Usage of SystemC-AMS MDVP for virtual prototyping of a MEMS application

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Outline 2

- Virtual Prototyping: the Objective
- Application description
- The MEMS sensors : modeling and MoCs
- Coherent Stimuli: the challenge
- MoC considerations & Conclusions



Objective

- SystemC AMS and Multi-Domain Virtual Prototyping (MDVP)
 virtual platforms will allow costs and time-to-market reduction
- The architect perspective:
 - HW/SW partitioning
 - HW resources specification
- The SW developer perspective
 - Early development/debug of the embedded SW before prototypes (with analog and mechanical parts)
 - Embedded SW validation for families of object movements and corners (Temperature)
 - Power efficient control/readout of MEMS (HW resources optimization)
- Virtual platform used as **demonstrator** for customers



Application description

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• iNemo board embedding:

- Accelerometer/Magnetometer
- Gyroscope
- Motion detection for:
 - Gesture recognition
 - Motion tracking
 - Fall detection
- Through:
 - Sensor fusion algorithms





3-axis angular rate Electro-Mechanical Electrical Analog Electrical Digital

3-axis

digitalized

angular

rate

MEMS sensor: Gyroscope example 6

- Sensor functioning overview
- TDF MoC model
- Bond-Graph MoC model proposal
- Non-linear refined model from FEA
- Digital on-chip processing



Gyroscope functioning overview



Coriolis force:

 $\boldsymbol{F}_{C} = -2 \, m \, \boldsymbol{\Omega} \times \boldsymbol{v}$

Where:
$$\mathbf{\Omega} \times \mathbf{v} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \Omega_x & \Omega_y & \Omega_z \\ v_x & v_y & v_z \end{vmatrix} = \begin{pmatrix} \Omega_y v_z - \Omega_z v_y \\ \Omega_z v_x - \Omega_x v_z \\ \Omega_x v_y - \Omega_y v_x \end{pmatrix} - \mathbf{F}_{\mathsf{cz}}$$
 on Sensing axis





Gyroscope TDF model

 Time step to be specified by user based on his knowledge of the system and independently from signal dynamics



Objective	Application	MEMS sensors	Coherent Stimuli Conclusions			
LEGEND: SystemC MDVP BlockDiagram SystemC MDVP BondGraph	SystemC AMS TDF	Bo	nd-Graph	MoC	model	proposa

- Signal typing (connectivity check)
- Time step adapted to signal dynamics (time step max specified)

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Non-linear refined model from FEA

Under development in MEMS+® by Coventor





- Component-based Finite Element Analysis (FEA)
- Coupling multiple physical domains *electrostatics, mechanics...*
- Based on state-space system inherent to MEMS+® 3D model
 - Model-Order Reduction thanks to state-number reduction
 - Non-linearity thanks to the interpolation of state-space linearizations
- Integration in SystemC-AMS
 - Custom TDF module with specific processing() method
 - Ongoing tests with Dynamic TDF (potential speed-up of the computation)



Register bank

	Slave address	Туре	Register address			
Name			Hex	Binary	Default	
Reserved (do not modify)	Table 14		00 - 1F			
CTRL_REG1_A	Table 14	rw	20	010 0000	00000111	
CTRL_REG2_A	Table 14	rw	21	010 0001	00000000	
CTRL_REG3_A	Table 14	rw	22	010 0010	00000000	
CTRL_REG4_A	Table 14	rw	23	010 0011	00000000	CONFIC
CTRL_REG5_A	Table 14	rw	24	010 0100	00000000	regioter
CTRL_REG6_A	Table 14	rw	25	010 0101	00000000	
REFERENCE_A	Table 14	rw	26	010 0110	00000000	
STATUS_REG_A	Table 14	r	27	010 0111	00000000	

Digital on-chip processing



Coherent stimuli generation 12

- Internal tool for
 - Object trajectory definition (both 3D path+temporal aspect)
 - Object orientation evolution along the trajectory (through Control Points CP)
 - Generate xml file to provide the stimuli to SystemC MEMS simulation





MoC considerations 13

MoC Time step		Advantages	Drawbacks	
TDF	constant & user defined	Easy to code	 time step constant → non-optimal for analog behaviors and closed loops user defined 	
Bond Graph	dynamic max limit to be specified	Dynamic time step →faster simulation Good accuracy on closed-loops (delay needed with TDF) Simulator accuracy tunable	Not trivial to code in current PoC	
Refined model from FEA (TDF)	efined lel from A (TDF) constan in current PoC & user defined High accuracy from FEA (driving voltages + non-linearities) Automatic code generation		Code interpreteability time step - user defined	



Bond Graph MoC and MEMS+ model are ongoing developments in the frame of CATRENE CA701 H-INCEPTION Project

Conclusions 14

- State-of-the-art for MEMS applications simulation
 - Co-simulation
 MEMS as FEM models + TLM VP on Linux : Too much compute-greedy
 - Co-emulation

MEMS on daughter board + *TLM VP on Linux :* Too many boards, tough reproducibility

- SystemC AMS-TLM Virtual Platform assembled and validated
- Next steps
 - Exploit the methodology for new projects during their architecture definition phase
 - Reuse the methodology for new projects with Multi-physical domains + Analog + Digital + SW parts

