Virtual Prototyping of Power Converter Systems based on AURIX™ using SystemC AMS

COSEDA User Group Meeting 2021

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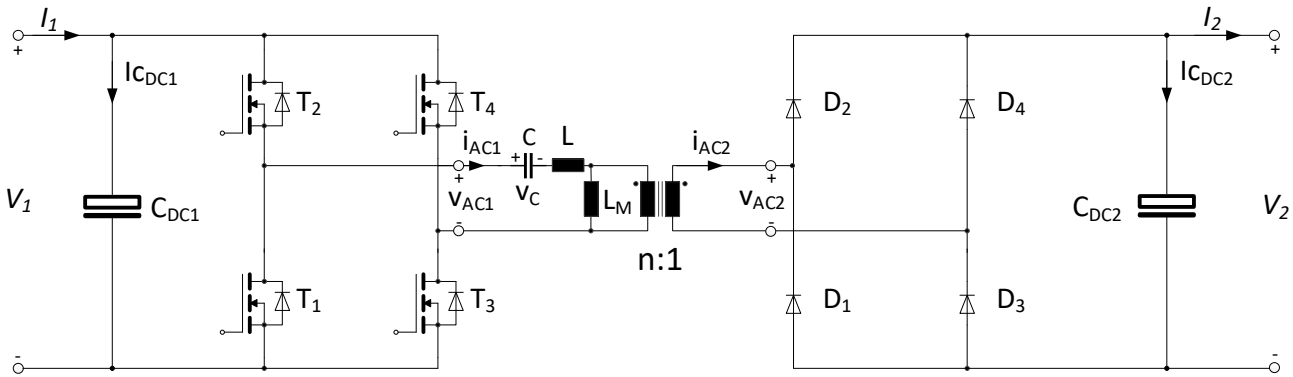
Motivation

Mixed-Signal Virtual Prototyping:

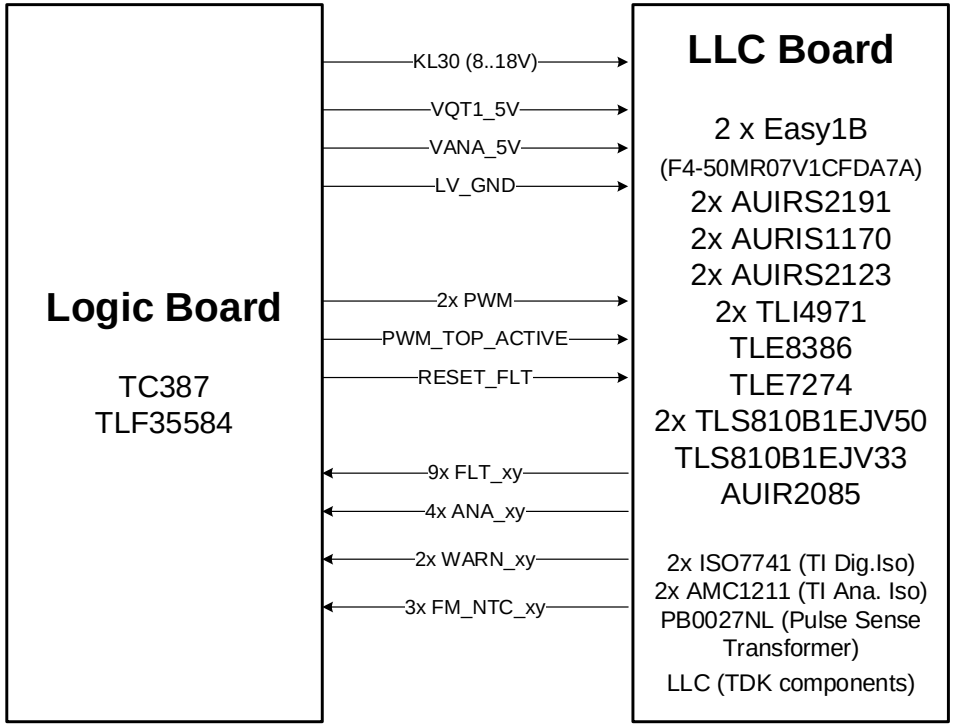
- Eases taking into the operation of power converter on application level
- Improves T2M - early start w/o real HW available
  - development of control algorithm
  - productive SW development
- Prevent malfunctions and laboratory equipment damage
- Enables exact reproducibility, corner cases can be analyzed to it limits

Unidirectional Series-Parallel Resonant LLC DC/DC Converter (1)



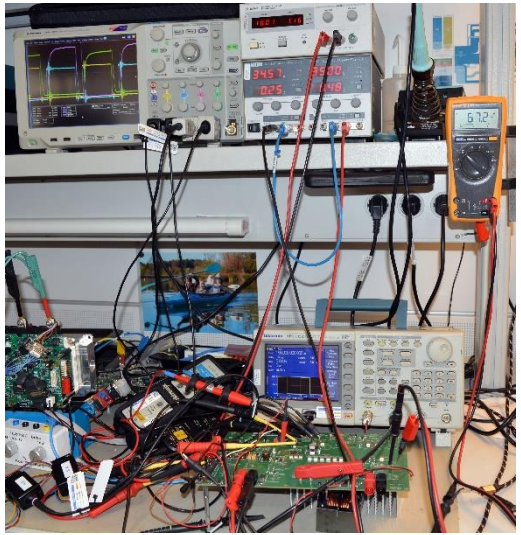
	Nominal	Minimum	Maximum
DC Bus Voltage [V]	380	360	400
Battery Voltage [V]	280	250	420
Load Power [W]	3300	400	3700

Unidirectional Series-Parallel Resonant LLC DC/DC Converter (2)

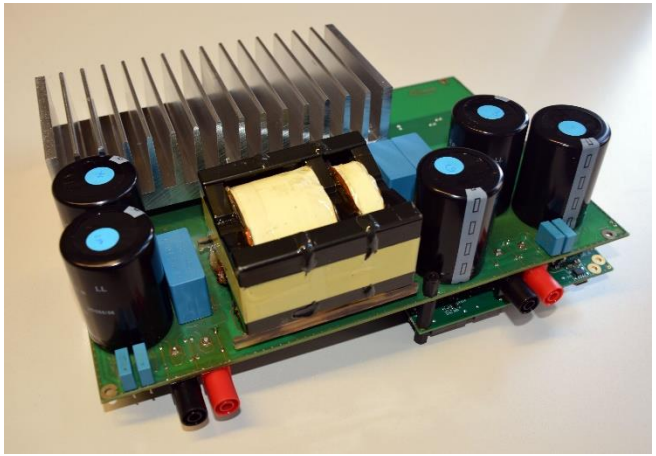


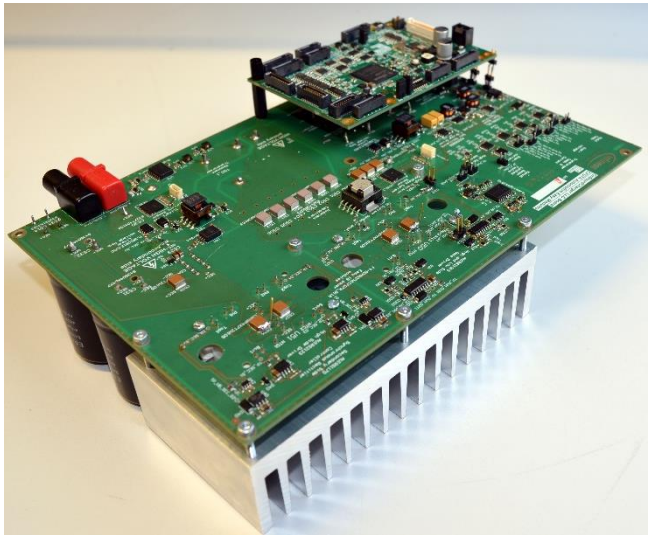
Unidirectional Series-Parallel Resonant LLC DC/DC Converter (3)

› Low voltage testbench

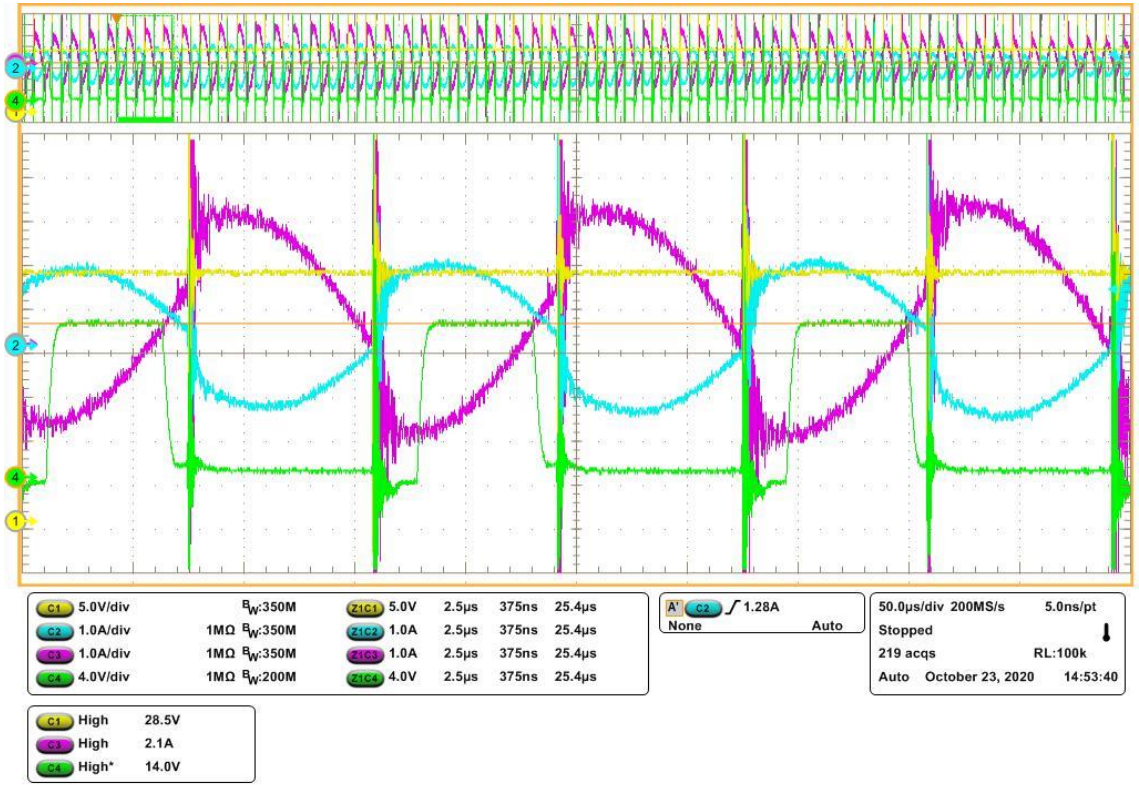


› LLC Demonstrator full mounted





Unidirectional Series-Parallel Resonant LLC DC/DC Converter (4)



A1:
Output voltage
(battery output voltage)

A2:
Primary side transformer current

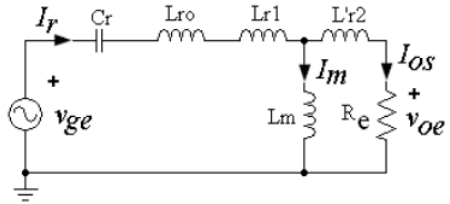
A3:
Secondary side transformer current

A4:
Secondary power module low side switch gate voltage

Input voltage 60 V_{DC}, R_{LOAD} 23,5 Ω, Switching frequency 120 kHz

Unidirectional Series-Parallel Resonant LLC DC/DC Converter (5) Selection of HF Transformer

HF Transformer is crucial component for operation of LLC converter, since it directly influences switching frequency range (PWM and selection of power switches), determines a transfer function of system and implicitly influences the efficiency of overall system



Equivalent ac circuit with the leakage inductance in consideration.

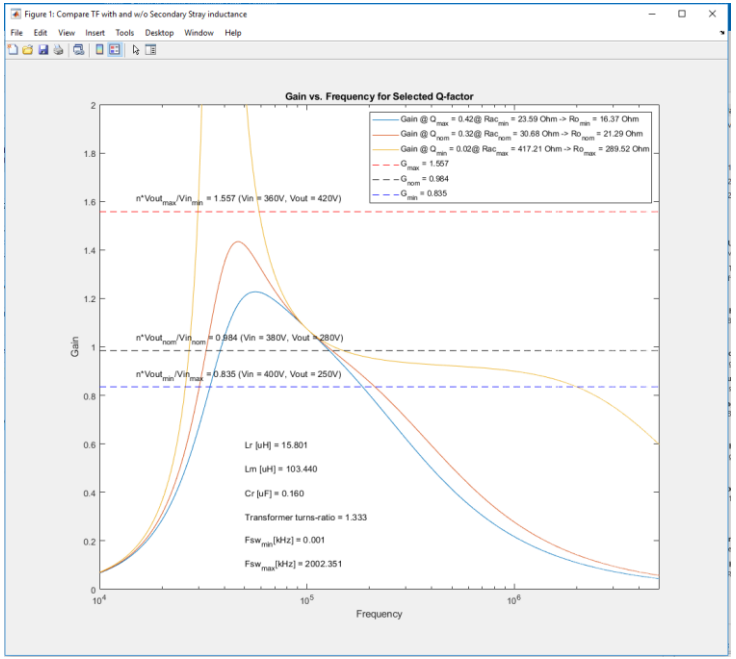
LLC Transfer Function

$$M_{gl}^{ac} = \left| \frac{(j\omega L_m)//(R_e + j\omega L'_{r2})}{(j\omega L_m)//(R_e + j\omega L'_{r2}) + j\omega L_r + 1/j\omega C_r} \times \frac{R_e}{(R_e + j\omega L'_{r2})} \right|$$

If L_{ro} = 0 (no external inductance), primary stray inductance is used as resonant inductance (but the secondary stray inductance has to be taken into the account as well)

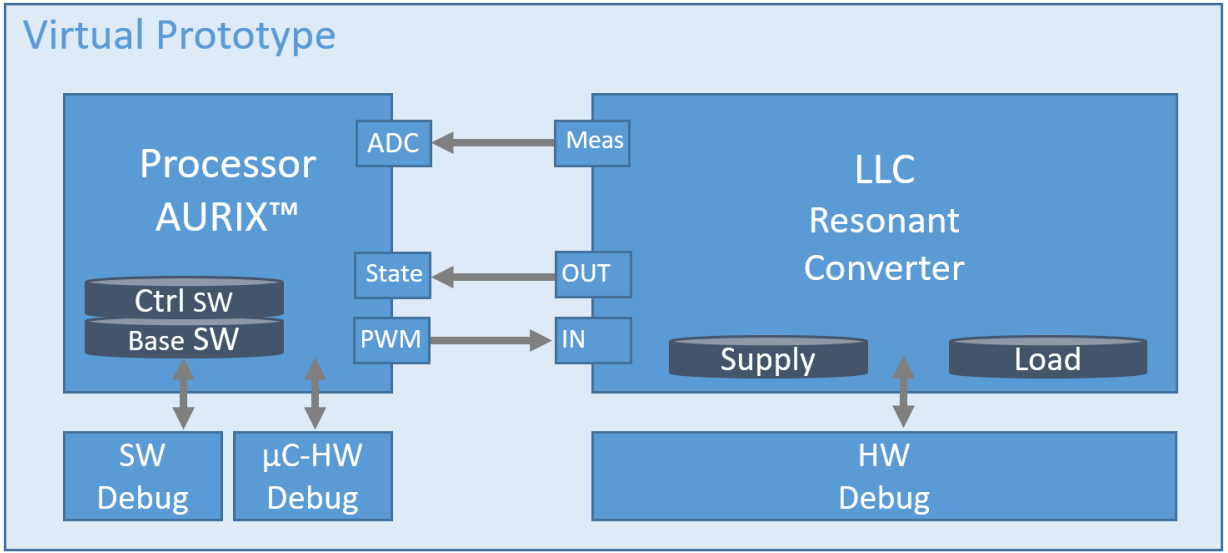
$$L_r = L_{r1} + L_m || L'_{r2}$$

LLC Transfer Function (Gain vs. Frequency)

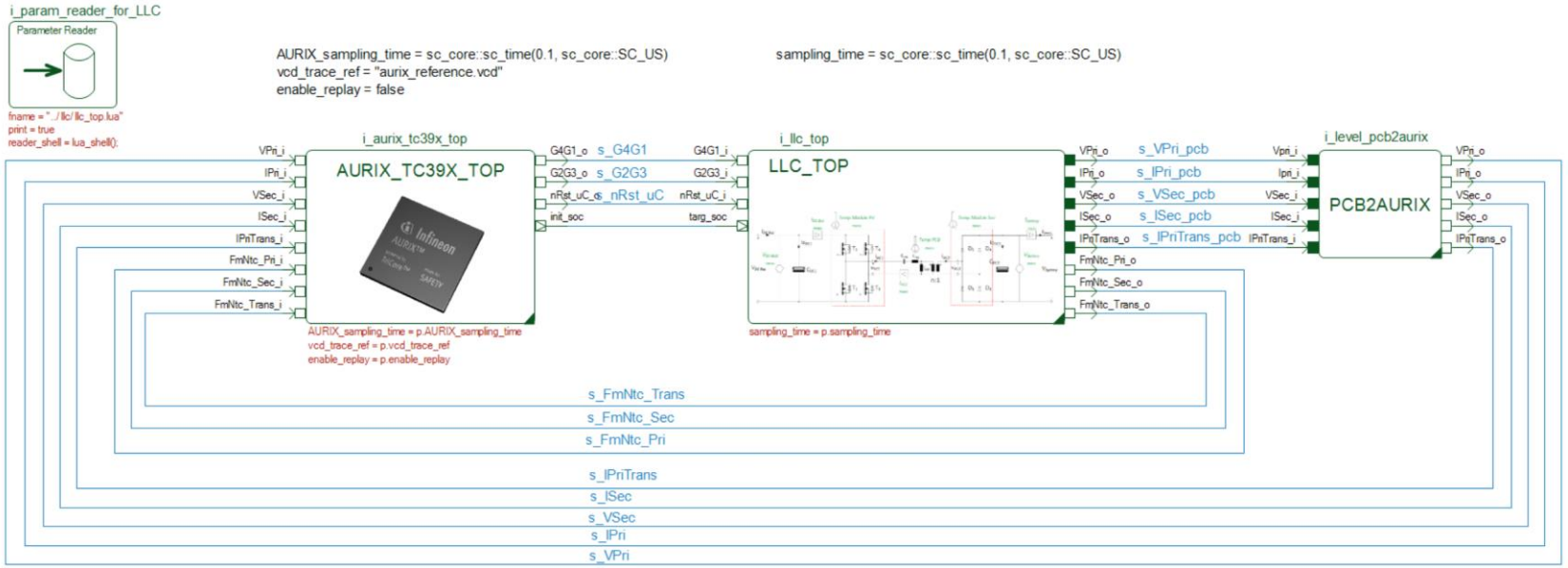


Overview

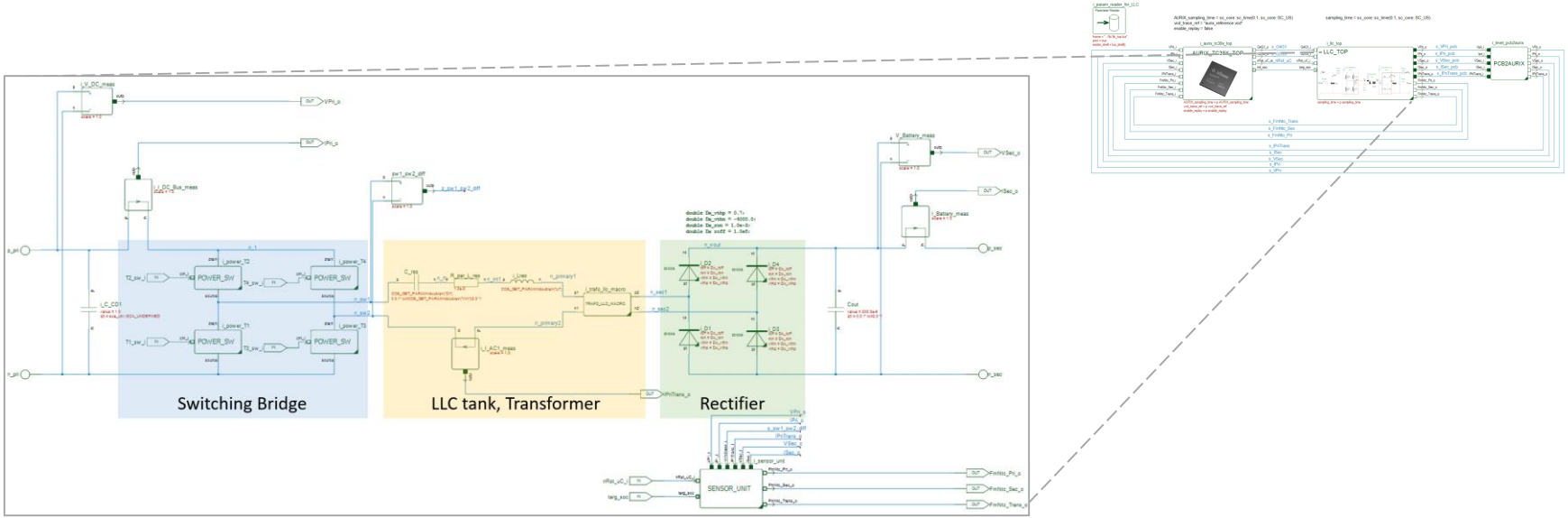
- Mixed-Signal Virtual-Prototype
- Processor Model (AURIX™)
  - SystemC TLM2
- LLC Resonant Converter
  - SystemC AMS
- HW/SW Co-Debugging



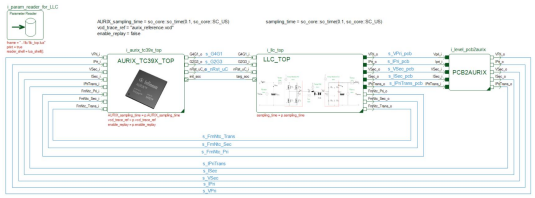
Overall System Model



Model of Unidirectional Series-Parallel Resonant LLC DC/DC Converter

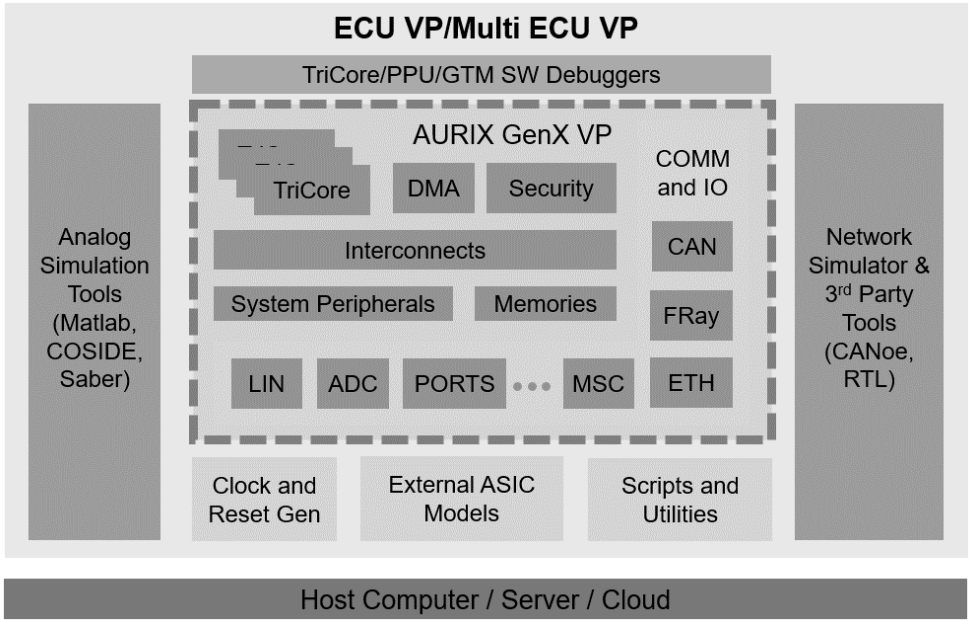


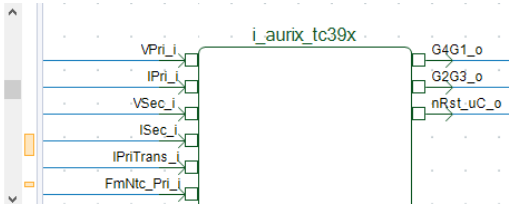
Infineon/Synopsys AURIX™ Processor Model & Integration of Processor Model



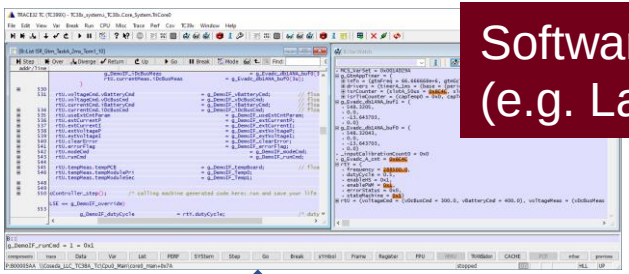
Parameter	Value	Type
i_TC38x		
Core_System		
TriCore0		
IOStubs		
Analog		
AN_14		
cosimPath	VSec_i	String
direction	out	String [in, out]
domainName	csb	String
AN_22		

```
////////////////////////////////////////////
// method called by constructor           //
////////////////////////////////////////////
void aurix_tc39x::construct()
{
    s.i_aurix_c->register_port(VPri_i, "VPri_i", "IOStubs/Analog/AN6");
    s.i_aurix_c->register_port(IPri_i, "IPri_i", "IOStubs/Analog/AN30");
    s.i_aurix_c->register_port(VSec_i, "VSec_i", "IOStubs/Analog/AN14");
    s.i_aurix_c->register_port(ISec_i, "ISec_i", "IOStubs/Analog/AN22");
    s.i_aurix_c->register_port(G4G1_o, "G4G1_o", "GPIO/IO_P00_2");
    s.i_aurix_c->register_port(G2G3_o, "G2G3_o", "GPIO/IO_P32_3");
    s.i_aurix_c->register_port(FmNtc_Pri_i, "FmNtc_Pri_i", "GPIO/IO_P11_13");
```

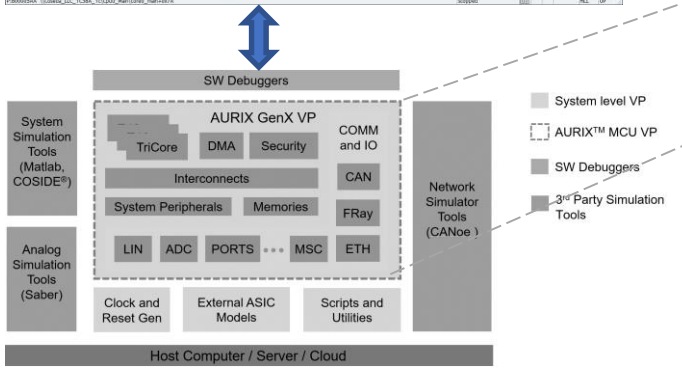


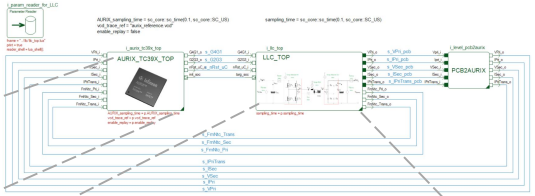


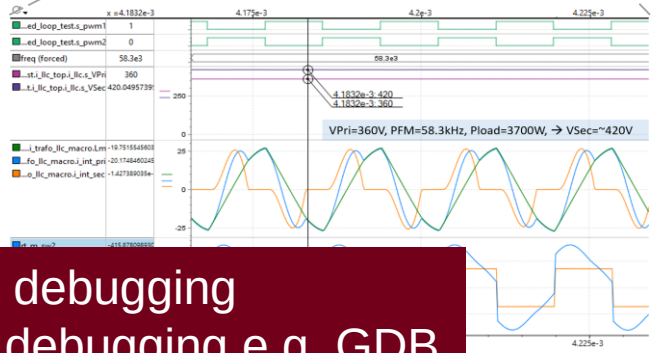
Software and Hardware Debugging



Software debugging
(e.g. Lauterbach Trace32)







Waveform debugging
Hardware debugging e.g. GDB

Conclusions

- Virtual Prototyping approach is sucesfully implemented on application level for isolated unidirectional DC/DC converter
  - HW is sucesfully modeled
  - Control algorithm is sucesfully implemented and tested
  - iLLD‘s are implemented and tested
  - Overall system is taken into the operation
- Feedback is given to developers of AURIX™ Processor Model

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