mains simulation (voltage, frequency, current, power and power factor). The other change is in current coil. The wire was changed with magnet wire with 3.15mm diameter and part of its length was planned for current tuning. For nonfunctional part of the current coil is used 10nm wire. All test bench staff is planned to be mounted on two aluminum or plastic panels.



In addition to above changes it was planned to add AC measurement staff to the Olmexino-Nano firmware based on original emonLib-CM library, LCD display, additional coil to the toroidal transformer (for voltage measurement) and precise LEM LTS 15-NP current transducer. In the final test bench version 4 this entire staff will substitute functionality of PZEM-022 AC multi-meter.

It was tested some calibration procedures based on class 1 Multicomp Pro MP730424 digital multi-meter. It is able to measure AC voltages precisely but the current measurement is up to 10Aac and requires high voltage. That is why the current measurement was done by using LTS 15-NP current transducer for 15A nominal AC/DC current, 0.2% accuracy and 0.1% linearity. In addition to the test bench output voltages and currents ZK-4KX converter parameters were also measured together with some DC digital multi-meters and used desktop units A830L and DT326L. The preliminary results are shown on pictures below.

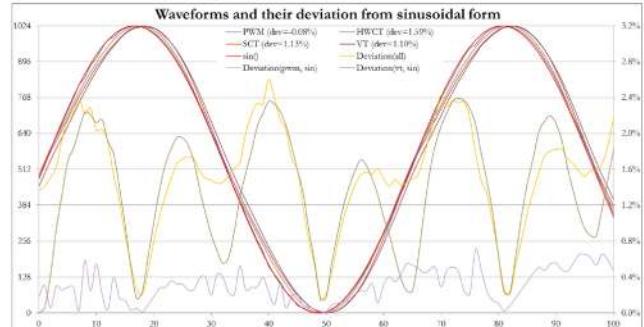


Interesting in the above measurement is that ZK-4KX converter and DC 33V/3A panel digital multi-meter are precise in almost all range. ZK-4KX has good setup and tuning features as well. Unfortunately, PZEM-022 AC multi-meter is not precise enough so its substitution with Olmexino-Nano firmware based measurement is highly recommended.

The main conclusion from this phase is that for the final test bench and MEM system calibration other more precise and appropriate multi-meter like Megger's DCA2000P power clamp meter should be used. It is recommendable in addition to the mains true RMS parameters to measure total harmonics distortion, power, crest and distortion factors and other helpful once.

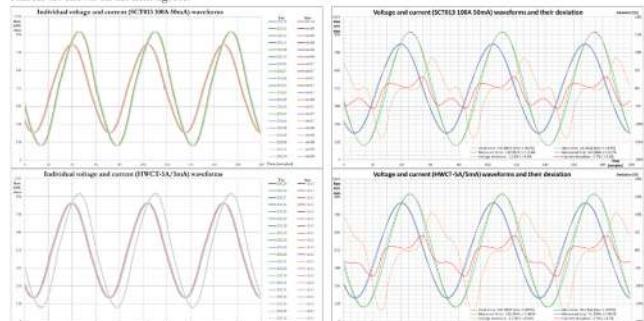
### MEM system – voltage / current sensing and waveform distortion assessment

This assessment was accomplished with the help of MEM system and its test bench (ver. 3) with modified emonLibCM library (Version 2.2.2.15/9/2022) including the raw data capturing. Because of memory restriction only captured signals were measured (the voltage and a single current from the tested CT). The captured results from 20 measurement cycles were averaged and compared with the ideal sinusoidal waveform. The assessment was done off-line in Excel 2010 calculating RMS (Root Mean Square), CF (Crest Factor), PP (Peak-to-Peak) and other values. Deviation was calculated for both the waveforms ( $\text{dev} = |X_i - \bar{X}| / \bar{X} - 1\% \text{ in } \%$ ) and the total values ( $\text{dev} = CF / \sqrt{2} - 1\% \text{ in } \%$ ). The waveforms as normalized raw data and their deviations from the sinusoidal form of the modulated PWM (the test bench generator), the voltage transformer (VT) and the current transformers (SCT013 100A/50mA and HWCT-5A/5mA) are shown on the next figure.



The total voltage and current deviations are in the interval from 1% to 1.6% while the generator's one (modulated PWM) is 0.08%. The relatively big dispersion of the signals is mainly caused by the discretization.

The individual and the averaged waveforms of the voltage and the currents for both SCT013 100A 50mA and HWCT-5A/5mA sensors are shown on the next figures.



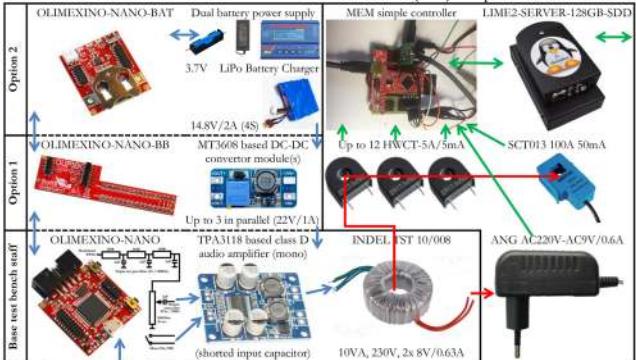
In addition to the waveform graphs calculated total RMS values and their deviations are shown. As it can be seen the latest version of the test bench grants extremely stable values for both the voltage and the currents (0.016% and less). Without matter that waveform deviations from sinusoidal form are relatively big (up to 17% at given individual points) the total deviations of the voltage and the currents are less than 1.15%.

### MEM system – test scenario 3<sup>rd</sup> version final implementation

Test bench (ver. 3) – final implementation with single adapter (5V/1.5A + 12V/1.5A) instead of batteries



Test bench (ver. 3) – components and interconnections



#### Notes about options of the final implementation:

- Dual battery supply is optional and can be replaced by external USB power supply for Olimexino-Nano and 12-15V/2A external power supply for DC-DC module(s);
- It also possible to replace the DC-DC module(s) with 20-24V/1A external power supply for the audio amplifier;
- The other option is to use dual voltage power supply (5V/1.5A & 12V/1.5A) instead of separate ones;
- The cheapest option is to use dual voltage power supply (5V/1.5A & 24V/1.5A) without DC-DC converter.

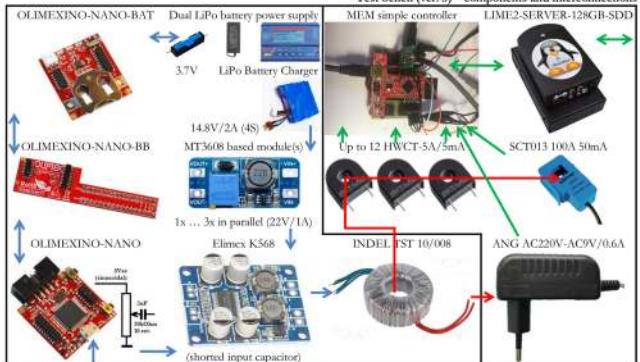
In case of single power supply special attention has to be paid to the common ground to prevent the influence of the high starting current of the audio amplifier on the MCU. The main 12V supply and the common GND should be connected to the DC-DC converter. Voltage and current measurement device can also be connected between the power supply and the other boards. The output 22V of the DC-DC converter and its GND should be connected to the audio amplifier. The common GND of the audio amplifier boards should be connected to the MCU board together with its output sinusoidal signal. Only the 5V of the power supply must be connected to the MCU board while the common GND will be taken via the audio amplifier board.

### MEM system – test scenario 3<sup>rd</sup> version final implementation

Test bench (ver. 3) – final implementation



Test bench (ver. 3) – components and interconnections



#### Notes for final implementation:

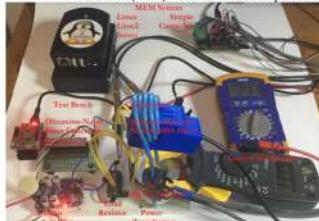
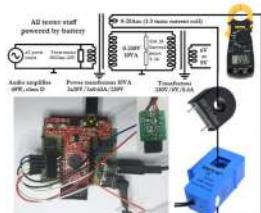
- Dual battery supply is used for separate powering of both Olimexino-Nano and audio amplifier;
- 4x 18650 LiPo batteries connected as 4S pack is provided with intermediate wires for balance charging with Imax B6 charger;
- BB-PWR-3608 is replaced with up to 3x connected in parallel MT3608 based modules with fine tuning of the output voltage;
- Using bigger power supply for the audio amplifier is required for avoiding signal distortion and reaching 250Vc values;
- Multi-turn potentiometer is used instead of linear one and additional load resistor at the amplifier output was removed;
- Input capacitor of the amplifier is shorted and external one with bigger capacity is added to avoid signal distortion.

Unfortunately, the shortcut current depends on both wire temperature (require time to stabilize) and number of the string current sensors (require adjustment by the multi-turn potentiometer or even by the wire length). Testing of both voltage and current sensors can be done separately using different voltage and current values of the transformer secondary coils. Calibration coefficients can be calculated individually by modified software for the controller of the MEM system and stored in nonvolatile memory.

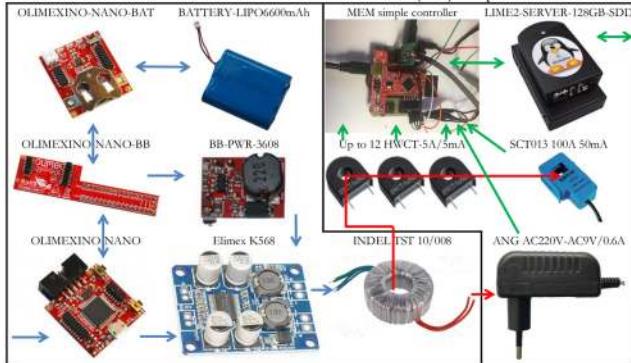
Dual battery supply and DC-DC module(s) are optional and can be replaced by USB power for Olimexino-Nano and 20-24V/1A external power supply for the audio amplifier.

### MEM system – test scenario 3<sup>rd</sup> version implementation

Test bench (ver. 3) – schematics and implementation



Test bench (ver. 3) – components and interconnections



#### Notes:

- BATTERY-LIPO6600mAh is optional for granting complete isolation of the test bench;
- BB-PWR-3608 can be powered by 5V\_USB or optionally by VBAT2 of OLIMEXINO-NANO-BB;
- OLIMEXINO-NANO-BB is stacked with a universal proto-board where low pass filter is mounted;
- Linear potentiometer 10k is mounted at the output of the low pass filter to regulate input voltage of Elmetex K568
- Power resistor 390Ωm/25W is mounted in parallel to the primary coil of the transformer;
- Resistive divider with different ratios (43, 230 etc.) is mounted to the terminal block for secondary coil interconnections;
- Resistive divider GND has to be connected to OLIMEXINO-NANO and Elmetex K568 GND if oscilloscope is used;
- High voltage of the transformer secondary coil has to be well isolated except the resistive divider GND if connected;
- Current coil has to be made by a single 4mm<sup>2</sup> wire with isolation and shorted by appropriate terminal block;
- Wire length and turns of the current coil has to be tuned to reach 16A<sub>AC</sub> at 230V<sub>AC</sub> on the transformer secondary coil;
- Additional 4.5 turns has to be made from current coil wire outside the transformer for SCT013 100A 50mA sensor;
- Optionally oscilloscope and multimeters like DSO5102P, A830L, and DT326L can be used for monitoring electrical quantities;
- Control equipment with higher precision and individual calibration of the sensors is recommended if better accuracy is required.

The current coil suffers from some drawbacks. When the current sensors are strong, the current on it decreases. For reaching higher current values, voltage on the amplifier input has to be increased. Unfortunately, the voltage on the secondary transformer coil will also grow up and reaching inadmissible values can damage the voltage sensor and the controller of the MEM system. To prevent any damages voltage sensor can be switched off. The limitation of the voltage and current values is the responsibility of the test bench operator. On the other hand shortcircuit current will fall down because of heating the wire therefore stabilization has to be awaited.

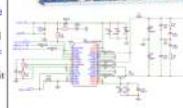
### MEM system – test scenario 3<sup>rd</sup> version

Sinusoidal waveform generator 50/60Hz



The hardware is based on Olimexino-Nano and includes a triple low-pass filter (F<sub>c</sub> 796Hz). The software is based on modified version of [EaganceGenerator ver. 1.00.2.5.21](#) written by Rick Groome. The waveform is created by 625 points with 9-bit resolution fast PWM on timer4 of ATmega32U4.

Audio amplifier 24V/60W, class D, mono

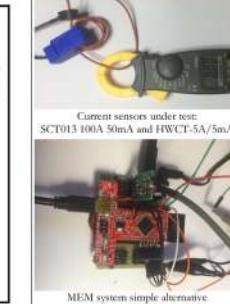
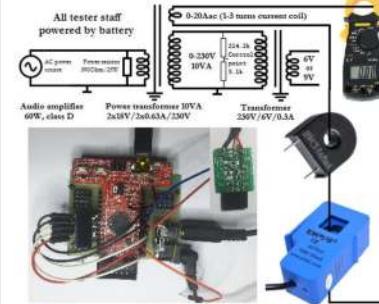


10VA 230V/2s/0.6A power transformer used as step-up

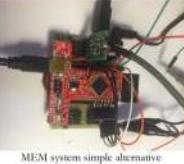


Voltage sensor under test: W-shaped transformer 1.8VA/230V/6V/0.5A or AC-AC adapter 230V/9V/6VA

All tester staff powered by battery



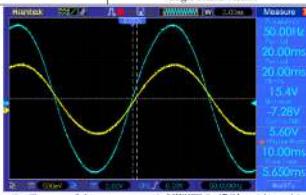
Current sensors under test:  
SCT013 100A 50mA and HWCT-5A/5mA



MEM system simple alternative single ended variant



Test scenario ver. 3 – amplifier loaded with power resistor (390Ωm, 25W) and the transformer primary coil



Oscilloscope of shortcircuit current & HWCT & 47Ωm (channel 1, yellow) and output AC voltage divided by 43 (channel 2, blue)

Measured parameters with a triple low-pass filter (Cut-off frequency 796Hz) between the generator and the amplifier: generator frequency 50.000 Hz, amplifier input up to 3V<sub>DC</sub>, audio input 15.4V<sub>DC</sub> (on each arm @ 20V<sub>DC</sub> and 1.1V<sub>DC</sub> input); transformer primary current 10.9VA (30.8V<sub>DC</sub>), transformer secondary voltage 230V<sub>AC</sub> (850V<sub>DC</sub>); shortcircuit current 16.05A<sub>DC</sub> (3.16mΩ @ 1.1mV, 74cm² area, 100A<sub>DC</sub>); main consumption 1.1W (idle mode 0.01V<sub>DC</sub> @ 20V<sub>DC</sub>) shortcircuit coil consumption 0.8 W (16.05A<sub>DC</sub> @ 3.16mΩ); load resistor consumption 0.3W (10.9VA @ 390Ωm) and total power consumption 2.2W (0.11 A<sub>DC</sub> @ 20V<sub>DC</sub> or 0.09 A<sub>DC</sub> @ 24V<sub>DC</sub>). Total power consumption is 3.0W (0.15 A<sub>DC</sub> @ 20V<sub>DC</sub>) when MEM system voltage transformer is switched on.

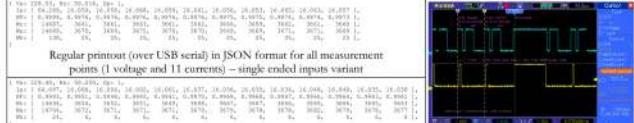
## MEM System – summary for both variants of the simple alternative in pictures and graphs

After performing series of tests and modifications of emonLibCM library (Version 2.2.2 15/9/2022) for the both variants (single ended and differential sensor connections) of MEM system (simple alternative) following results could be announced:

### Pin assignment, main emonLibCM library modifications and test scenario

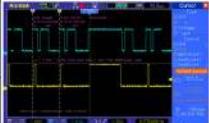


Printouts from both single ended and mixed and interrupt routine timings for mixed variants



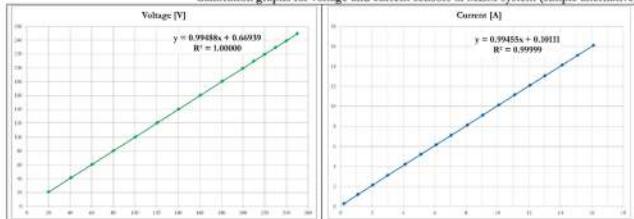
Regular printout (over USB serial) in JSON format for all measurement points (1 voltage and 11 currents) – single ended inputs variant

Regular printout (over USB serial) in JSON format for all measurement points (1 voltage and 13 currents) – mixed inputs variant

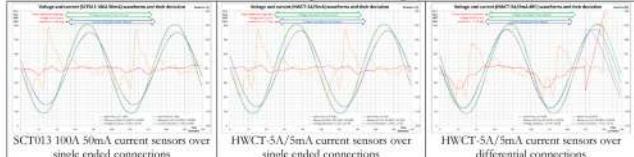


Oscillogram of interrupt timing for the modified emonLibCM (mixed variant)

Calibration graphs for voltage and current sensors of MEM system (simple alternative)



Graphs for used voltage (ANG AC-AC 9V/6VA) and current sensors



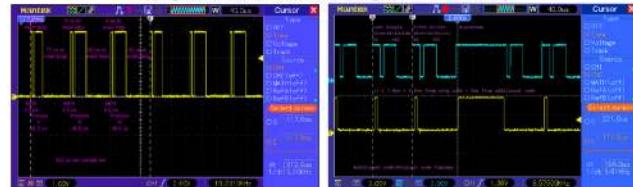
The next step is the main and sensor boards to be re-designed for the final variant of the MEM system (simple alternative). The choice has to be made if to use Olinex AVR-T33U4 board as-is or to modify it for a single main board solution. The modified board design is preferable because battery power and charging options can be added, which in combination with additional wireless module (like MOD-WIFI-ESP8266) will make its standalone usage possible.

## MEM System (simple alternative) – problem with wrong calculations at mixed sequence

More tests were done with 14 sensors (1 VT and 13 CT) with mixed connection types (6 single ended and 8 differentially). Single ended inputs (1x VT, 1x SCT013 100A 50mA and 4x HWCT-5A/5mA sensors) and differential inputs (8x HWCT-5A/5mA sensors) share 5 real sensors (1x VT, 1x SCT013 100A 50mA and 3x HWCT-5A/5mA sensors).

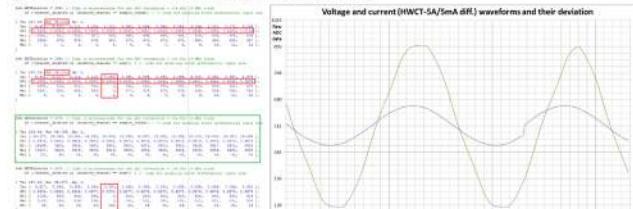


Interrupt routing related code added to the original emonLibCM library



Original emonPi with only 2 current inputs (Robert Wall)      Modified emonLibCM library (Version 2.2.2 15/9/2022)

As can be seen, the additional code takes 3us. It is also seen the part of the scan sequence with the last single ended input (conversion time 104us) and the first differential one (conversion time 112us). The times at current readings left for the main loop are 42us and 50us instead of 50us but there are no any side effects from that. The time distribution in the interrupt routine is quite similar to that from the original emonLibCM library. It can also be seen doubletching and discarding of calculation for the first differential input. There is no observation for overlapping of ADC interrupt at all. These facts suggest that the additional code is not the cause for the wrong calculations as shown on the next left picture. There are also problems with debug scenario if capturing waveforms like in the next right picture where the shapes and current values (must be 16ADCs) are wrong.



Printouts vs ADCduration and condition of the code for doubling the first differential input scan

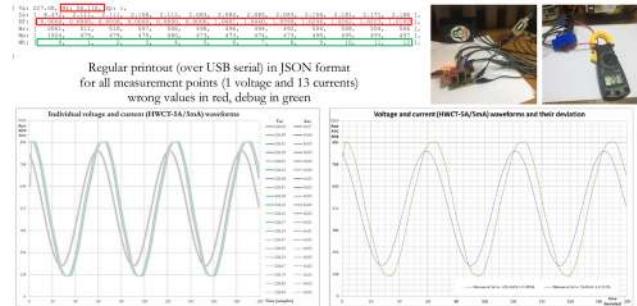
The problem with wrongly calculated figures is solved if ADCDuration value is set to 11us instead of 10us or 112us (derived empirically). It is also empirically derived (but not logically explained) that for the right functioning the code for doubling the first differential input scan have to use following condition: `(channel_doubled && (doubled_channel == sample_index))`. It can also be seen in the oscillogram (but not logically explained) that the first 112us conversion interval (coming from differentially connected CT) is from regular interrupt routine execution while the second one is from slippage interrupt processing.

Averaged voltage and current waveforms for differential input (from 20 individual scan sets 96 point each taken sequentially)

### MEM System (simple single ended and differential alternative) – history in pictures and graphs

After tests with sequence of only single ended inputs (1 voltage and 11 current sensors) two current sensors (HWCT-5A/5mA) connected to differential inputs is setup. One current sensor (SC1013 100A 50mA) is also connected to a single ended input. Other inputs are connected to the sensors as well. All 1 (voltage and 13 current) sensors are scanned in a sequence as shown on a picture below. Preliminary printouts, test scenario and waveform graphs are shown on the pictures below:

Regular printout (over USB serial) in JSON format  
for all measurement points (1 voltage and 13 currents)  
wrong values in red, debug in green



Results for voltage (ANG AC-AC 9V/6VA) and current (HWCT-5A/5mA connected to differential input) sensors (not complete)



Printout (in green) and changed emonLibCM parts: ADC MUX values setup in red, code to double the first channel in sequence after single ended to differential input change in blue and recalculating of raw ADC data in gold color)

Wrong calculation at switching from single ended to differential inputs is encountered. The reason is explained in ATMega32U4 datasheet (24.5 Changing Channel or Reference Selection).

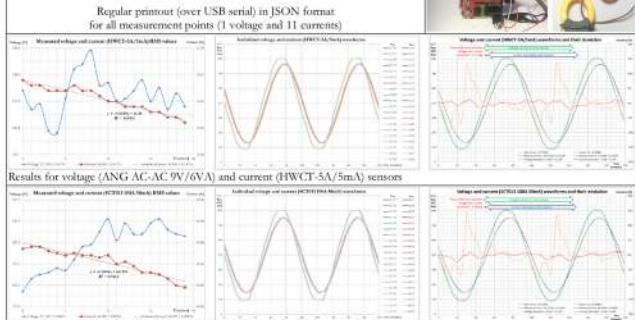
Special care should be taken when changing differential channels. Once a differential channel has been selected, the stage may take as much as 125us to stabilize to the new value. Thus conversions should not be started within the first 125us after selecting a new differential channel. Alternatively, conversion results obtained within this period should be discarded.

The same setting time should be observed for the first differential conversion after changing ADC reference (by changing the REFRESH bits in ADMUX).

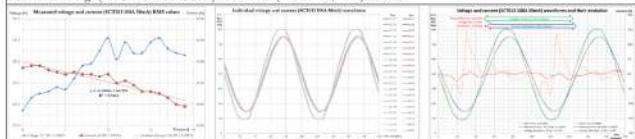
To avoid switching time problem the sampling of the first differential input is doubled and wrong values are discarded as shown on the oscillogram in red. Unfortunately, other values were wrongly calculated (mains frequency and PF – some zero, other greater than one) as shown on the picture above. Voltage and current values are accurate.

### MEM System (simple single ended alternative) – history in pictures and graphs

Printout (over USB serial) in JSON format  
for all measurement points (1 voltage and 11 currents)



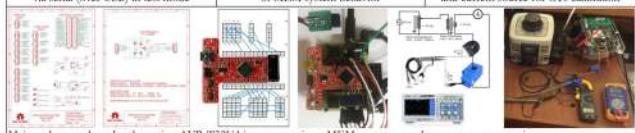
Results for voltage (ANG AC-AC 9V/6VA) and current (HWCT-5A/5mA) sensors



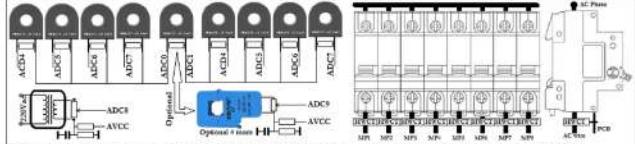
Results for voltage (ANG AC-AC 9V/6VA) and current (SC1013 100A 50mA) sensors



Printout of MEM system firmware via serial (over USB) in test mode



Main and sensor boards schematics, AVR-T32U4 interconnections, MEM prototype and measurement scenario



Initial idea: up to 9 current differential measurement points (16A<sub>AC</sub> each), total I<sub>max</sub> (64A<sub>AC</sub>) and V<sub>max</sub> (230V<sub>AC</sub>)

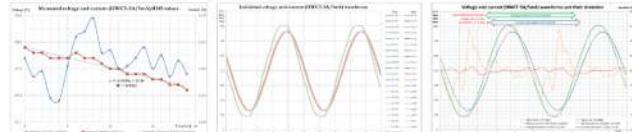
## MEM System (waveform distortion and voltage / current sensing) – continued

The tests to investigate the influence of the waveform distortion over the measurement precision were continued with some changes and expansion. The voltage sensing input resistor divider was changed from 20k/1k to 12k/1k which increase the signal amplitude to 2.5V-p-p. HWCT-5A/5mA sensors was also connected via a sensor board to the system and investigated. Current simulation scenario was changed to use 4 winds for SCT013 100A 50mA sensors for simulating currents up to 80A.

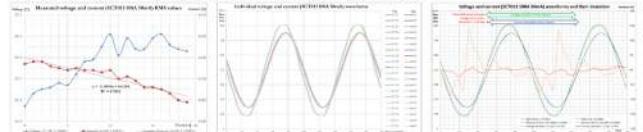


Current simulation schematics and test scenario after changes

The results from the new tests are shown on figures below.



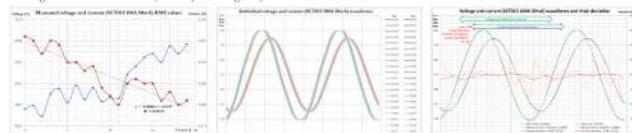
Results for voltage (ANG AC-AC 9V/6VA) and current (HWCT-5A/5mA) sensors



Results for voltage (ANG AC-AC 9V/6VA) and current (SCT013 100A 50mA) sensors

Unfortunately, it is unexplainable increase of deviation figures for both voltage (from -5.0%/-4.7% at the first tests to -8.5%/+14.5% and -9.6%/+13.9% at the next tests) and current (from -0.1%/+0.6% at the first tests to -2.3%/+0.8% and -2.0%/+1.3% at the next tests) waveforms. Fortunately, the correlation between voltage and current waveforms deviations remains approximately the same.

One more test was done with changes of the ADC frequency from CLK/128 to CLK/64 and CLK/32. While the firmware works fine at CLK/64 it stops working in normal way at CLK/32. At the test with CLK/64 (CLK/128 at debug mode) emonLibCM library was extended at the same time to scan all 12 ADCs and 2 buffers with length of 64 (200 at debug mode) raw data each for capturing samples of voltage and one of the current inputs. These changes are optimal for the system to work normally and not to exceed the limits of the size of the used memory. The sketch was changed to send always via USB serial both captured waveform data and the measurement results of all channels (11 current and a voltage). The idea is to have opportunity to observe waveforms at normal working mode of the firmware (not only in debug one).



Results for voltage (ANG AC-AC 9V/6VA) and current (SCT013 100A 50mA) sensors at ADC frequency CLK/64

The result is decrease of waveform data points from 96 to 32. As it can be seen distortion and saturation at voltage waveform is still visible but more tests should be done in case of bigger deviations from sinusoidal shape. On the other hand precise assessment should be done for influence of the bigger ADC frequency over the measurement precision in general. In case of negative influence waveforms capturing will be used at debug mode only.

## MEM System (waveform distortion and voltage / current sensing)

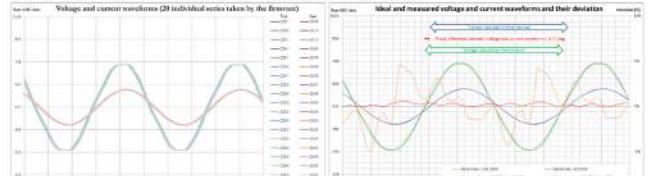
A new test to establish the influence of the waveform distortion was planned and executed. The test scenario scheme is shown in the figure below. ANG standard AC-AC adapter with 6VA transformer (input: 220-230Vac, output: 9Vac/0.66Aac) is used as voltage sensor. It gives 11.9Vac on the secondary coil at 230Vac on its primary coil. Otherwise SNS-CURRENT-CT013-100A sensor is connected to CT0 input of the MEM system measuring total current.

Voltage and current values (200 samples each) are captured by a special addition to Robert Wall's [emonLibCM](#) library and compared in Excel 2010 with ideal sinusoidal waveforms. The screenshot from the firmware via serial (over USB) output is shown in the figure below. Individual, ideal and real values are calculated by the firmware and printed in the beginning of each row. Measured by the firmware RMS values and time are presented in the graph below and shows tendency to fall in time probably depending on the temperature of the transformer with shortcut coil which will influence over calibration process.



The power schematics, the firmware output in test scenario and measured voltage and current values in time

Real voltage and current waveforms are averaged from 20 different takes 200 samples each captured once after the other and synchronously. Sinusoidal waveforms are calculated to best fit real once. Real and ideal RMS values and waveform deviations are calculated from both real and ideal waveforms. All they are shown on the figures below:



Individual, ideal and measured voltage and current waveforms and their deviations

As can be seen from the first graph the voltage curves have significant distortion while the current once are much closer to the ideal sinusoidal shape. The same can be seen even better in the second graph, where the averaged real waveforms are compared with the sinusoidal shapes. Deviations between real and ideal waveforms are also calculated and shown for voltage (-5.0%/-4.7%) and current (-0.1%/+0.6%) waveforms. It is clear that because of lower distortion and saturation lack the current waveform has more than one order of magnitude smaller deviation than the voltage one.

Calculated voltage and current RMS values are 228.781V  $\pm 0.29\%$  and 20.059A  $\pm 0.152\%$  respectively. Deviations of measured values mainly depend on mains voltage variation and transformer heating up. Time intervals for RMS calculations are also shown on the second graph. The phase difference between voltage and current waveforms is 4.77 degrees (4 samples by 208ms) and mainly depends on the used AC-AC adapter and transformer for current simulation.

The conclusion from previous test and recommendations from ANG experts can be summarized that it is better to use ANG 6VA transformer as both voltage sensor and current source for calibration of CTs. The primary coil has to be for nominal voltage 230Vac. It has to have two secondary coils – one for 9V/10-20mA and other with 5-10 turns wind with 1.12mm wire (thicker is preferable). Long enough 1.5mm<sup>2</sup> wire with PVC insulation will be used to reach 16A shortcircuit current thanks to its resistance and for stringing up CTs. Saturation power can be as small as possible for avoiding transformer heating up.

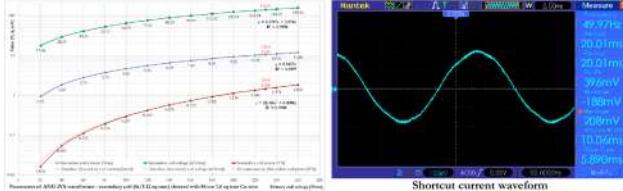
Following conclusions can be made:

- Olmex SNS-CURRENT-CT013-100A sensor is precise enough for measuring of total currents up to 100A;
- ANG standard AC-AC 230V/0.66A adapter with GVA transformer is relatively good as voltage sensor;
- Resistive divider for the voltage input should be changed to increase signal amplitude for better precision;
- ANG 6VA transformer with additional secondary coil can be used as current source for CTs calibration;
- Calibration process should be short enough to avoid transformer temperature influence over the current.

Olmex SNS-CURRENT-HWCT-5A-3MA current sensor has to be tested as well. This test has to be repeated with a special ANG 6VA transformer prepared for MIM system usage as voltage sensor and CT calibration current source.

### MEM System (voltage sensing and current transformers calibration)

Test with ANG special 2VA transformer (5600 turns  $\times \Phi 07\text{mm} / 6$  turns  $\times \Phi 1.12\text{mm}$ ) at 230V on a primary coil gives 19.8A on a shorted with 10cm 1.5mm<sup>2</sup> wire and 10.43A if shorted with 88cm 1.5mm<sup>2</sup> wire (10.032mΩhmm theoretically). Measured voltage on a wire ends was 140mV<sub>rms</sub> (396mV<sub>peak</sub>) which gives 1.46VA power at 230VRMS on a primary coil. Shortcut current waveform and parameters graph are shown on pictures below.

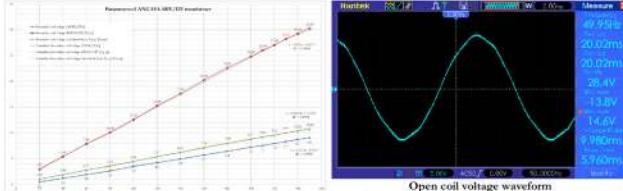


The waveform is relatively good and probably acceptable for a simple alternative of MEM System. Strange is the phase difference at AC50 synchronization (-37.8 degree) which has to be investigated. Calculated power of 1.46VA on a primary coil and 10.43A if secondary coil is shorted with 88cm 1.5mm<sup>2</sup> gives potential for combination of both voltage sensing and current source for CTs calibration on a single transformer. The main idea is to have two secondary coils. The first will be used for voltage sensing giving 9V<sub>peak</sub> for example. The second coil will be used as a current source for CT's calibration. It could be wound with 1mm<sup>2</sup> copper wire and working temperature up to 105°C (optionally with PVC insulation). The wire length of 1m for example will be enough to reach total resistance 10mΩhmm. Some of the wire will be used to wind 5-10 turns as a secondary coil. Other part of the wire will be left free for strapping up the CTs and to short the circuit at calibration. Final length of the wire will be taken at production process to grant fixed shortcut current (16mA<sub>short</sub> for example) at nominal voltage on a primary coil (230V<sub>RMS</sub>). On site calibration will be done with measuring of the voltage from each CT and the voltage of the secondary coil which will be used at calculation of the calibration coefficients. The calibration time has to be minimized to avoid temperature increase which will influence wire resistance.

Maximal current in Amperes vs. insulation material and copper temperature of the wire

AWG	Wire diameter [mm]	Wire cross section [mm <sup>2</sup> ]	Polymer insulation		Kynar (135°C)		FEP PFA	Enamelled copper wire	Resistance [mΩ/mm]
			Neoprene (High Density)	Polyvinylchloride (Semi-Rigid)	Polypropylene Polyethylene (High Density)	Polyvinylchloride PVC (Irradiated Nylon)			
14	1.63	2.082	27.0	30.0	33.0	40.0	45.0	5.9	8.59
15	1.43	1.631	25.0	26.0	26.5	33.0	56.5	4.7	10.81
16	1.29	1.369	19.0	22.0	24.0	26.0	32.0	3.7	13.64
17	1.15	1.039	17.0	19.5	21.0	23.0	28.0	2.9	17.19
18	1.03	0.824	15.0	17.0	18.0	20.0	24.0	2.3	21.68
19	0.91	0.653	12.5	14.5	15.5	17.0	20.5	1.8	27.34
20	0.81	0.519	10.0	12.0	13.0	14.0	17.0	1.5	34.42

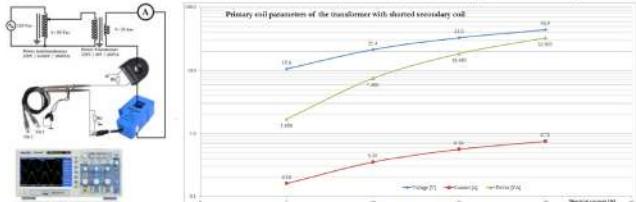
For improvement of transformer characteristics as voltage sensor it is important to decrease distortion of the voltage waveform. A good idea is to use transformer with higher power (6VA for example) with primary coil for 400VRMS instead of 230VRMS. Open coil voltage waveform and parameters graph of ANG 6VA 400V/12V transformer is shown on pictures below.



The conclusion is that ANG special 2VA transformer has better secondary voltage waveform and lower saturation power. It makes this transformer preferable to 6VA one. The primary coil has to be for nominal voltage (230Vac). The special 2VA transformer has to have two secondary coils – one for 9V/10mA and other 5-10 turns wind with 1 or 1.5mm<sup>2</sup> wire long enough to reach 16A shortcut current thanks to its resistance at saturation power less than 1.5VA.

### MEM System (precision improvement)

One of the ways to maximize precision of the MEM system is to make on-site calibration. The test scenario, where the CTs measure the shortcut current of secondary coil of a transformer, shows that it is possible to generate relatively high current at low power.



Test scenario and the result of measured primary coil parameters of 180VA transformer with shorted secondary coil

The idea for on-site MEM system calibration is to use voltage transformer (VT) with additional coil to generate big enough shortcut current. The shortcut wire can be used to string up the CTs, measure the current and recalculate calibration coefficients. One potential problem is the possibility the shortcut current to influence measurement coil voltage and has to be investigated. Fortunately, this influence can be measured and taken into account at calculation of the calibration coefficients.

Other influence over the system precision is the noise induced in CTs and connection cables. While nothing to do with CT itself the cable can be shielded and the location of the burden resistor and the filter has to be investigated.

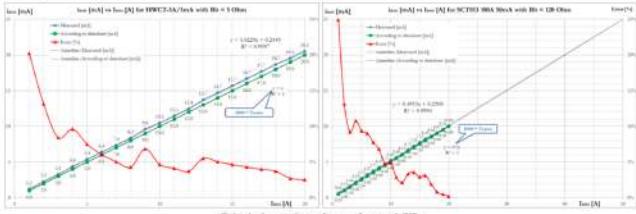


Exemplary label

Sensor set CT: HWCT-5A/5mΩ  
Calibration coefficient:  
Attached to MEM channel: 3  
Current rating name:  
lighting / kitchens / living room /  
padouk / bedroom 1 / bedroom 2 /  
bathroom 1 / bathroom 2 /  
bedr. 1 / bedr. 2 / open 1 / open 2 /  
refrigerator 1 / refrigerator 2 /  
other:

Without matter where they will be located all components (CT, the cable, the burden resistor and the filter components) can be mounted together and calibrated at production process. This is the main idea to develop separate sensor board carrying all relevant components. In addition recalibration can be made by the user and eventually periodically.

Individual calibration coefficient has to be printed on a label, fixed to the sensor set and used at MEM system on-site setup. The label can be used to write down MEM channel and current circuit name attached to. All this information collected together will help the user in system setup process.

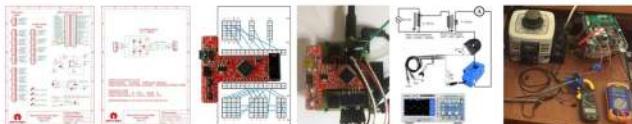


Calibration ratio and error for used CTs

Other big issue is the great error at measuring of small currents. This problem can be solved with using built-in operational amplifier to increase the signal from CTs. It is possible only if differential ADC inputs are in use. One drawback is the noise amplification but the influence over MEM system precision has to be investigated.

## MEM System (simple alternative prototype and first tests with single ended ADC inputs)

The simple alternative of MEM system prototype as hardware is implemented with universal PCB (as a main board) stacked with Olimex's AVR-T32U4 board (Leonardo compatible). AVR-T32U4 board is preferred to Olimexino-Nano because all ADC inputs are free for use. Unfortunately, AVCC and AGND are not wind to the connector and it has no battery supply but these problems can be solved with adding its modified variant to the main board itself because it is OSHW licensed.



Main and sensor boards schematics, AVR-T32U4 interconnections, MEM prototype and measurement scenario

For testing is used scenario with 0-250V/2kVA autotransformer and 220V/18V/180VA transformer with secondary coil shorted. ANG AC-AC 9V/0.6A adapter is used as VT (connected to ADC13 and the oscilloscope channel 1) and a single SCT013-000 100A 50mA is used as CT (connected to ADC12 and the oscilloscope channel 2). Other 10 ADC inputs are connected to ADC12. Hancock's DSOS10P DSOS is used to observe waveforms. DT3266L multimeter with current clamp is used to measure short cut current. Robert Wall's [emontLib.CM](#) library and EmontTxV34CM\_minimo sketch are used for the first test. The main changes made in the sketch are to set pins 6-11 (ADCS-13) as inputs in setup function and to form appropriate JSON output to serial (over USB) channel. In emontLibCM.cpp except extending arrays from 4/5 to 11/12 members following essential changes (marked in red) were made:

```
static byte ADC_Matches[11][4] = {{0x00, 0x00, 0x00, 0x00}, {0x00, 0x00, 0x00, 0x00}}; // added
static byte ADC_Signamps[10][4] = {{0x00, 0x00, 0x00, 0x00}, {0x00, 0x00, 0x00, 0x00}}; // changed

// An function with void loop(void) is added
void loop() {
    ADCS-13 = 0; // set to 00000000
    ADCS-12 = 0; // set to 00000000
    ADCS-11 = 0; // set to 00000000
    ADCS-10 = 0; // set to 00000000
    ADCS-9 = 0; // set to 00000000
    ADCS-8 = 0; // set to 00000000
    ADCS-7 = 0; // set to 00000000
    ADCS-6 = 0; // set to 00000000
    ADCS-5 = 0; // set to 00000000
    ADCS-4 = 0; // set to 00000000
    ADCS-3 = 0; // set to 00000000
    ADCS-2 = 0; // set to 00000000
    ADCS-1 = 0; // set to 00000000
    ADCS-0 = 0; // set to 00000000
}

// instead of:
// ADCS-13 = ADCS-13 + ADCS-13 * sinePhase[next];
ADCs-13 = ADCS-13 + ADCS-13 * sinePhase[next]; // set up the next-but-one conversion
ADCs-12 = ADCS-12 + ADCS-12 * sinePhase[next]; // set up the heat-but-one conversion
```

The result sent via USB serial is:

Serial via USB monitor Continuous Monitoring Minimal Demo

Maximal number of channels is 10. I'm using 8

ADCs-13, ADCS-12, ADCS-11, ADCS-10, ADCS-9,

ADCs-8, ADCS-7, ADCS-6, ADCS-5, ADCS-4,

ADCs-3, ADCS-2, ADCS-1, ADCS-0

Case 1: Immediately after starting up at 50Hz

```
Var: 237.74, H1: 50.004, H2: 1
Var: 18.098, 16.951, 18.274, 18.975, 18.074, 18.077, 18.077, 18.077, 18.077, 18.074
Var: 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991
Var: 1156, 1151, 1150, 1150, 1156, 1152, 1150, 1150, 1149, 1156, 1150
Var: 3336, 3335, 3334, 3334, 3335, 3334, 3334, 3334, 3334, 3334
Var: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
H1: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
H2: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

Case 2: Later on at 140A

```
Var: 237.40, H1: 53.002, H2: 1
Var: 18.098, 16.951, 18.274, 18.975, 18.074, 18.077, 18.077, 18.077, 18.077, 18.074
Var: 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991
Var: 1154, 1153, 1152, 1150, 1150, 1151, 1150, 1150, 1149, 1156, 1150
Var: 3335, 3334, 3333, 3333, 3334, 3333, 3333, 3333, 3333, 3333
Var: 47, 46, 46, 46, 46, 46, 46, 46, 46, 46
H1: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
H2: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

Case 3: Later on at 6kV load on transformer switched off

```
Var: 235.40, H1: 53.002, H2: 1
Var: 18.098, 16.951, 18.274, 18.975, 18.074, 18.077, 18.077, 18.077, 18.077, 18.074
Var: 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991
Var: 1153, 1152, 1151, 1150, 1150, 1151, 1150, 1150, 1149, 1156, 1150
Var: 3334, 3333, 3332, 3332, 3333, 3332, 3332, 3332, 3332, 3332
Var: 47, 46, 46, 46, 46, 46, 46, 46, 46, 46
H1: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
H2: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

Case 4: Later on at 150A (autotransformer move to lower position)

```
Var: 234.40, H1: 53.002, H2: 1
Var: 18.098, 16.951, 18.274, 18.975, 18.074, 18.077, 18.077, 18.077, 18.077, 18.074
Var: 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991, 0.0991
Var: 1152, 1151, 1150, 1150, 1151, 1150, 1150, 1150, 1149, 1156, 1150
Var: 3333, 3332, 3331, 3331, 3332, 3331, 3331, 3331, 3331, 3331
Var: 47, 46, 46, 46, 46, 46, 46, 46, 46, 46
H1: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
H2: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

Problems found are marked in red. Wrong getLogicalChannel return result probably reflects to impossibility to setup some of the channels to scan (currently out of the scope of the development). Other problems are the big noise and wrong results in case 3. Used transformers in measurement scenario add big phase shift (~40°) compensated by calibration value (phaseCal\_CTY).

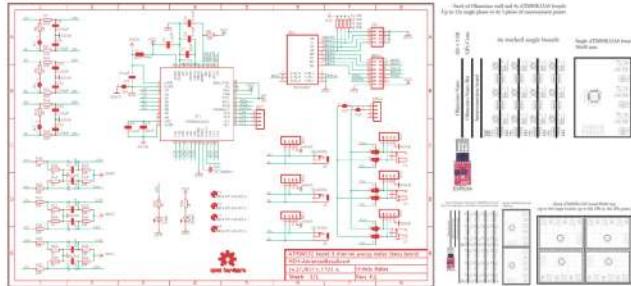
## Multichannel Home Electricity Monitoring System (advanced alternative)

This alternative of the project is inspired by CircuitSetup's [Expandable 6 Channel ESP32 Energy Meter](#) based on Microchip's ATM90E32AS IC for power metering and monitoring. It uses 6x1000GBN (500mA) for 3-phase electricity and 3 current inputs. Apart from the high price and strange 3 phase solution (use 2 chips while single one supports it) is very ineffective to have 2 almost the same boards with SPI connectivity. On the other hand it is inefficient to connect over audio jacks many CTs like SNS\_CURRENT-HWCT-SA/5mA CTs (offered by Olimex for 1€ instead of SNS\_CURRENT-STC103\_100A for 100). For example for monitoring of my apartment with 9 local circuits (up to 16A each) and total input (up to 64A) the price is between \$24.58 and \$36.68 without VAT and delivery taxes. If add 115€ (without VAT and delivery taxes) for Olimex's [OHW-Lite2-Server](#) (minimal configuration with 12/GB SSD) I have to pay approximately 300\$RGN without VAT and delivery taxes or something like 100\$RGN (500€ total). The half of the price is for 2x 6 channel measurement boards and 9x YHDC STC106. Provided I manage to save 10% (which is overrated) on my electricity bill this cost will be recouped in more than 5 years. The calculation does not include the cost of electrical appliances that must be replaced to actually reduce the bill. In conclusion, the purchase and installation of such a household electricity consumption monitoring system is more a matter of feeling in control of running costs mainly in view of the current crisis.

For the above reasons, reducing the price and combining the monitoring system with other activities is imperative. A simple and lower in price alternative is discussed later on and it is based on Lite2-Server hardware via USB with Olimexino-Nano, HWCT-SA/5mA CTs and [OpenEnergyMonitor project](#) (especially [ctrl4JCM](#)) by Robert Wall and [enorm-MIS](#). A simple interconnection board has to be developed and for the BOM of 150€ (including Lite2-Server, Olimexino-Nano, CTs, VTY) the system can be used for additional home applications. The disadvantage is that such a system will not be precise enough (it is hard to reach 1% precision) to control the bill which is essential for a countries like Bulgaria.

As a result of the reasoning, a more precise solution based on the ATM90E32AS IC (4,6€ at small quantity) is proposed. To avoid the shortcomings of the GreenPower's system, a different design of the measurement board is planned. The main ATM90E32AS based board will consist of a single IC with 3x current and 3x voltage inputs. The board will be designed to be stackable with Olimexino-Nano and SMD components. The voltage inputs and current inputs for multiple CTs can be measured easily. In addition to optional audio jacks a cleaver header can be used to connect directly CTs. The AC voltage inputs can be selected to use external transformers (one to 3x on each board with optional power jacks) or single one connected to any of the voltage inputs. The powering of the boards will be over USB from Olimexino-Nano to the voltage sensors can be smaller like 1.2V/2A transformers and 1.3mm power jacks for reaching lower price and the board dimensions like 30x40mm. The optional jacks will also increase dramatically the BOM and end price in case of using CT's like HWCT-SA/5mA (10 times cheaper than STC-006/STC-013). Double and quadruple board variants will be achieved by simple multiplication of a single board. All measurement board variants can be stacked with cheap 2.54mm pin header connectors. A simple interconnection board will be developed for stacking with Olimexino-Nano. It will also carry LiPo battery when possible. On the other hand Olimexino-Nano can be stacked with Olimexino-Bar and ESP8266 WiFi module for wireless communication with Lite2-Server in case of usage of the monitoring unit as a remote node in multi-node installations.

Maximal number of single boards could be addressed via SPI is 16 to up to 48s 1 phase or up to 16s 3 phase measurement point are possible. The final BOM for comparable number of CTs will exceed the BOM (Olimex sale price of 150€ including Lite2-Server, Olimexino-Nano, CTs, VTY) of the simple alternative with less than 50€ even of optional jacks (half of that price) are mounted. It can be supposed that for a typical installation with 12 measurement points with single voltage sensor and usage of HWCT-SA/5mA current sensors final price will be 250€ (or 300\$RGN without VAT and delivery taxes) is feasible.



### Single, double and quadruple variants of the measurement part of the system (ESP8266 and LiPo battery are optional)

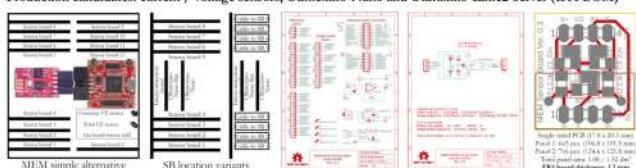
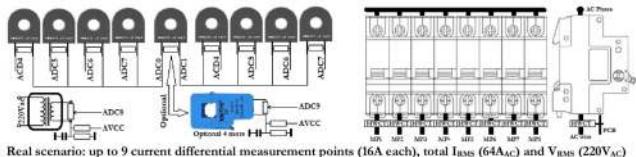
In addition to above a simple weather station and room climate monitoring units based on ESP8266 and appropriate temperature, humidity, light etc. sensors can be used. Currently only electric company's electricity is hard to connect because in blocks of flats they are in locked cabinets in the basements. In houses they are located on the streets and optical counter sensor wireless connected to Lite2-Server by ESP8266 can be used but the problem is the vandalism protection and distance.

And finally, the commercial usage of such a system is also relevant because of possibility to monitor all electric consumers (including 3-phase ones) for optimizing their electric bills. In such installations ESP8266 WiFi module could be changed to RS485/RS422 one (like MOD-RS485-1 or MOD-RS485-3) with or without galvanic isolation usable for long distances of full or half duplex communication in noisy environments.

**Notes:** The prices above are approximate. The calculations do not include any production expenses. All they can be used for reference only.

### Multichannel Home Electricity Monitoring System (simple alternative)

The simple alternative as hardware will be based on low cost (a hundred euros) and low consumption (a few watts) Linux server like Olimex' OSW HME2-SERVER (with battery backup and SSD) and web application written on JavaScript and using Web Sockets (WS). Real time data will be processed by Arduino application working in Atmega32u4. Data will be archived on the SSD. The system could be connected via Gigabit Ethernet, Wi-Fi or 3G/4G Mobile and accessed locally or globally from Internet. The compact and countless current sensors like HWCT-5A/5mA can be added to an existing electricity switchboard without modifications and additional safety requirements. In case of wireless communication in local network the system will be completely isolated and safe. Of course, general safety rules have to be applied when installing the sensors in the electricity switchboard. In case of wired communication the standard rules for computer equipment powering will be applied.



Different interconnection scenarios grant big flexibility of the simple alternative of MEM system

The idea is to separate CT resistor and filter on an additional sensor board will simplify the main MEM board and will add flexibility. A single sensor board can be used for both differential and single ended connections to ADC. It can be used in both simple and advanced MEM alternatives. On the other hand the sensor board can be located at CT, main board sides even in the middle. The same idea can be applied for voltage sensors which will make possible to use different kinds of VTs.

Optionally, internal and external temperature (DS18B20 based) and other environmental sensors could be connected as well. The low consumption Lime2-Server with built-in UPS itself can be used to host also other home services like WEB, TOR, NextCloud, HomeAssistant etc.

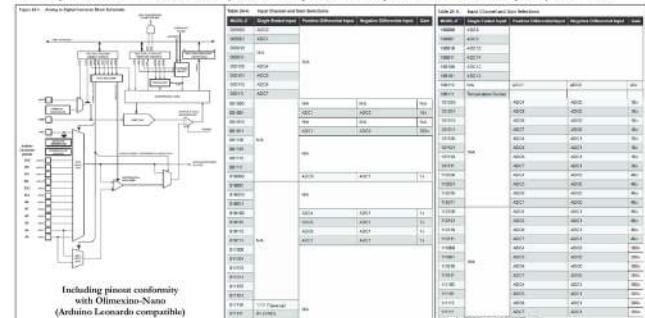
Built-in analytical and long term observation can be used for optimizing and decreasing the home electricity consumption, from the one hand. On the other hand, the metering accuracy can be certified by an authorized organization and served to control the electricity supply company.

The limitation in monitoring of two-way interconnected homes can be avoided in future by using advanced measurement algorithms and probably more resourceful real time processing unit (based on ARM Cortex-M4 MCUs like STM32F3xx/4xx). The other direction in Multichannel Home Electricity Monitoring System development could be the measurement and the observation of the self-produced electricity from photovoltaic, wind generator, geothermal etc. equipment targeting to reach sustainable green homes.

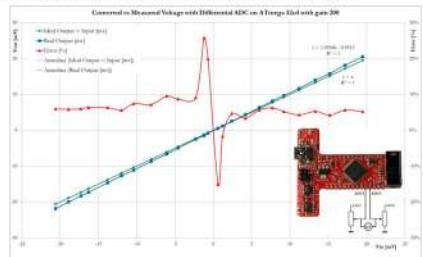
Consumption control based on time zones and priorities could be added as functionality in addition to metering. In case of unidirectional or two-way connectivity some home appliances can be limited to user defined time zones. In case of self-production of electricity all home appliances can be divided in groups with different priorities and corresponding powering rules. For implementing of such functionality current circuits should be switched on and off using relays controlled by real time processing unit. In case of self-production of electricity without two-way connectivity switching devices should also be used. In such advanced use cases a special electricity switchboard should be used as well.

### HWCT-5A/5mA and SCT013-000 100A 50mA measurement scenario based on Arduino ATmega 32u4 (Olimex' OLIMEXINO-NANO board), David Pilling's Differential ADC library and Arduino DiffADCInterrupts sketch

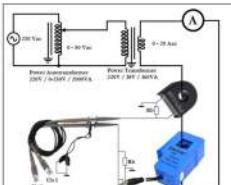
The idea is inspired by OpenEnergyMonitor project, David Pilling's Differential ADC library and appropriate current transformer (CT) sensors offered by Olimex. According to Figure 24-1 and Table 24-4 (Input Channel and Gain Selections) in the Atmel's AVR 8 Atmega32u4 datasheet it can be seen that MCU has 9 differential inputs combined with 3 gain selections for the built-in amplifier. A possible data capture scenario could be Free Running mode with auto trigger enabled and ADC interrupt at sampling end. In such a set up conversion takes 14 ADC clocks. In case of using 0.6 KHz sample rate (divide by 128 pre-scaler) it can be captured 178 samples for 20ms (1 AC cycle) which is enough for precise RMS value calculation of the selected channel. It probably will be possible to calculate sum of squared values in interrupt routine which will stop after each 178-th sample. In main loop it has to be set up the channel selection before starting capture and will be possible to get RMS for given value after that. Two more capture cycles have to be done for calculating of  $V_{\text{AC}}$  and total  $I_{\text{AC}}$  taken form electricity mains via transformer and SCT013 connected to the single ended ADC inputs (ADC8 – ADC13). As a result ten RMS values ( $V_{\text{RMS}}$  and  $I_{\text{RMS}}$  –  $I_{\text{RMS}}$ ) can be obtained for 200ms and up to 5 measurements per second will be possible. Of course, additional processing will down this rate but even a single measurement of the AC power for 8+1 home electricity consumers per second is quite attractive and completely reachable.



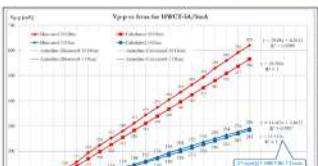
Testing differential inputs on Atmega32u4 with 200 gain of the built-in amplifier



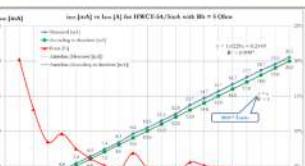
## HWCT-5A/5mA and SCT013-000-100A-50mA sensors calibration charts



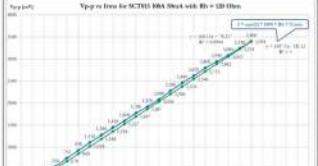
Modified test bed



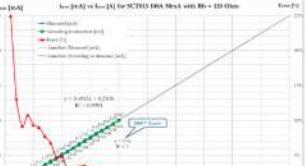
Back calculated  $T_{ratio}$  is 1.922 and 1.978 at 10 and 5 Ohm  $R_b$  instead of 1:1000 (7.8% and 2.2% error respectively)



To measure  $I_{out}$  up to 16A and  $V_{p-p}$  up to 3.3V  
 $R_b$  should be 7.06 Ohm  $\pm 0.1\%$  and gain 10



Back calculated  $T_{ratio}$  is 1.2019 at 120 Ohm  $R_b$  instead of 12000 (9.4% error)



To measure  $I_{out}$  up to 64A and  $V_{p-p}$  up to 3.3V  
 $R_b$  should be 36.1 Ohm  $\pm 0.1\%$  and gain 1

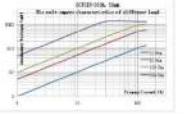
**Notes:** The measurement in the tests till now is not precise enough,  
 Power circuit current is not more than 20A for safety reasons,  
 More precise calibration should be done before final usage.

## HWCT-5A/5mA and SCT013-000-100A-50mA comparison

Feature	HWCT-5A/5mA		SCT013-000 100A 50mA	
	Datasheet	Measured	Datasheet	Measured
Nominal current	5 A	1 A	100 A	1 A
Maximum current	20 A		120 A	
Turns ratio	1:1000	1:833	1:2000	1:1667
Current ratio	5A:5mA	1A:1.2mA	100A:50mA	1A:0.6mA
DC resistance	155 Ohms	45 Ohms		103 Ohms
Load resistor	2 Ohms	120 Ohms	10 Ohms	120 Ohms
Accuracy	$\pm 2\%$		$\pm 1\%$	
Linearity				$\leq 0.2\%$



Characteristic curve in different load volt-sensors



### First test results (measured AC voltage at given AC current in the power chain)

HWCT-5A/5mA	SCT013-100A 50mA
<b>Test conditions</b>	
$R_b$	5 Ohms
$V$	5 Volts
$A$	1 A/MS
$R$	120 Ohms
<b>Calculations (datasheet based)</b>	
$V_{p-p} = 2 * \sqrt{2} * I * R * T_{ratio}$	
$V_{p-p}$	339.4 mV
	169.7 mV
<b>Test results</b>	
Ch.	1      2
Scale	100 mV/div
$V_{p-p}$	408 mV
	204 mV
<b>Diff.</b>	20%
	20%

The big difference for the both sensors can eventually be explained mainly with not very precise measurement. On the other hand there is a quite big difference in declared in the data sheet DC resistance (155 Ohms) and measured (45 Ohms) for the HWCT-5A/5mA sensor.

