DOLPHIN INTEGRATION

Gerhard Mercator University

Combining Models of Physical Effects for Describing Complex Electromechanical Devices

Lars M. Voßkämper

Dolphin Integration GmbH

Gerhard Mercator University Duisburg

DOLPHIN INTEGRATION

Gerhard Mercator University

Outline

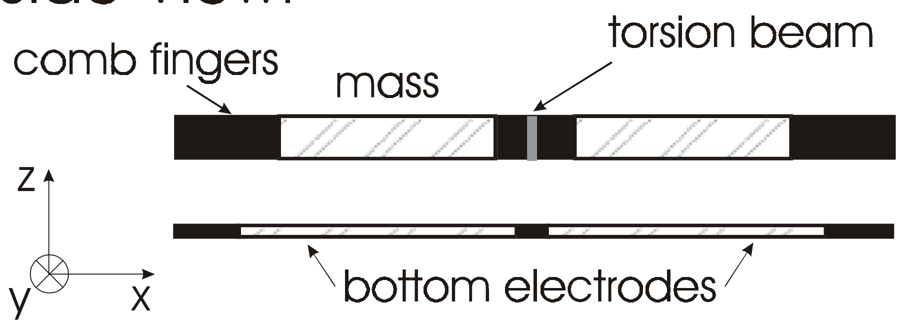
- Demonstrator: gyroscope
- Basic effects occurring in the gyroscope
- Implementation in VHDL-AMS
- Object models created with basic effects
- Device modeling and simulation
- System modeling and simulation
- Conclusion

DOLPHIN
INTEGRATION

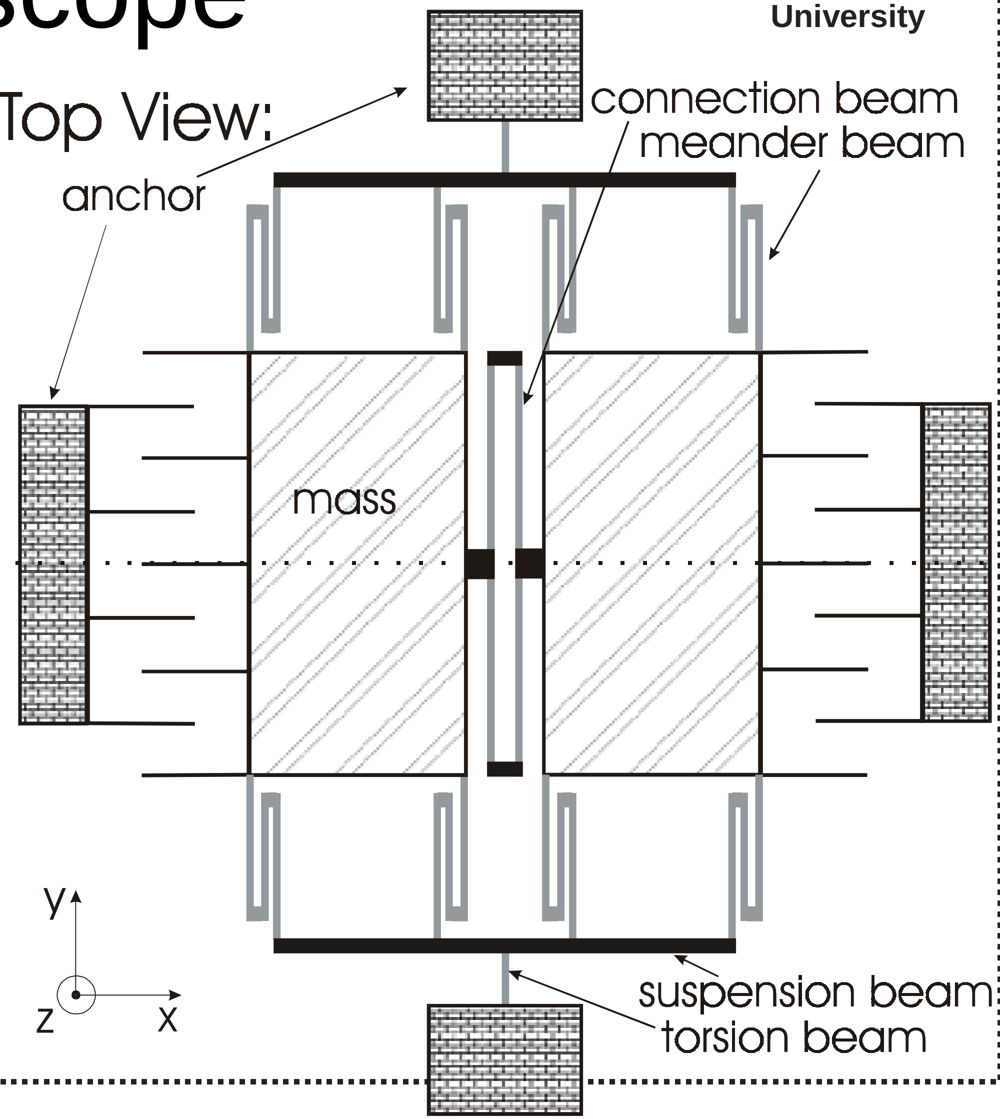
Demonstrator: Gyroscope

Gerhard Mercator
University

Side View:



Top View:



- opposite in phase motion of masses
- angular velocity induces tilting of masses
- detection due to capacity difference

DOLPHIN INTEGRATION

Gerhard Mercator University

Basic Effects Occurring in the Gyroscope

- Bending and torsion effects of beams
- Translational and rotational inertia effects
- Air damping effects
- Capacity effect between two conductive plates
- Attraction effect of two conductive plates
- Coriolis effect

DOLPHIN INTEGRATION

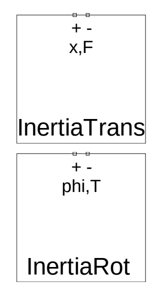
Gerhard Mercator University

Analytical Modeling of Basic Effects

Port definition to make models compatible with each other

type of variable	electrical network	rotational movement	translational movement
"through"-variable	current i	torque T	force F
"across"-variable	voltage v	angle φ angular velocity ω	displacement x velocity v

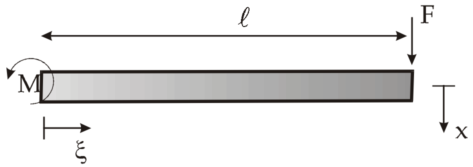
Effect	Equation	Symbol
translational inertia effect of masses	$F = -m \frac{d^2}{dt^2} x$	
rotational inertia effect of masses	$T = -J_A \frac{d^2}{dt^2} \varphi$	



DOLPHIN INTEGRATION

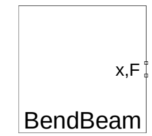
Analytical Modeling of Basic Effects

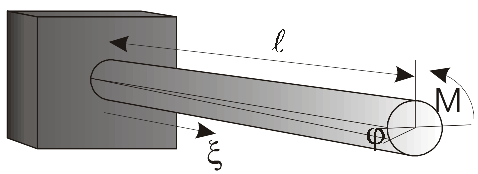
Gerhard Mercator University



bending effect of beams

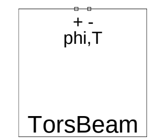
$$\frac{d^2 x_{(\xi)}}{d\xi^2} = -\frac{M_{(\xi)}}{EI_{(\xi)}} \Longrightarrow F = \frac{3EI}{l^3} x$$

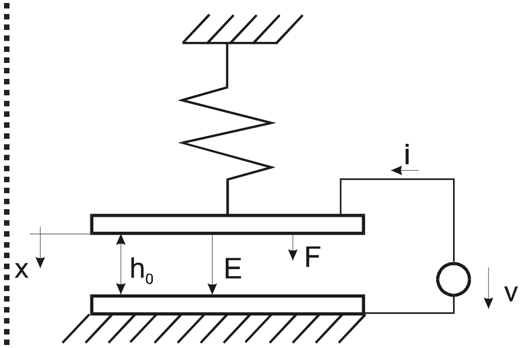




torsion effect of beams

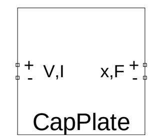
$$\frac{d\varphi_{(\xi)}}{d\xi} = \frac{T_{(\xi)}}{GI} \Longrightarrow T = \frac{GI}{l}\varphi$$





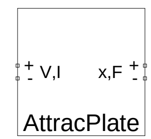
capacity effect between two conductive plates

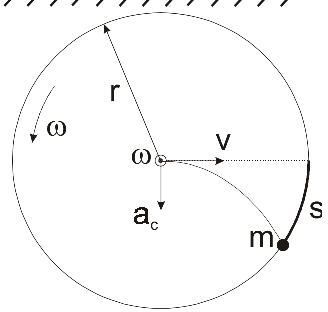
$$C_{(x)} = \varepsilon \frac{A}{h_0 - x} \Longrightarrow i = C_{(x)} \frac{d}{dt} v$$



attraction effect between conductive plates

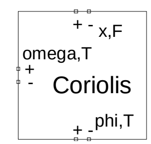
$$\vec{F} = \frac{dE}{d\vec{x}} \Longrightarrow F_x = \frac{1}{2}\varepsilon A \frac{v^2}{(h_0 - x)^2}$$





Coriolis effect

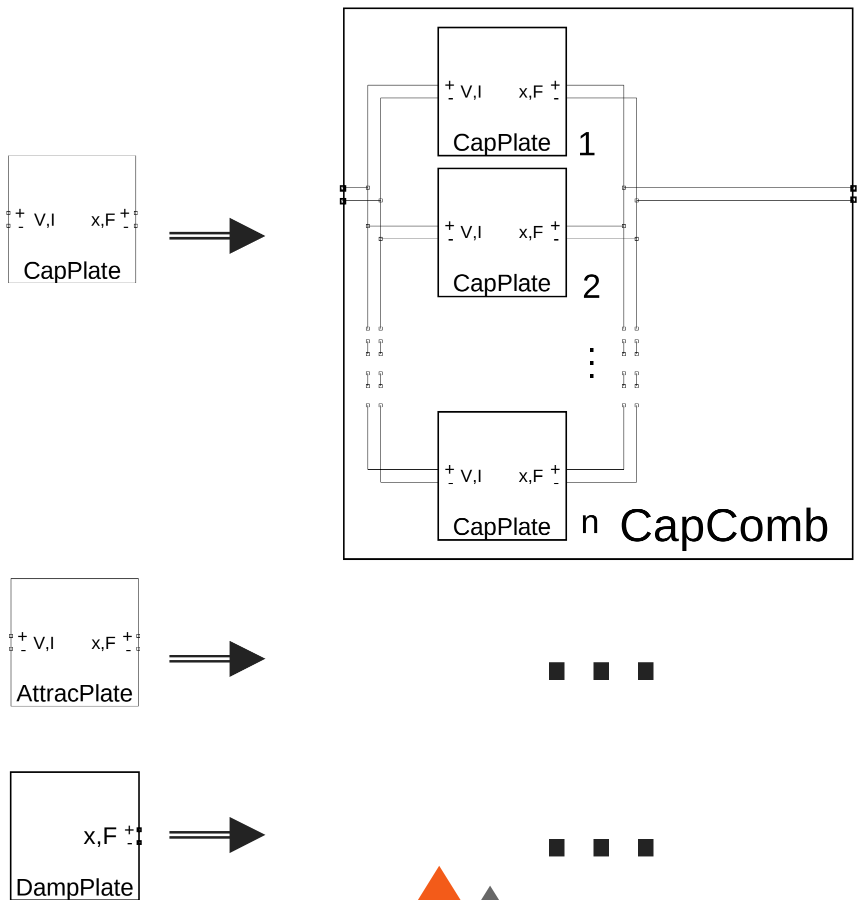
$$\vec{T} = 2 \cdot m \cdot \vec{r} \times (\vec{v} \times \vec{\omega}) \Longrightarrow T = 2m\omega x \frac{d}{dt} x$$



DOLPHIN
INTEGRATION

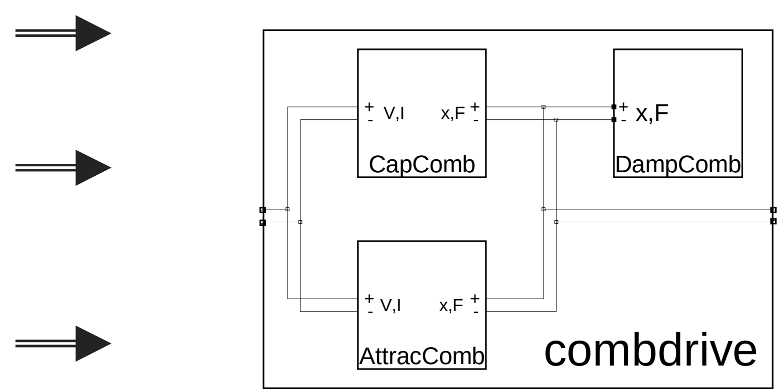
Gerhard Mercator
University

Object Models Created with Basic Effects



Modeling a comb drive out of basic effects:

- capacity effect between plates
- attraction effect between plates
- damping effect of moving plates



DOLPHIN INTEGRATION

Implementation in VHDL-AMS

Gerhard Mercator University

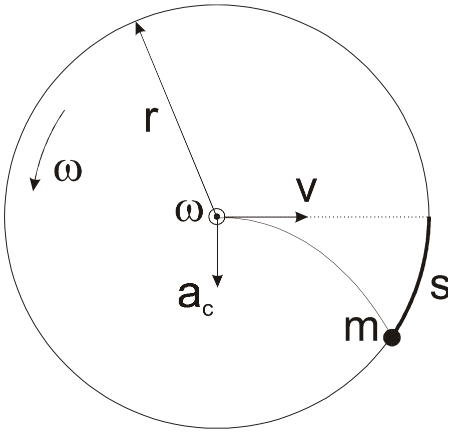
```
PACKAGE translational_system IS
   ATTRIBUTE unit : string;
-- Displacement in meter
   SUBTYPE displacement IS REAL TOLERANCE "default_displacement";
   ATTRIBUTE unit OF displacement : SUBTYPE IS "m";
-- Velocity in meter/second
   SUBTYPE velocity IS REAL TOLERANCE "default_velocity";
   ATTRIBUTE unit OF velocity : SUBTYPE IS "m/s";
-- Force in newton
   SUBTYPE force IS REAL TOLERANCE "default_force";
   ATTRIBUTE unit OF force : SUBTYPE IS "N";
-- Translational Natures
   NATURE translational IS
     displacement ACROSS
     force THROUGH
     translational_ref REFERENCE;
END PACKAGE translational_system;
```

Extract from the implementation of variables types used in translational system

Implementation in VHDL-AMS

DOLPHIN INTEGRATION

Gerhard Mercator University

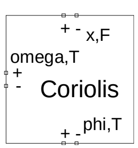


Coriolis acceleration $\vec{a}_c = 2\vec{v} \times \vec{\omega}$

Coriolis force $\vec{F}_c = 2m\vec{v} \times \vec{\omega}$

Coriolis torque $\vec{T} = 2 \cdot m \cdot \vec{r} \times (\vec{v} \times \vec{\omega})$

$$T = 2m\omega x \frac{d}{dt} x$$



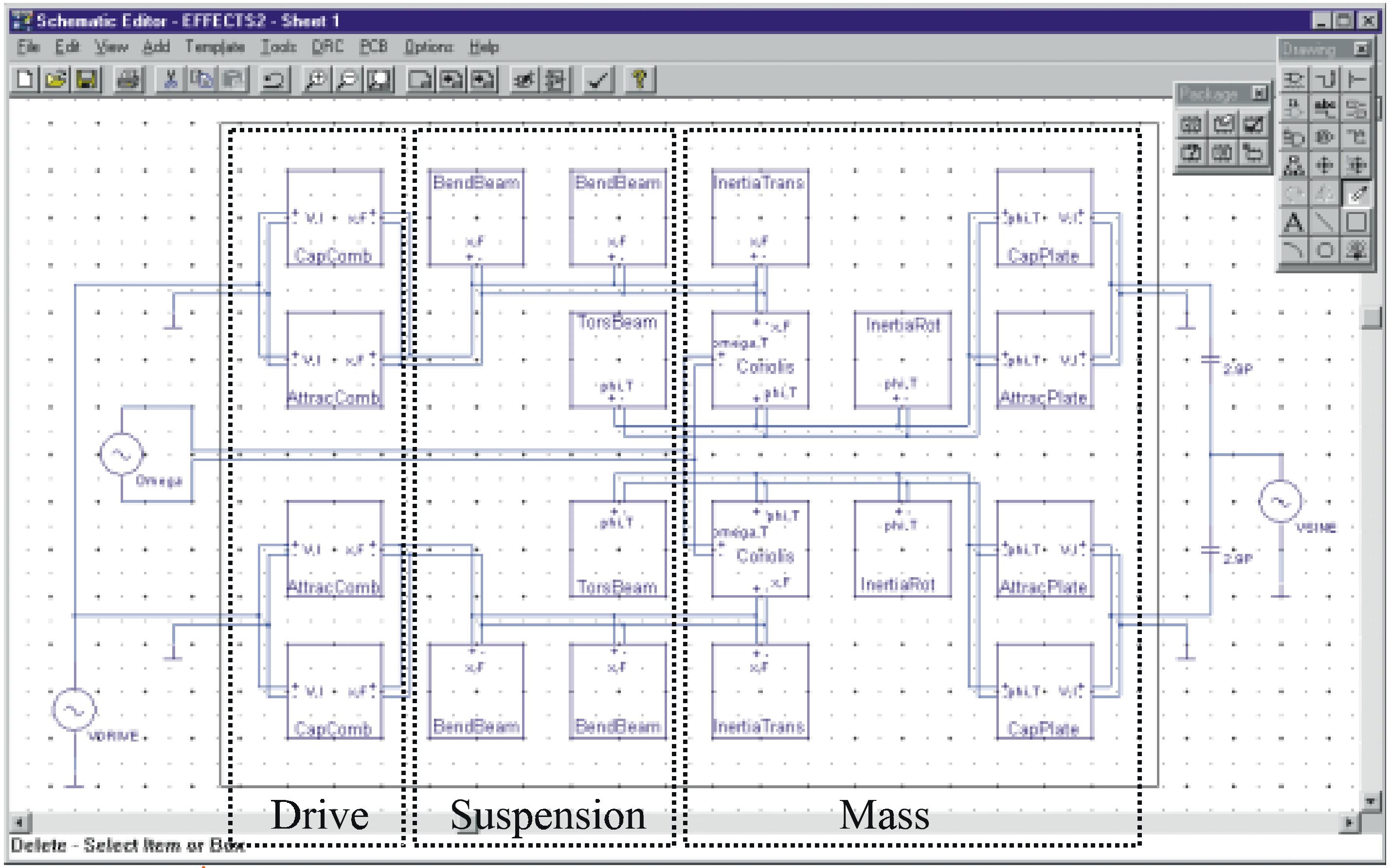

```
USE work.translational_system.all;
USE work.rotational_system.all;

ENTITY Coriolis IS
  GENERIC (width, length, depth : REAL;
                roh : REAL := 2.32e3);
  PORT (TERMINAL trans_p,  trans_n  : TRANSLATIONAL;
        TERMINAL rot_p,    rot_n    : ROTATIONAL;
        TERMINAL rot_om_p, rot_om_n : ROTATIONAL_OMEGA);
END ENTITY Coriolis;

ARCHITECTURE simple OF Coriolis IS
  QUANTITY pos    ACROSS  trans_p  TO trans_n;
  QUANTITY torque THROUGH rot_p    TO rot_n;
  QUANTITY omega  ACROSS  rot_om_p TO rot_om_n;
  CONSTANT mass : REAL := width*length*depth*roh;
BEGIN
  torque == 2.0 * mass * omega * pos * pos'dot;
END ARCHITECTURE simple;
```

Implementation of Coriolis effect

DOLPHIN
INTEGRATION

Device Modeling

Gerhard Mercator
University

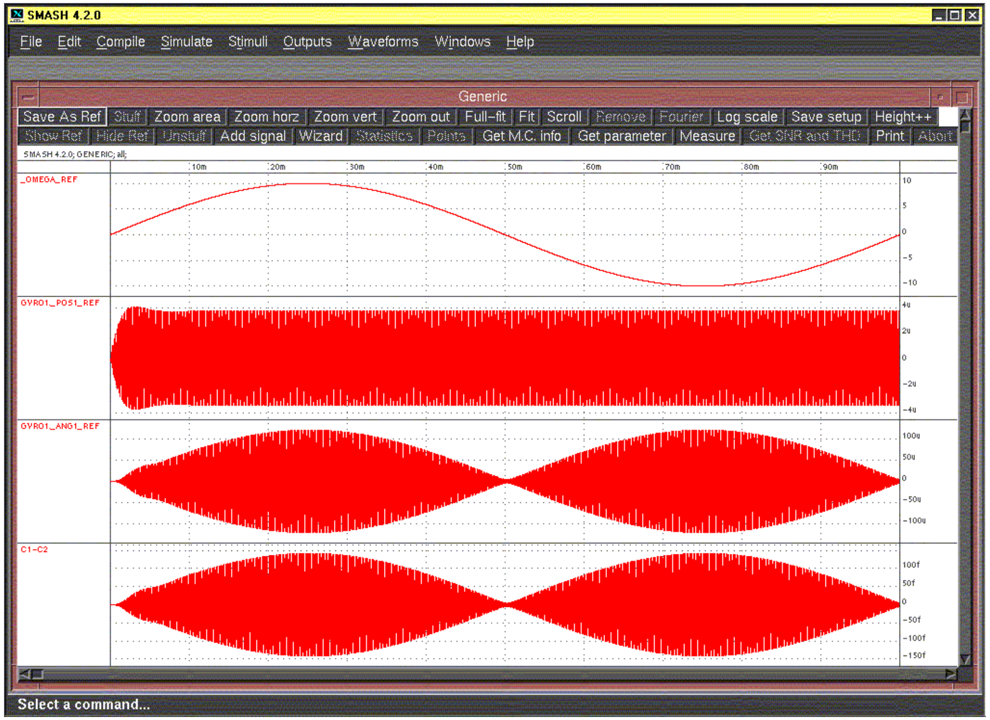


Gyroscope’s netlist with basic testbench for device simulation

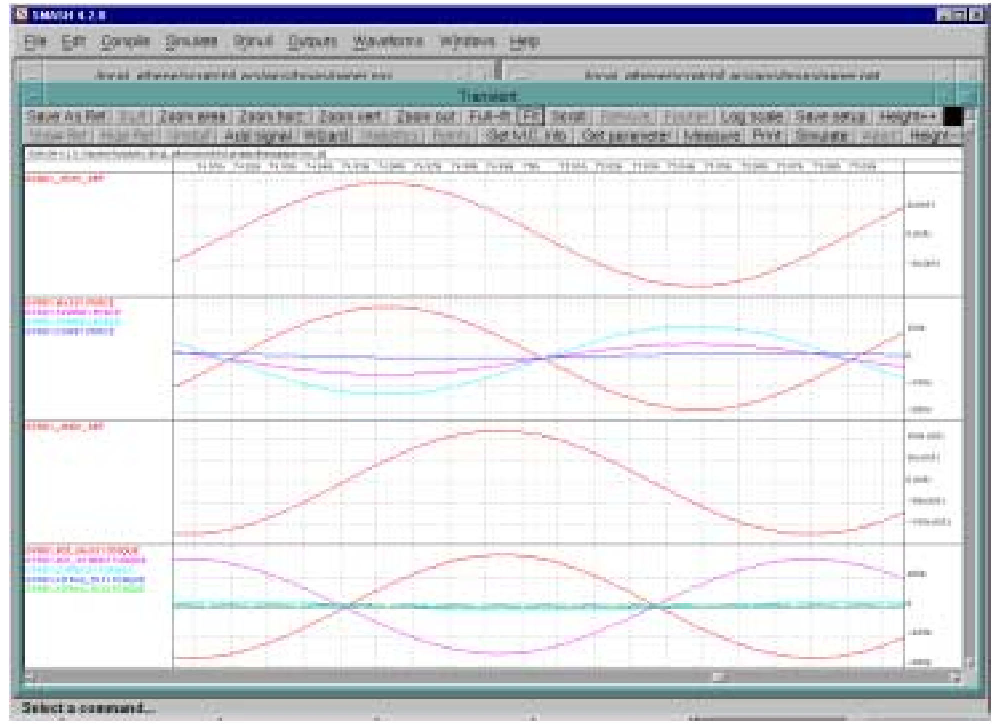
DOLPHIN INTEGRATION

Device Simulation

Gerhard Mercator University



angular velocity, displacement, tilt angle and capacity difference

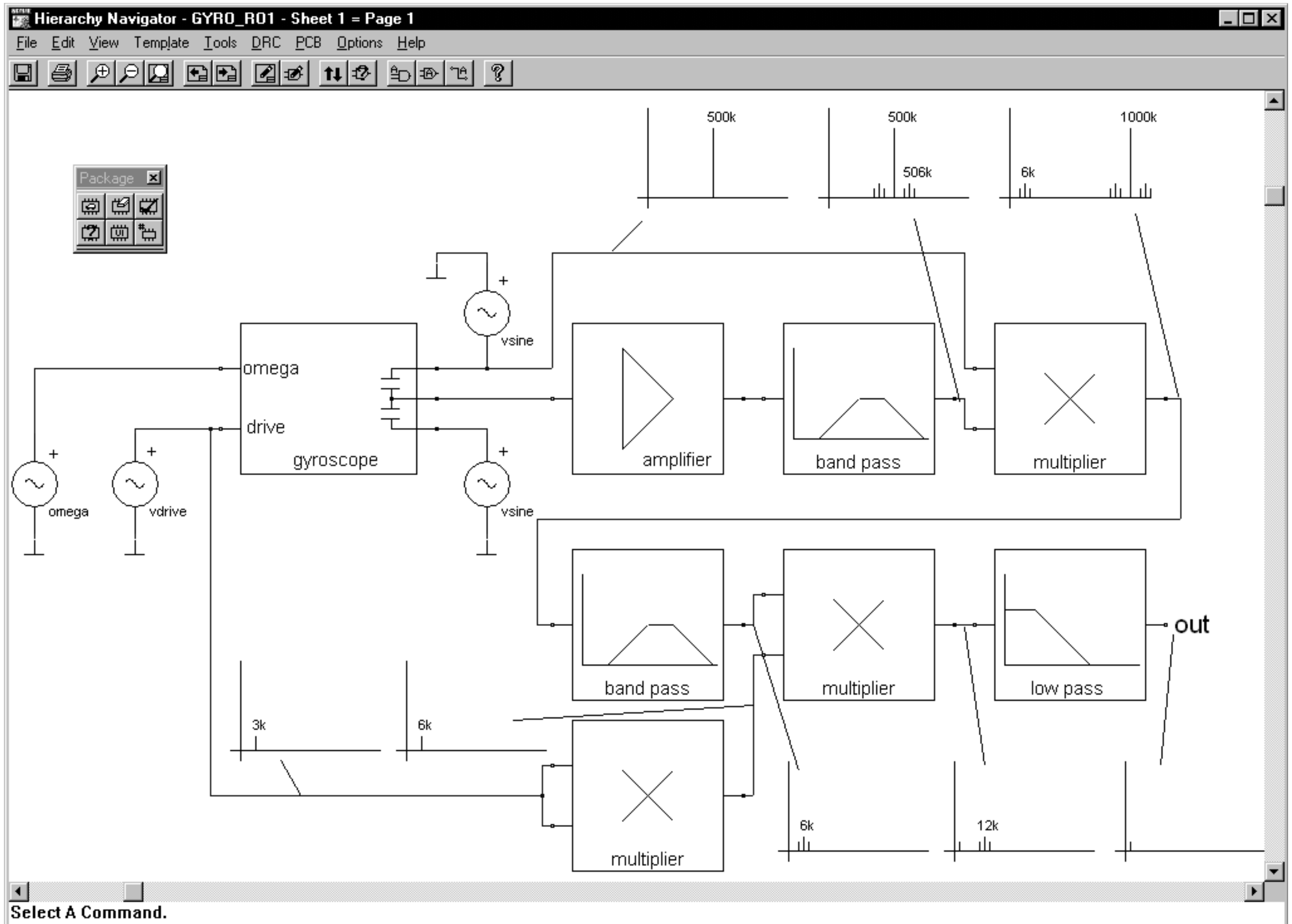


displacement, forces, tilt angle and torques

DOLPHIN INTEGRATION

System Modeling

Gerhard Mercator University

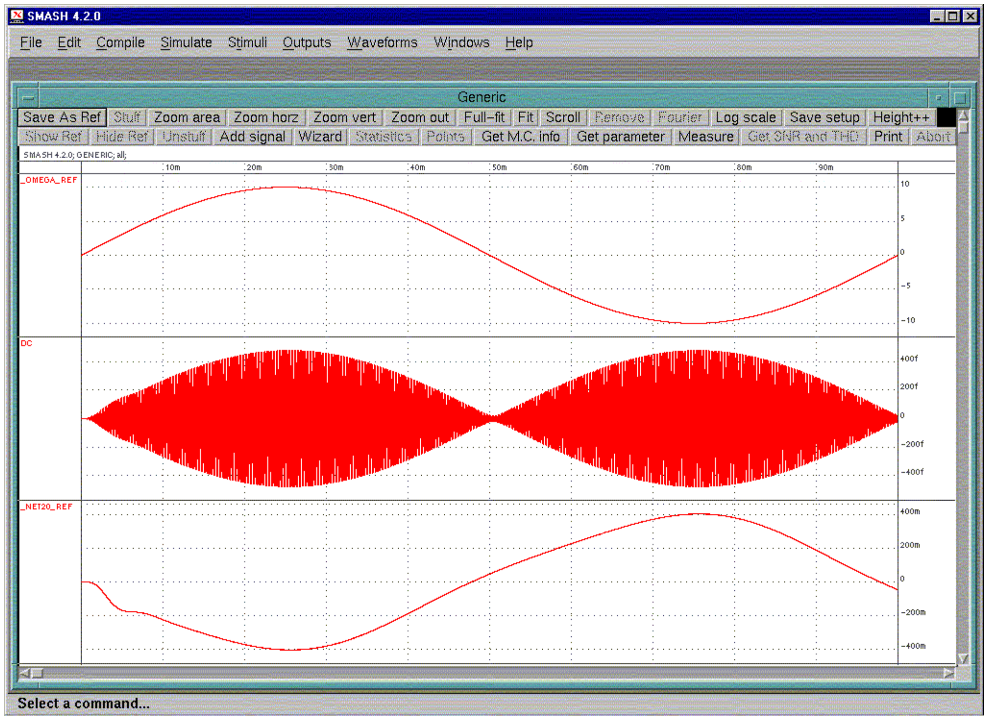


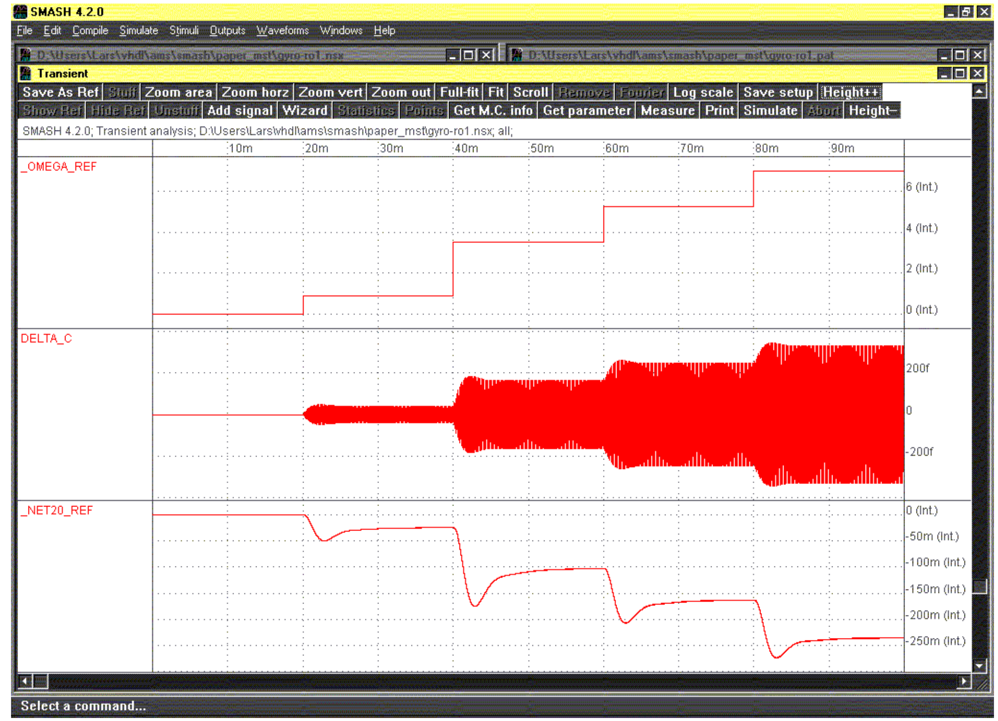
Functional view of the gyroscope readout circuit

DOLPHIN
INTEGRATION

System Simulation

Gerhard Mercator
University





angular velocity, capacity difference and output voltage

DOLPHIN INTEGRATION

Gerhard Mercator University

Conclusion

Basic effect library:

- constructing most (electro-) mechanical devices
- controlling simulation speed and accuracy
- easy extension of the library

Implementation in VHDL-AMS:

- straightforward implementation of mathematical functions
- mixed-domain and mixed-signal modeling with *one* HDL
- system simulation becomes easy