Synthesis of Torque Vectoring Topologies with Hybrid Functionalities

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European All-Wheel Drive Congress 2017
06.04.2017

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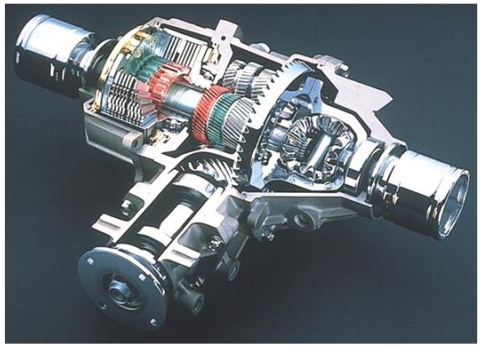
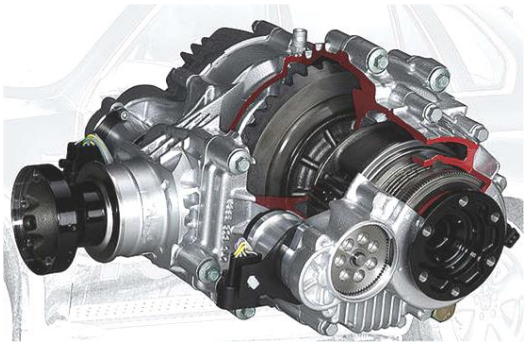
- Overview
- Basic Principle of Torque Vectoring with Superimposing Unit
- PlanGear – Synthesis Program
- Example
- Summary

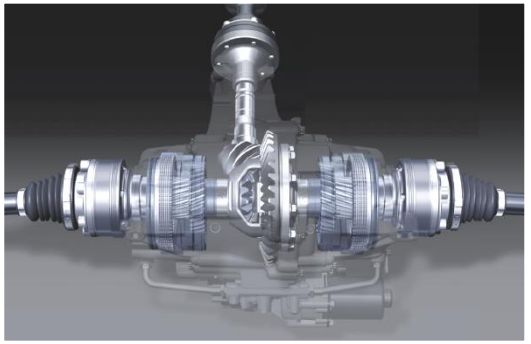
Overview
Torque Vectoring in series production



since 1996



since 2008



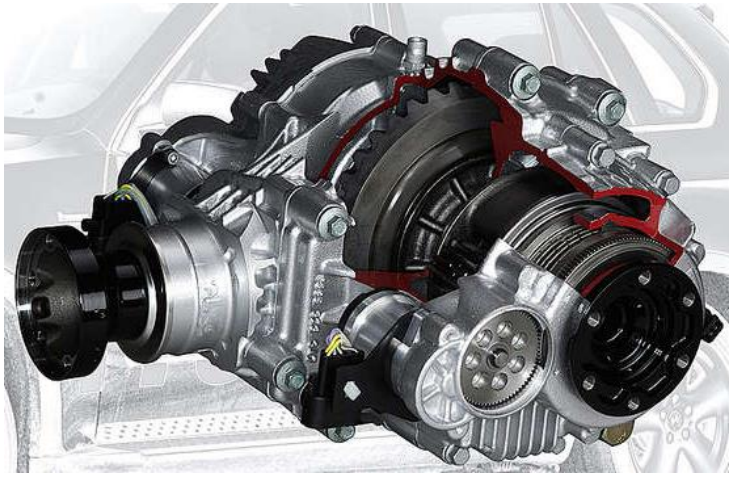
since 2008

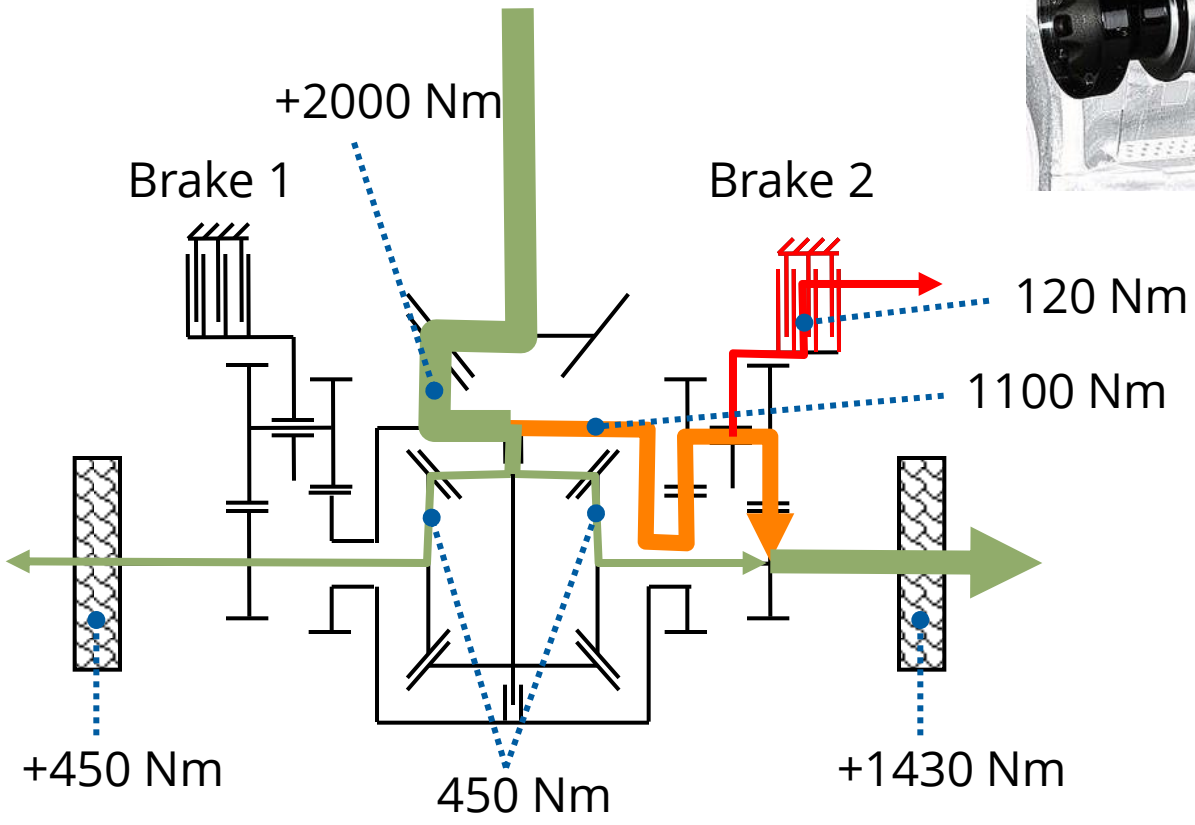
Quellen:
http://m.audi-quattro-highlights.de/de/aqh/Technologien/Sportdifferenzial

http://www.lancerregister.com/faq/G04/g04.html

Overview

Power flow - Vector Drive (BMW X6)





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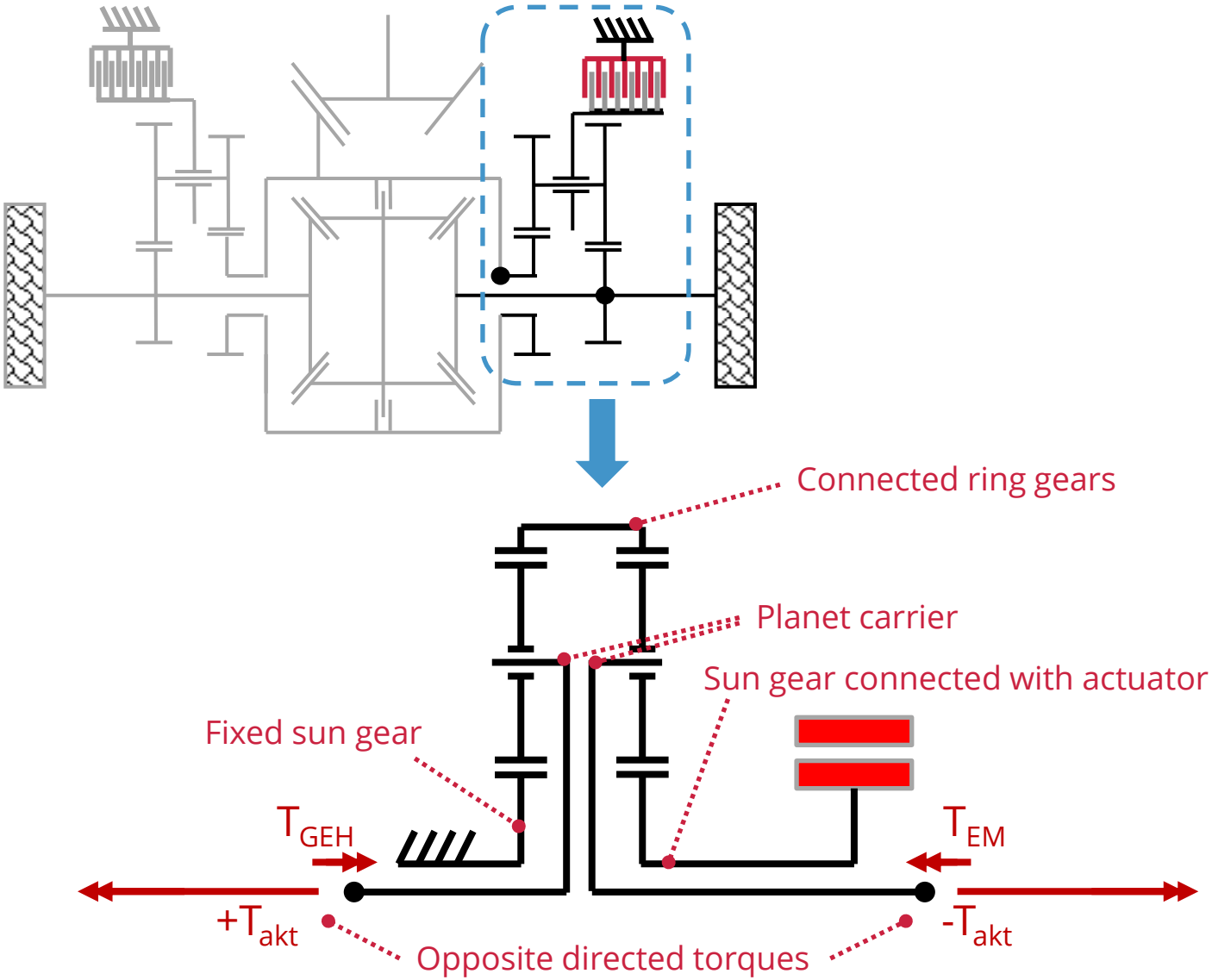
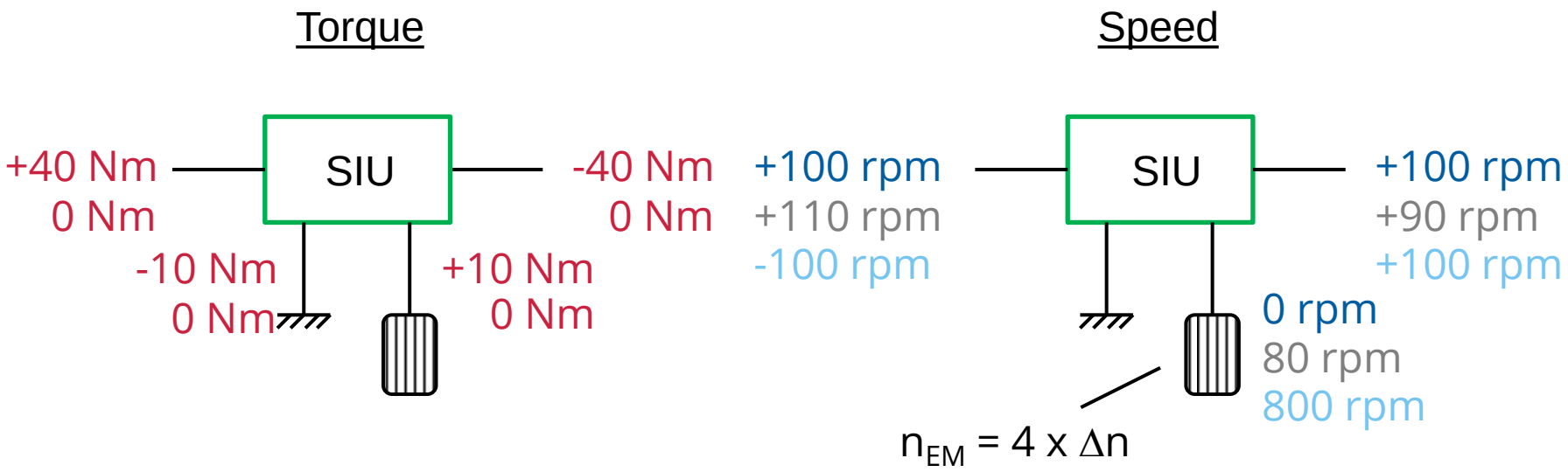
Torque Vectoring Topologies
Superimposing Unit

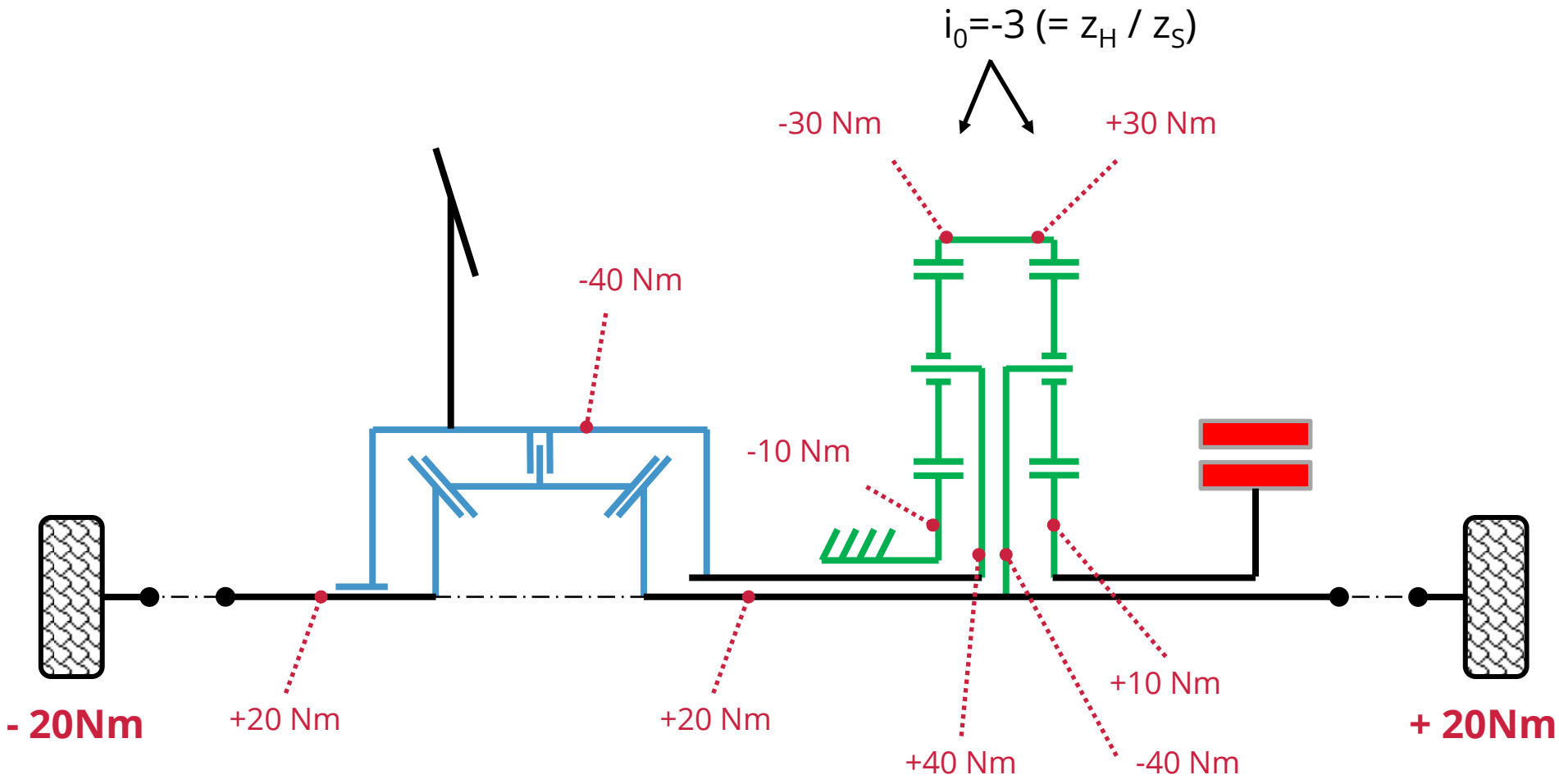


Torque Vectoring Topologies
Basic Principle - Superimposing Unit (SIU)



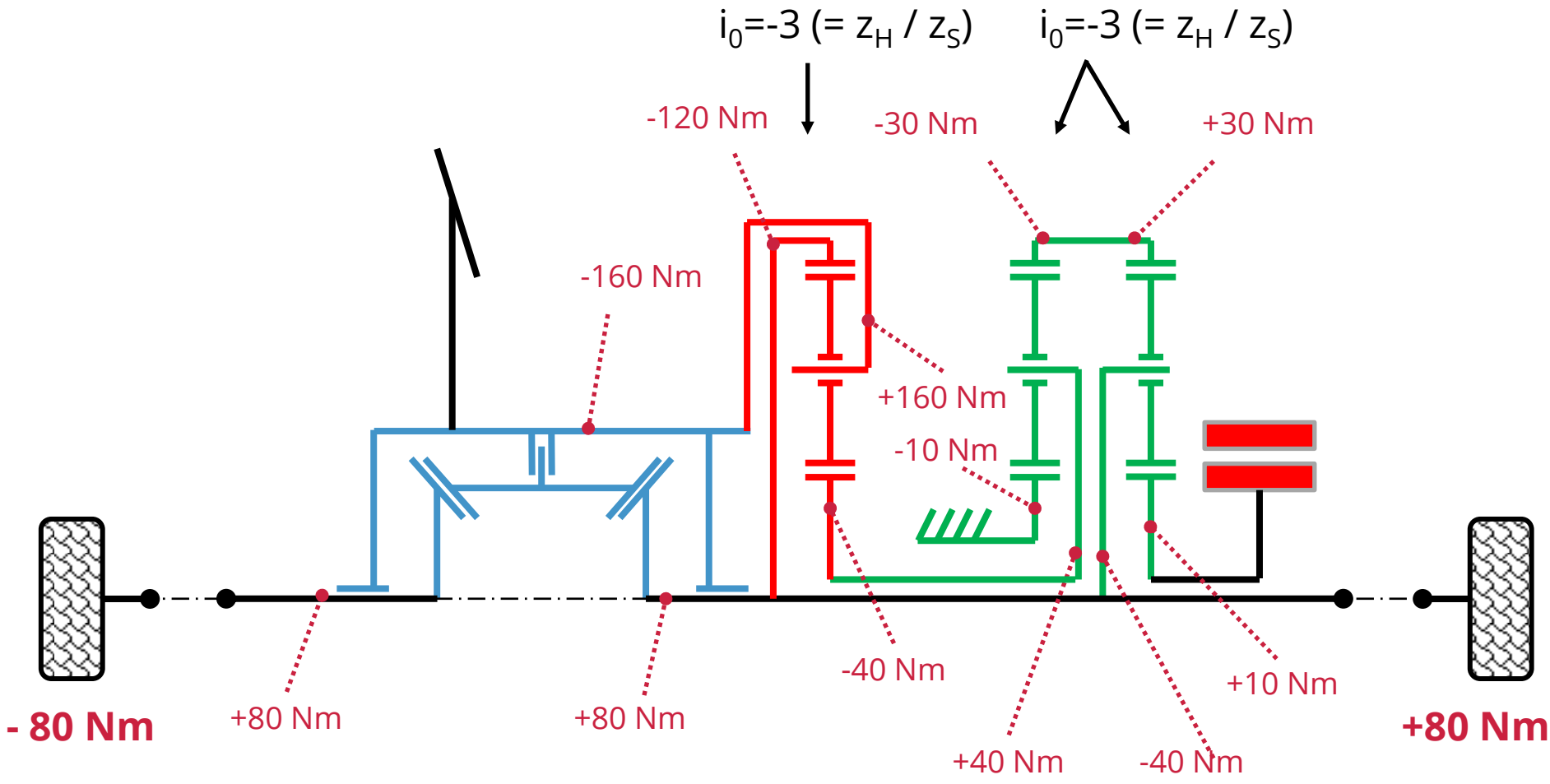
- → *Generation of torque difference independently from speeds*
- → *Generation of opposite torques*
- → *Ratio between torque difference between wheels to E-Motor*
- → *Superimposing unit is state of the art (e.g. in WO 2006/029434 A3)*

Torque Vectoring Topologies
Superimposing Unit



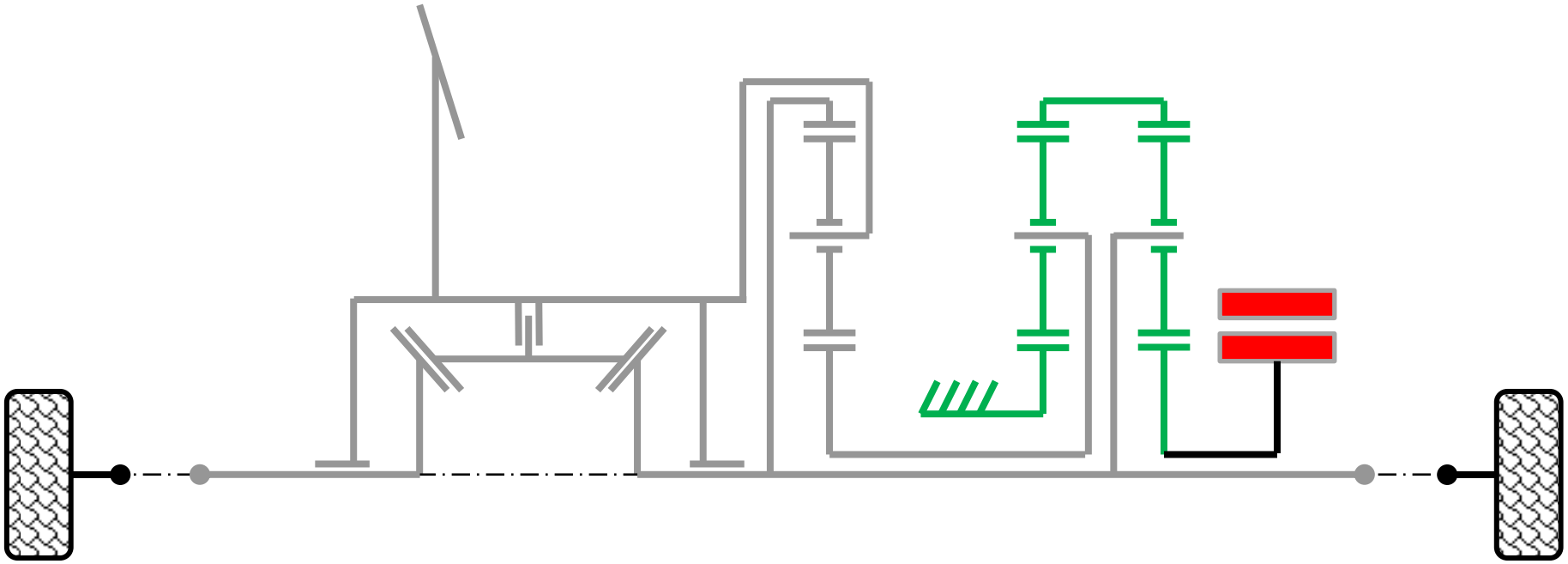
$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{20 - (-20)}{10} = 4$$

Torque Vectoring Topologies
Amplifying planetary gear



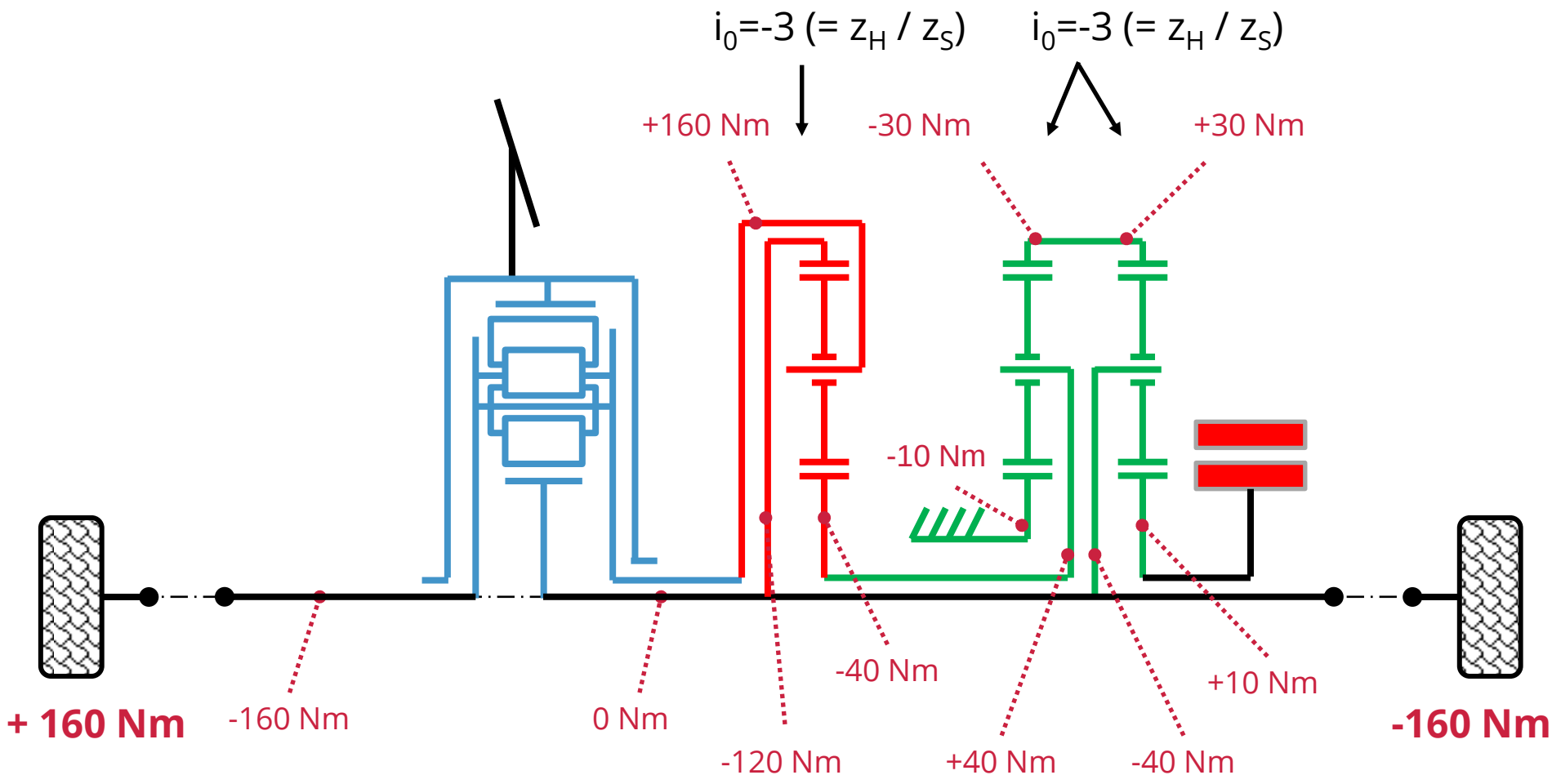
$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{80 - (-80)}{10} = 16$$

Torque Vectoring Topologies
Amplifying planetary gear



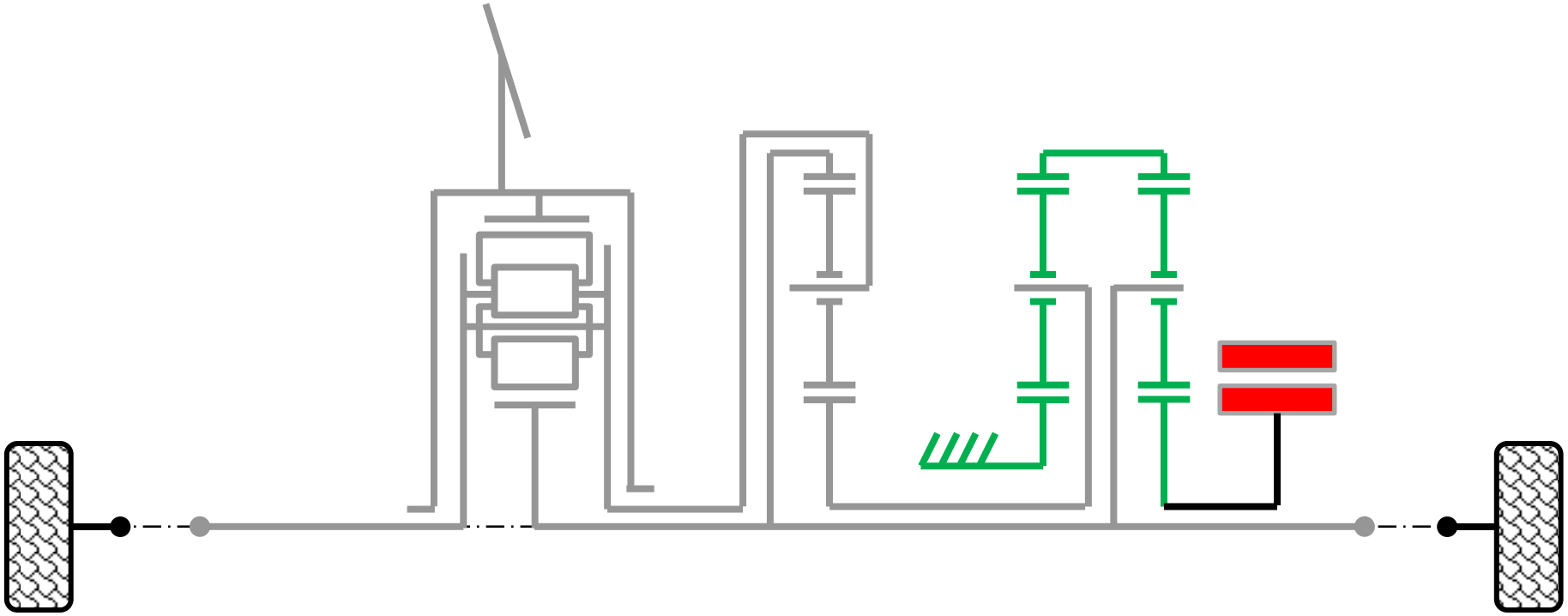
Shafts / gears with speed of wheels

Torque Vectoring Topologies
Amplifying gear + Cylindrical gear diff.



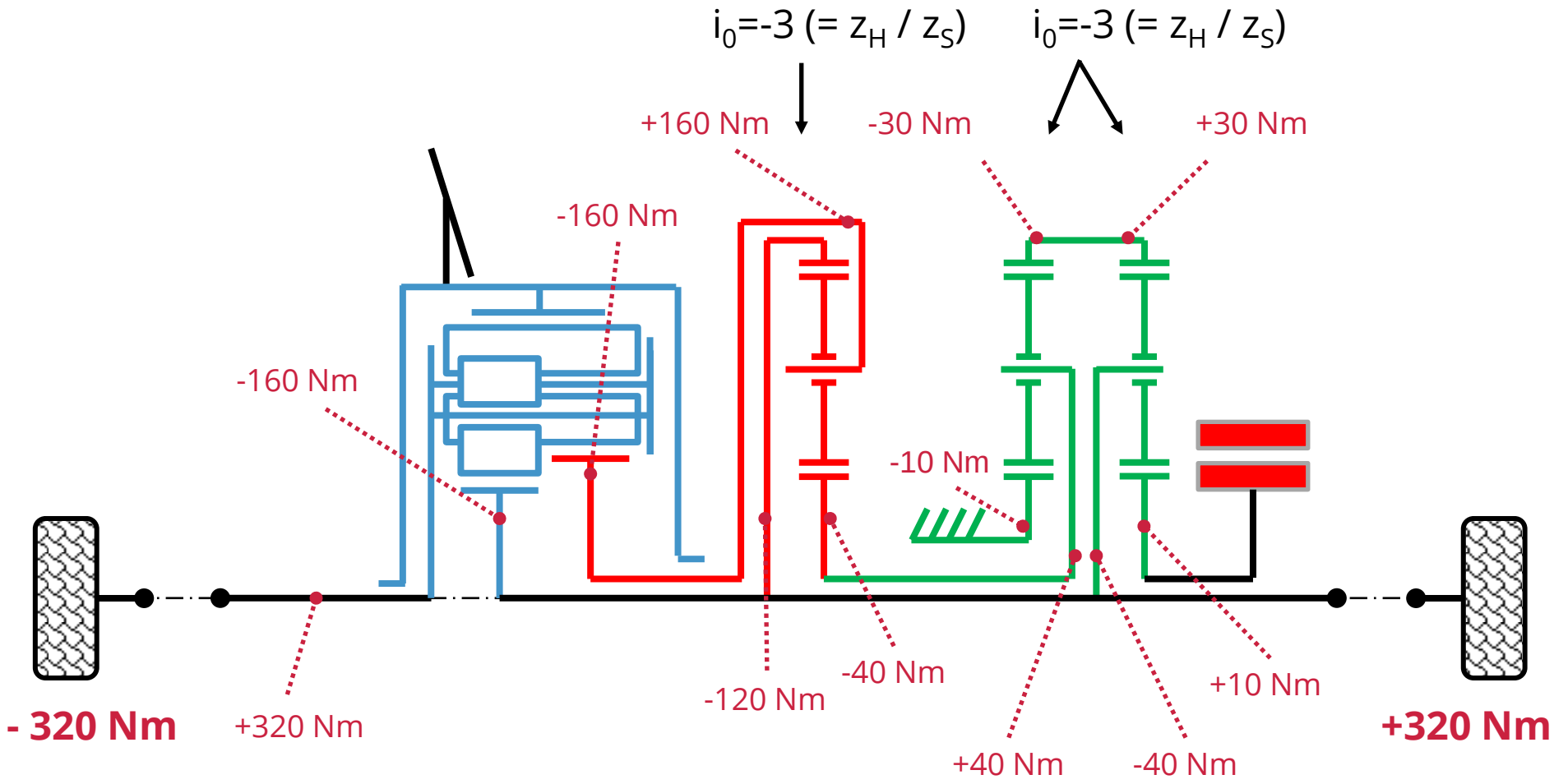
$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{160 - (-160)}{10} = 32$$

Torque Vectoring Topologies
Amplifying gear + Cylindrical gear diff.



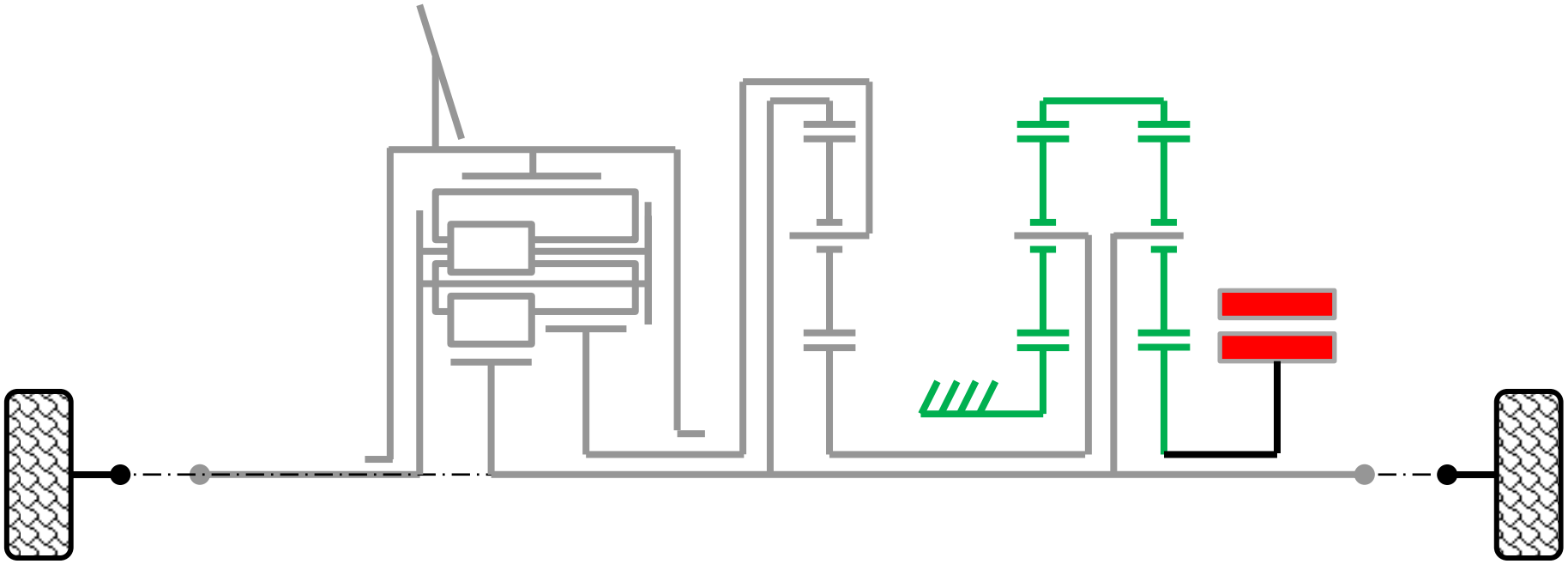
Shafts / gears with speed of wheels

Torque Vectoring Topologies
2x Amplifying gear



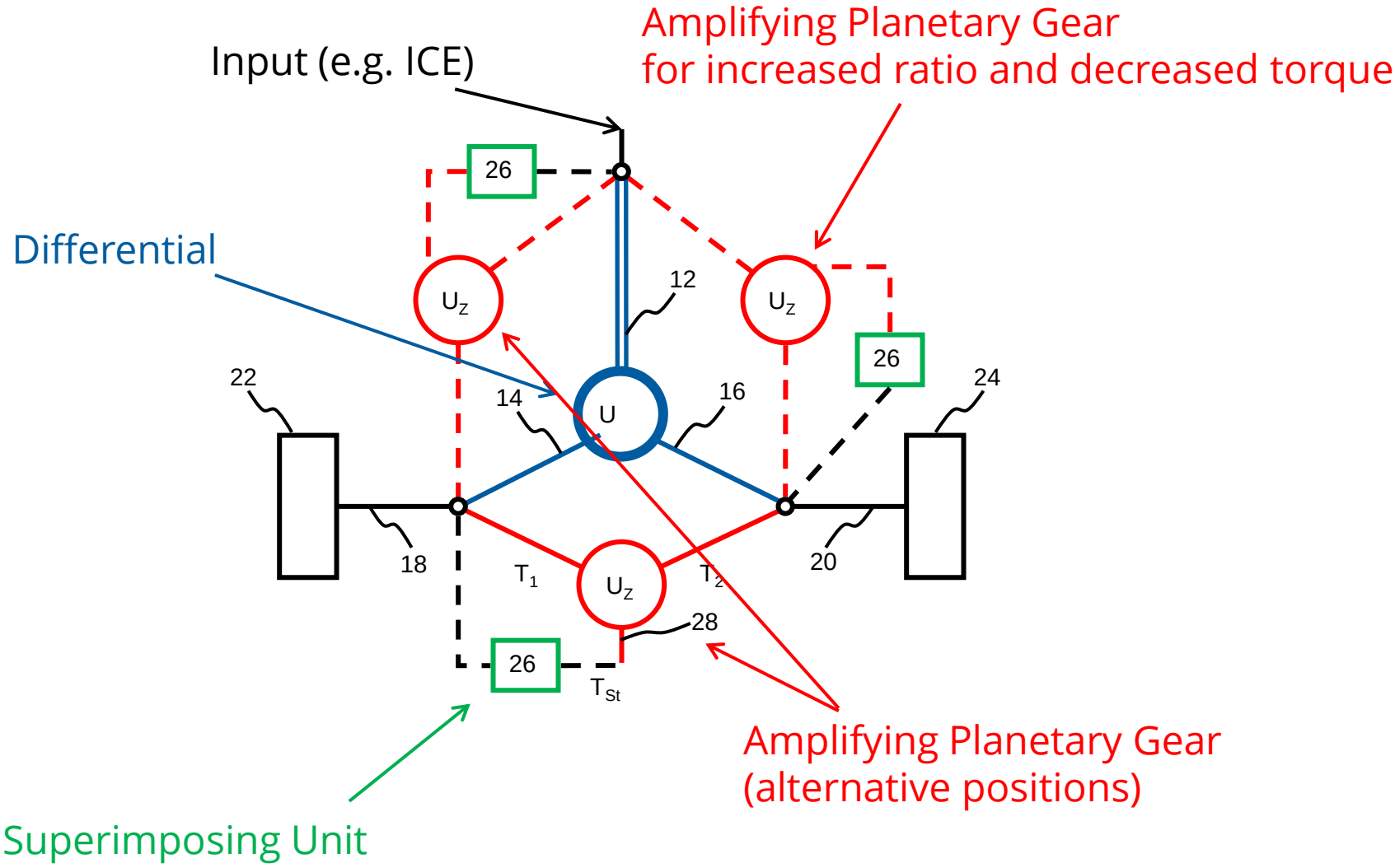
$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{320 - (-320)}{10} = 64$$

Torque Vectoring Topologies
2x Amplifying gear



Shafts / gears with speed of wheels

Basic principle
DE 102007017185 / Prof. Höhn



Content

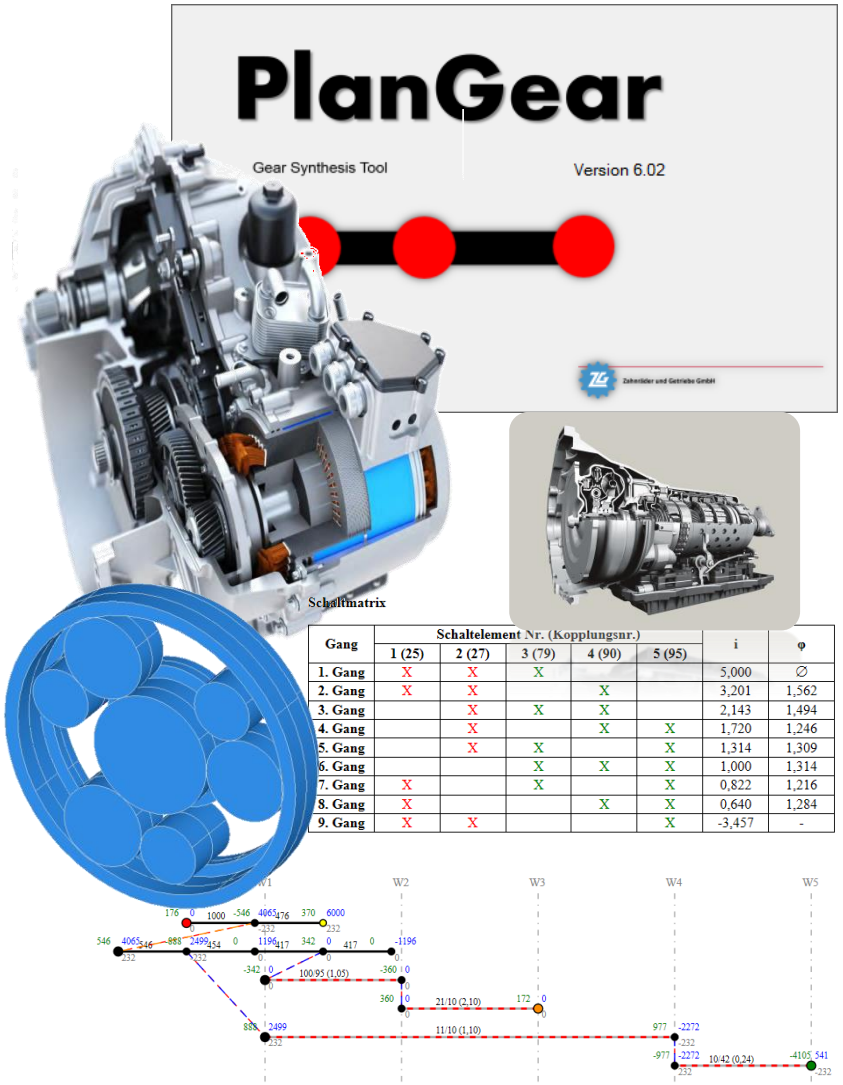
PlanGear – Synthesis Program
Overview and Features

Gear synthesis is the systematic approach of a gear structure with given boundary conditions

ZG is developing its own synthesis tool „PlanGear“ since 2010.

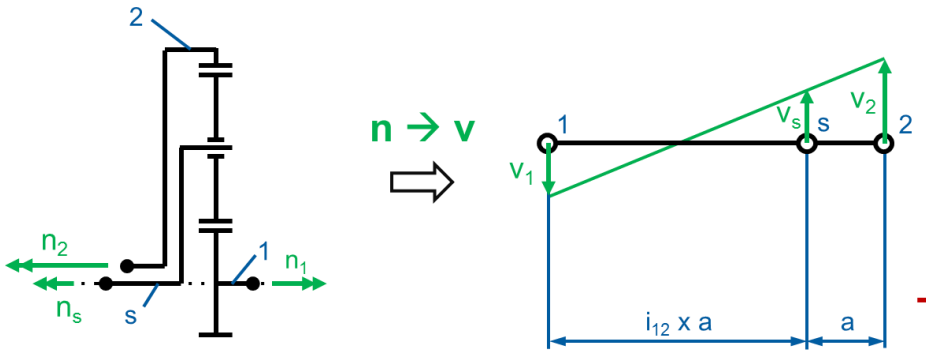
PlanGear is used for generation of gear structures:

- **Simple** and **complex compound** gear sets (e.g. Ravigneaux)
- Transmissions with **any number of shafts** (connected by spur gear stages)
- **AT** and **DCT** (and also crosses between both types → **MCT**)
- Conventional transmissions and hybrid powertrain structures (2 drives, ICE and EM)
- **Torque Vectoring** topologies with hybrid functions

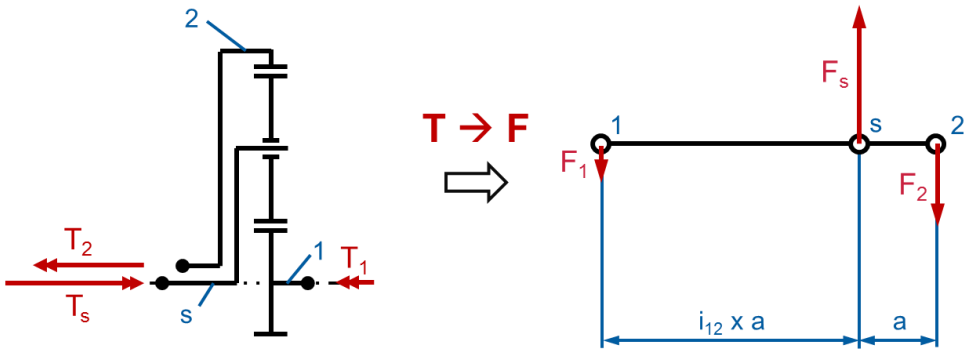


PlanGear – Synthesis Program
Analogy Model according to Helfer*

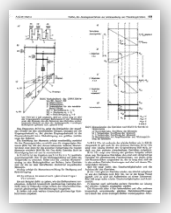
Kinematic equivalence



Static equivalence



*** Dipl.-Ing. F. Helfer:**
Ein Analogieverfahren zur Untersuchung von Planetengetrieben, ATZ 69 (1967), S. 149-152



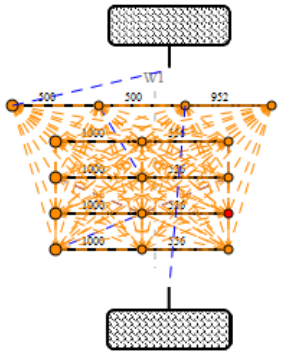
Content

Example
Frame conditions for PlanGear

Note: Following demonstration example is <u>any</u> example. Clearly not best!

<u>Input data for PlanGear:</u>

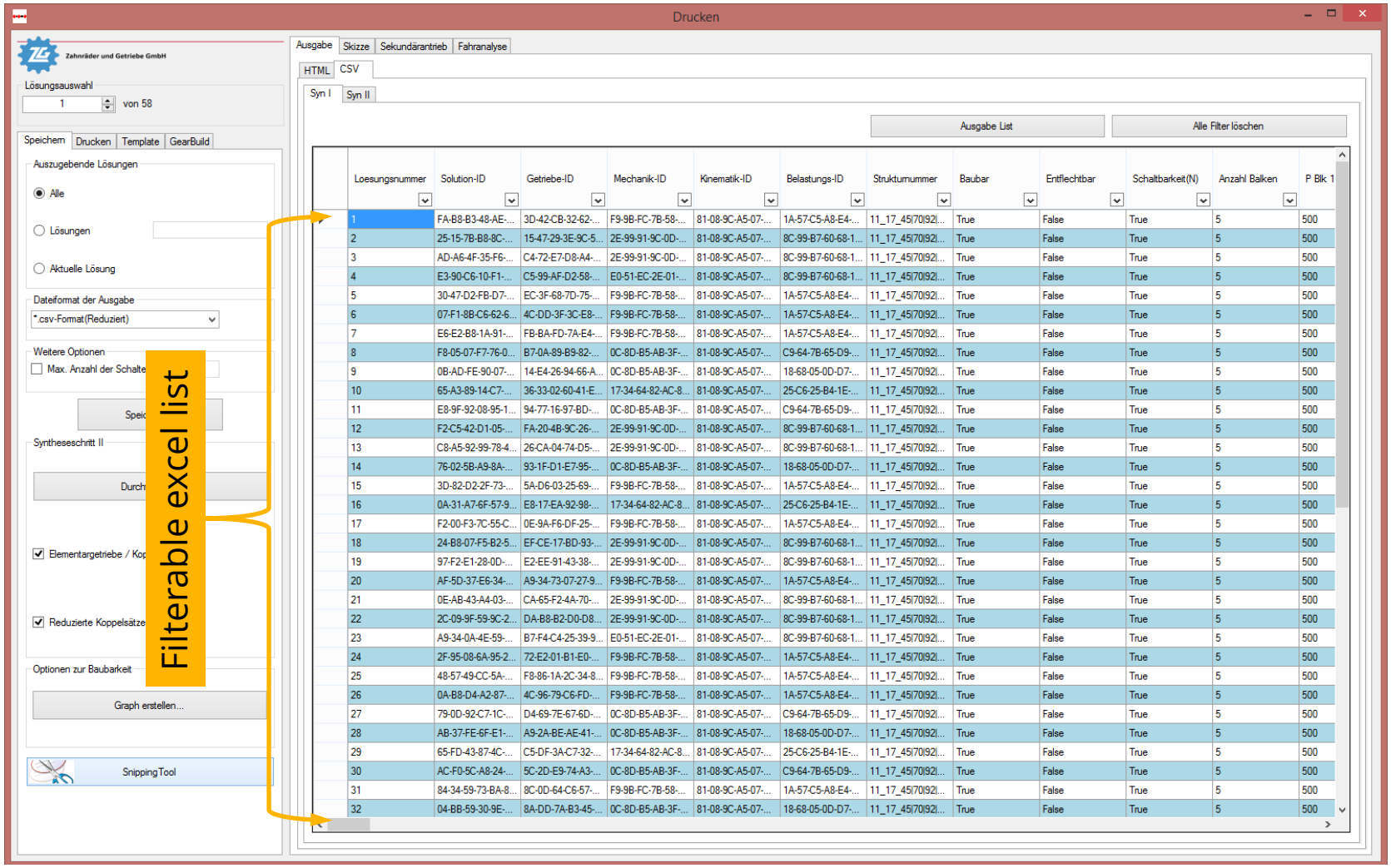
Ratios:
- Gear 1: 14…35 - Parking / maneuvering
- Gear 2: 5…13 - 0…120 km/h
- Gear 3: 2…4 - 120…250 km/h
- TV: $\Delta T_{max} / T_{EM} = 20…25$



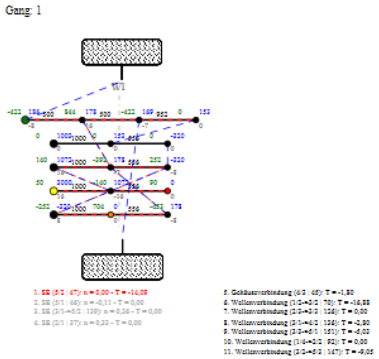
Übersetzungsvorgabe des Primärantriebs

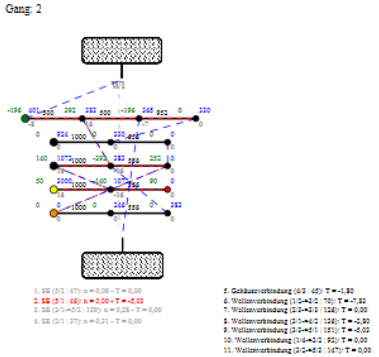
#	R(TV)	Absolut	i_min	i_max	phi_min	phi_max
1	☐	☑	14	35	/	/
2	☐	☑	5	13	1,1	5
3	☐	☑	2	4	1,1	5
4	☑	☑	0,5	2	1,2	10
*	☐	☐				

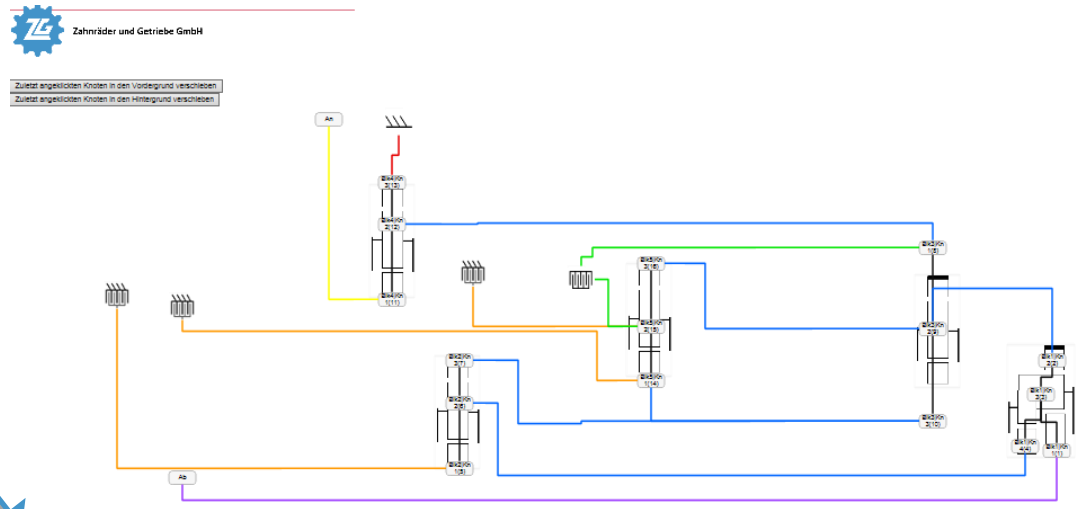
Example
List of results

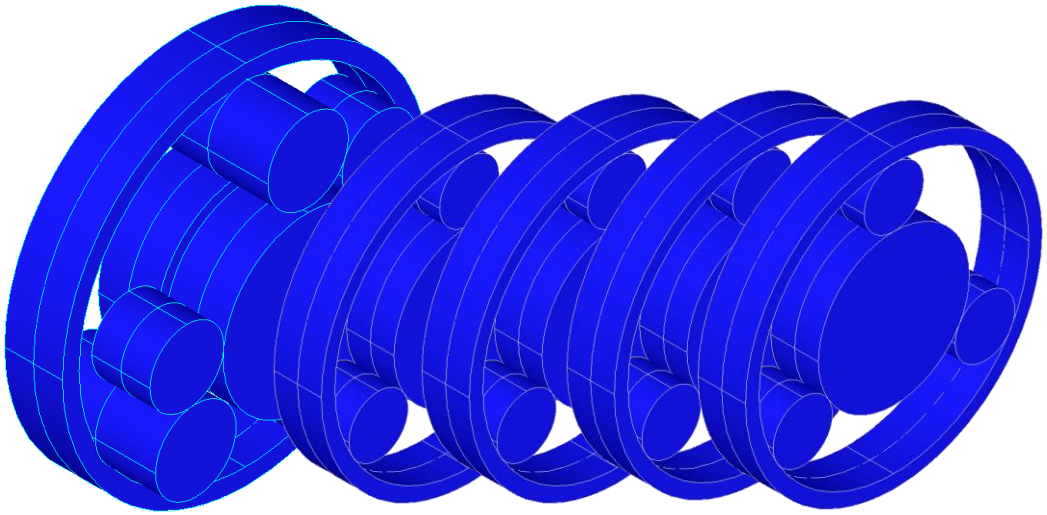


Example
Developing results in PlanGear







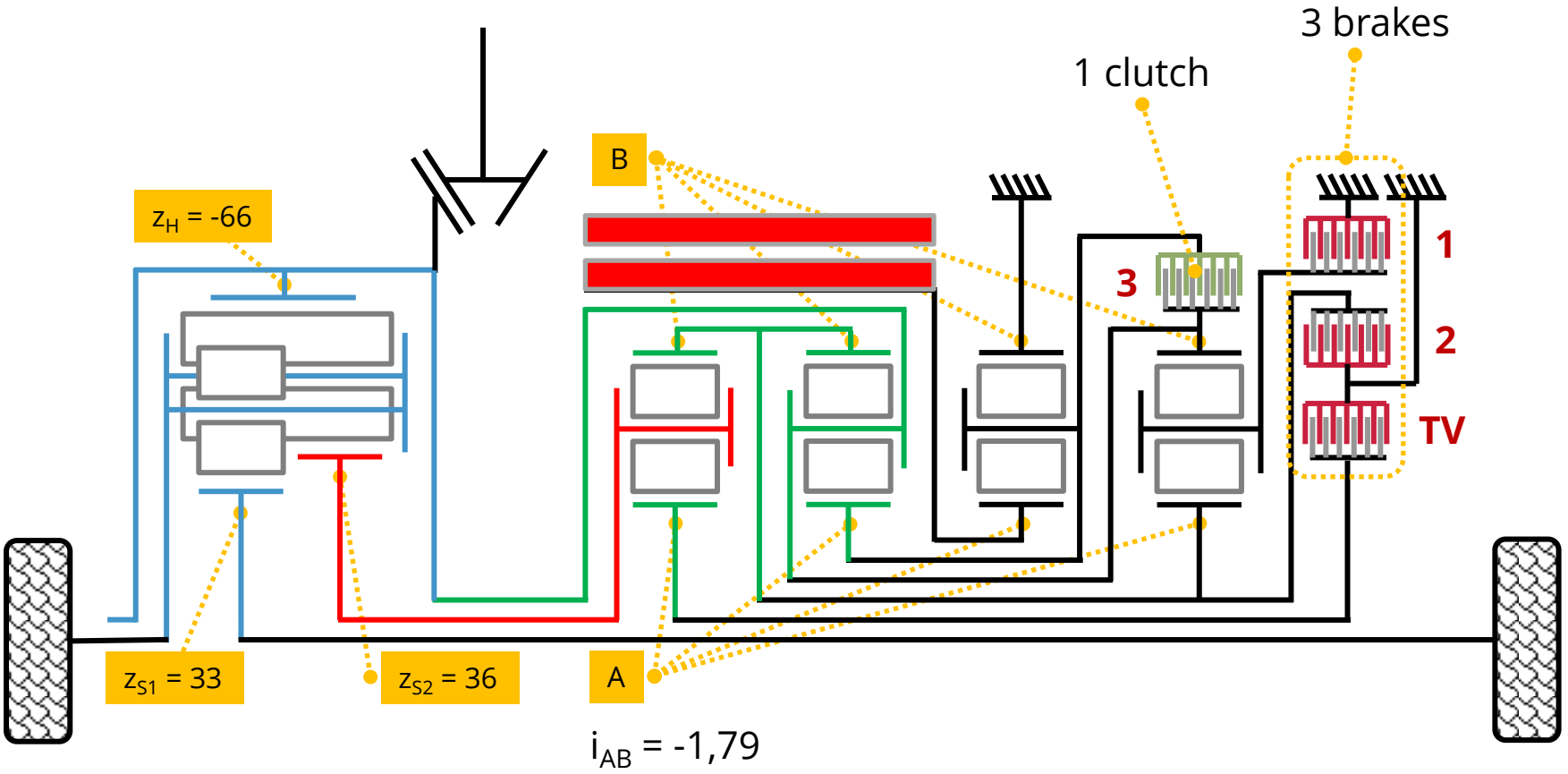


Gear	Shift Element Nr. (Coupling Nr.)				i	φ
	1 (47)	2 (46)	3 (139)	4 (37)		
1. Gear	X				16,122	∅
2. Gear		X			7,478	2,156
3. Gear			X		2,672	2,799
4. Gear				X	1,027	2,601

Gear	Shift Element Nr. (Coupling Nr.)				i	φ
	1 (47)	2 (46)	3 (139)	4 (37)		
1. Gear	-14,086	-0,107	0,357	0,334	16,122	∅
2. Gear	0,082	-5,033	0,275	0,308	7,478	2,156
3. Gear	0,357	0,357	2,335	0,219	2,672	2,799
4. Gear	1,036	1,238	-0,678	2,799	1,027	2,601

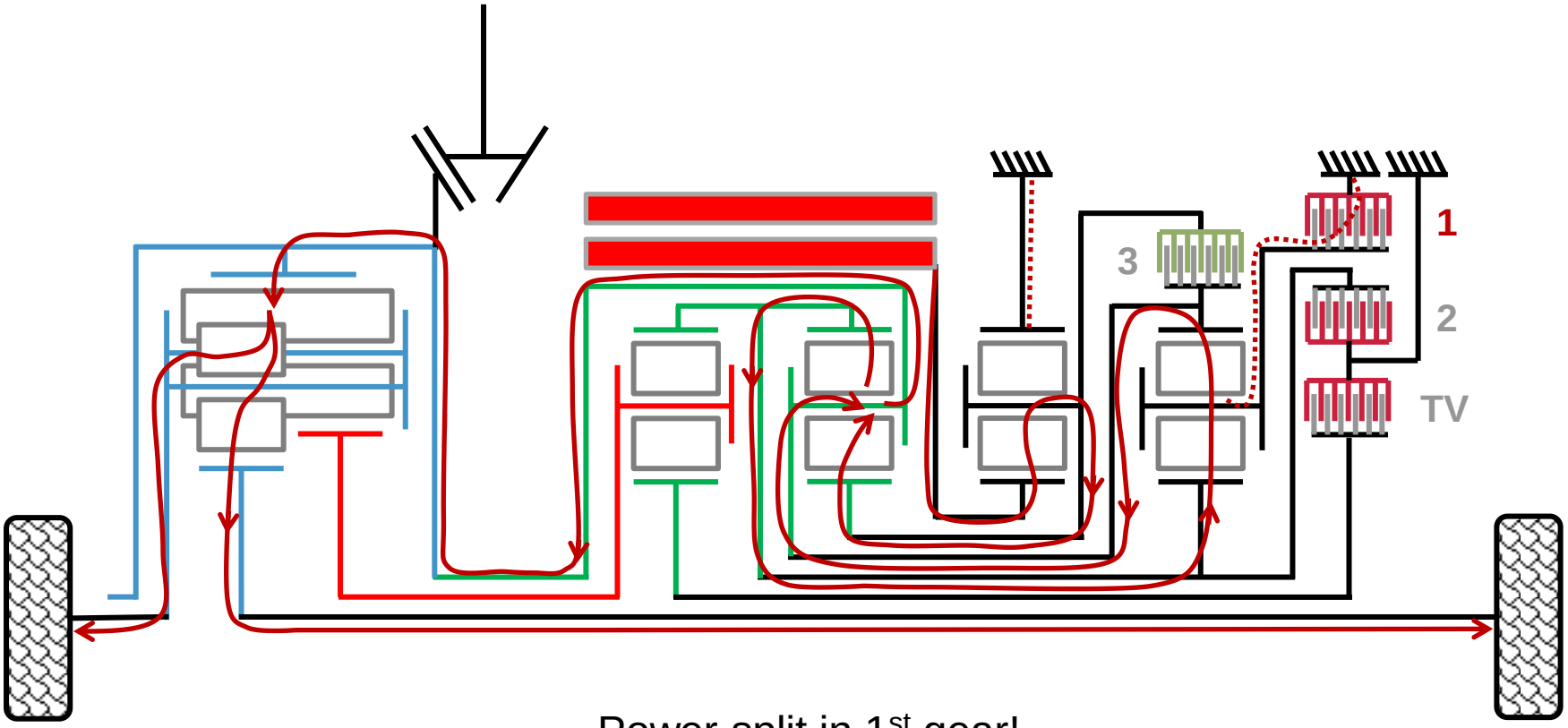
Example
Possible topology with 5 planetary gears

! Demonstration example – better solutions possible !



Example
Power flow – 1st Gear

! Demonstration example – better solutions possible !

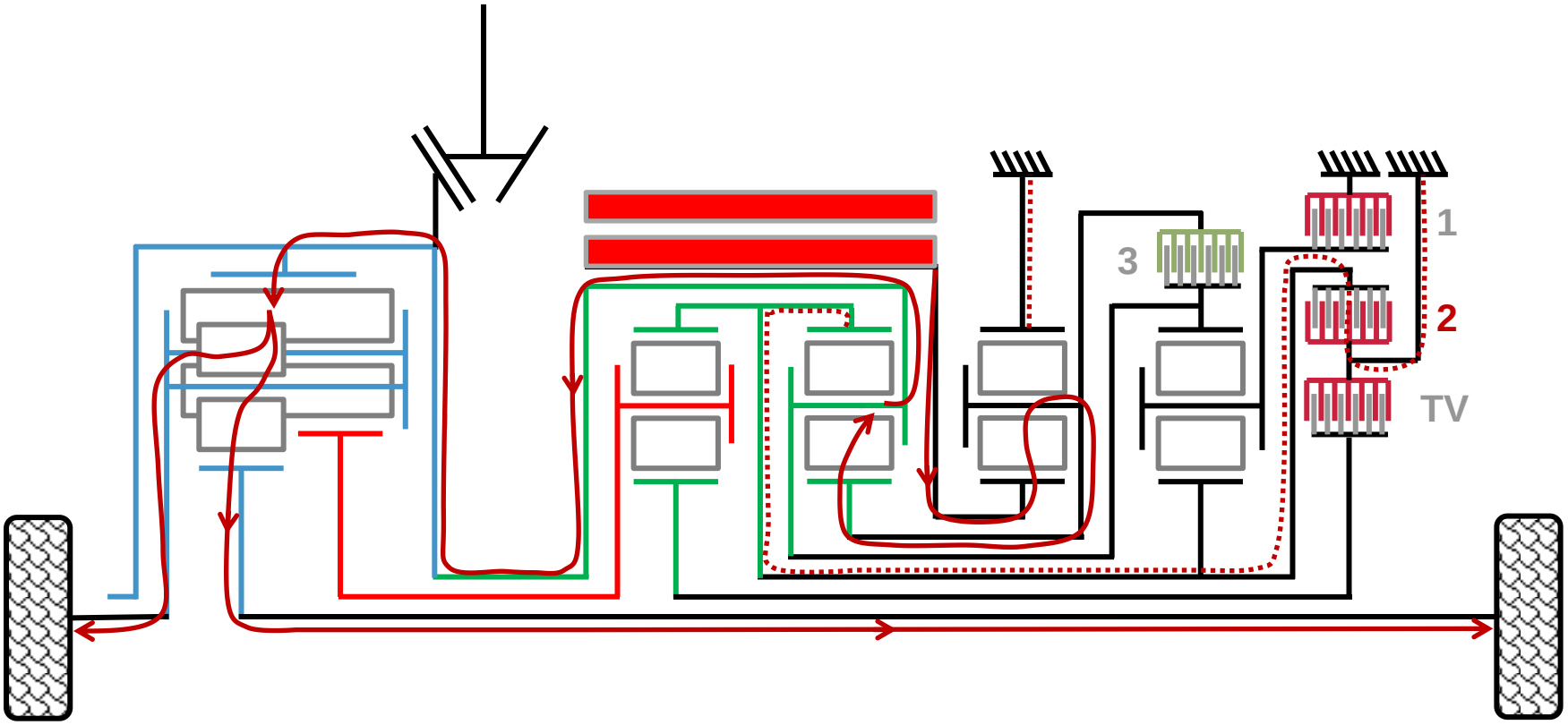


Power split in 1st gear!

$i_1 = 16{,}12$

Example
Power flow – 2nd Gear

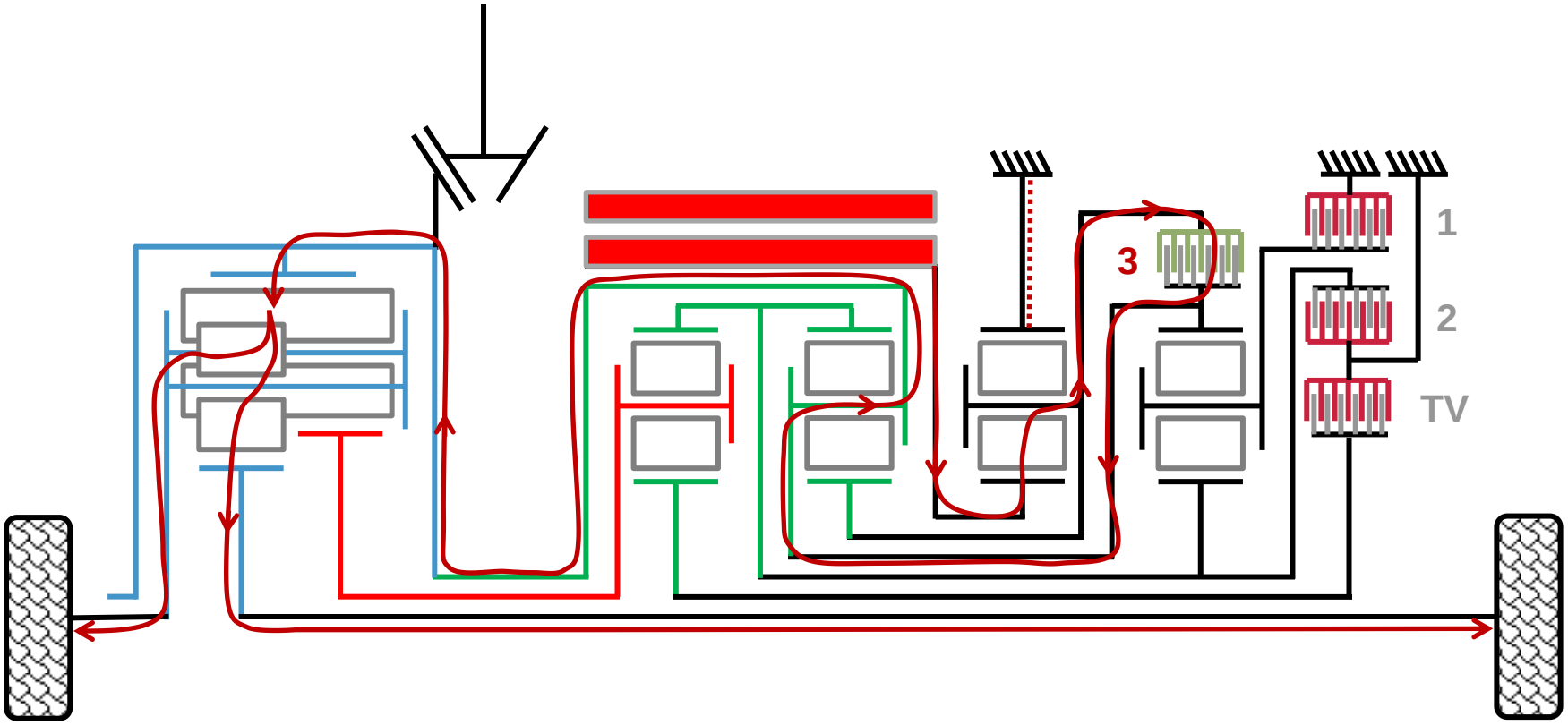
! Demonstration example – better solutions possible !



$i_2 = 7{,}48$

Example
Power flow – 3rd Gear

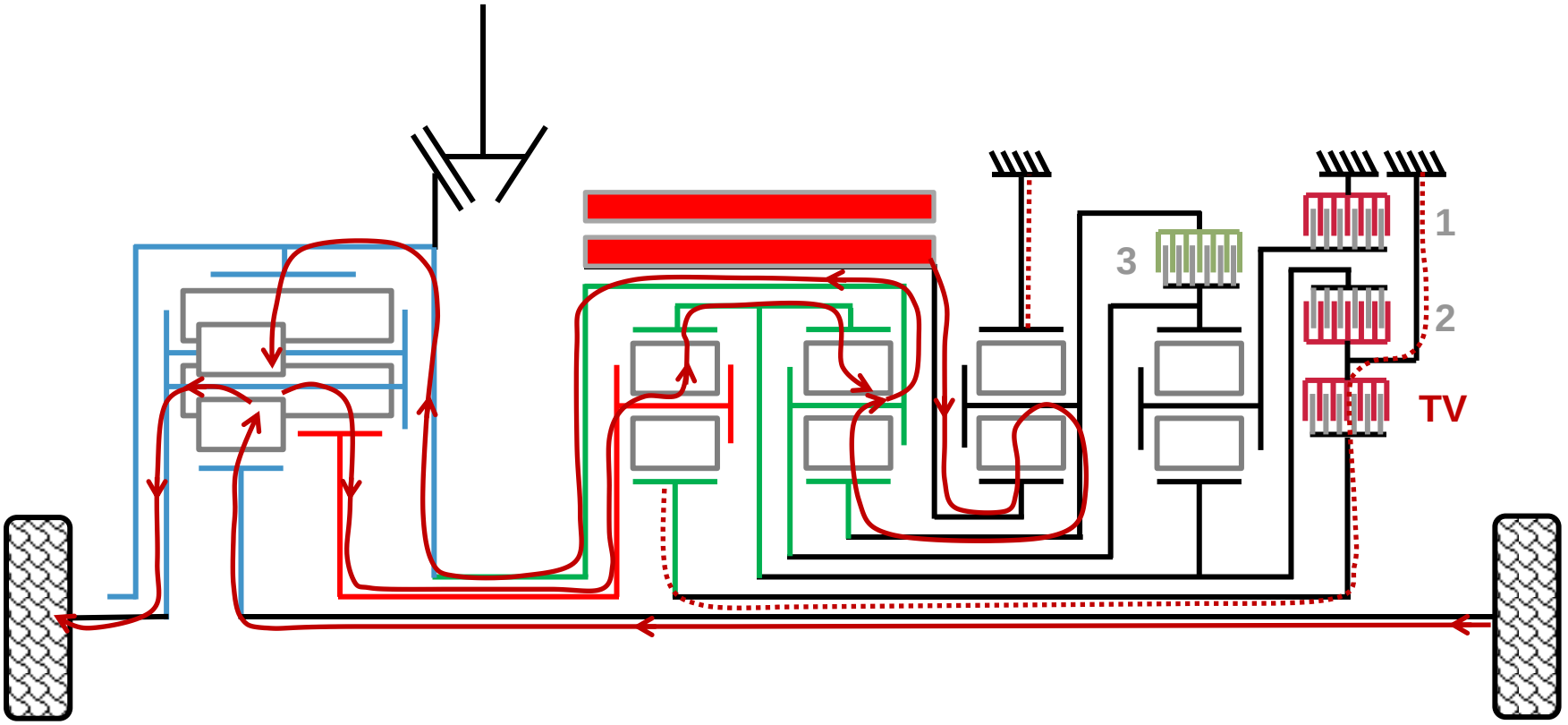
! Demonstration example – better solutions possible !



$i_3 = 2{,}67$

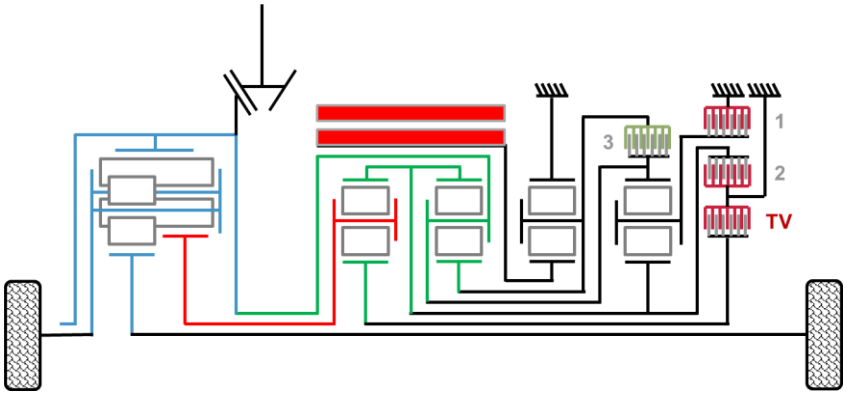
Example
Power flow – Torque Vectoring

! Demonstration example – better solutions possible !



$\Delta T_{Wheels} / T_{EM} = 22{,}76$

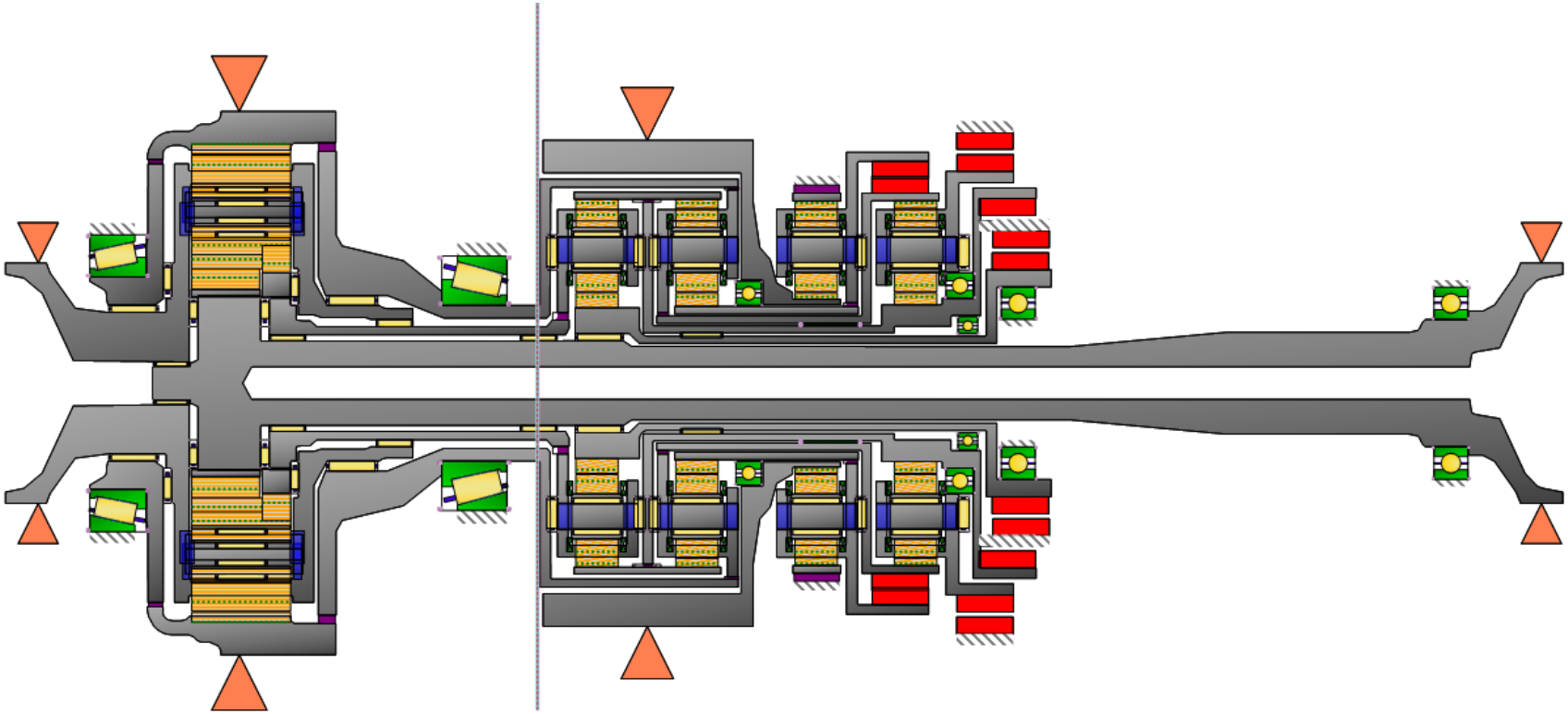
Example
Efficiency grades



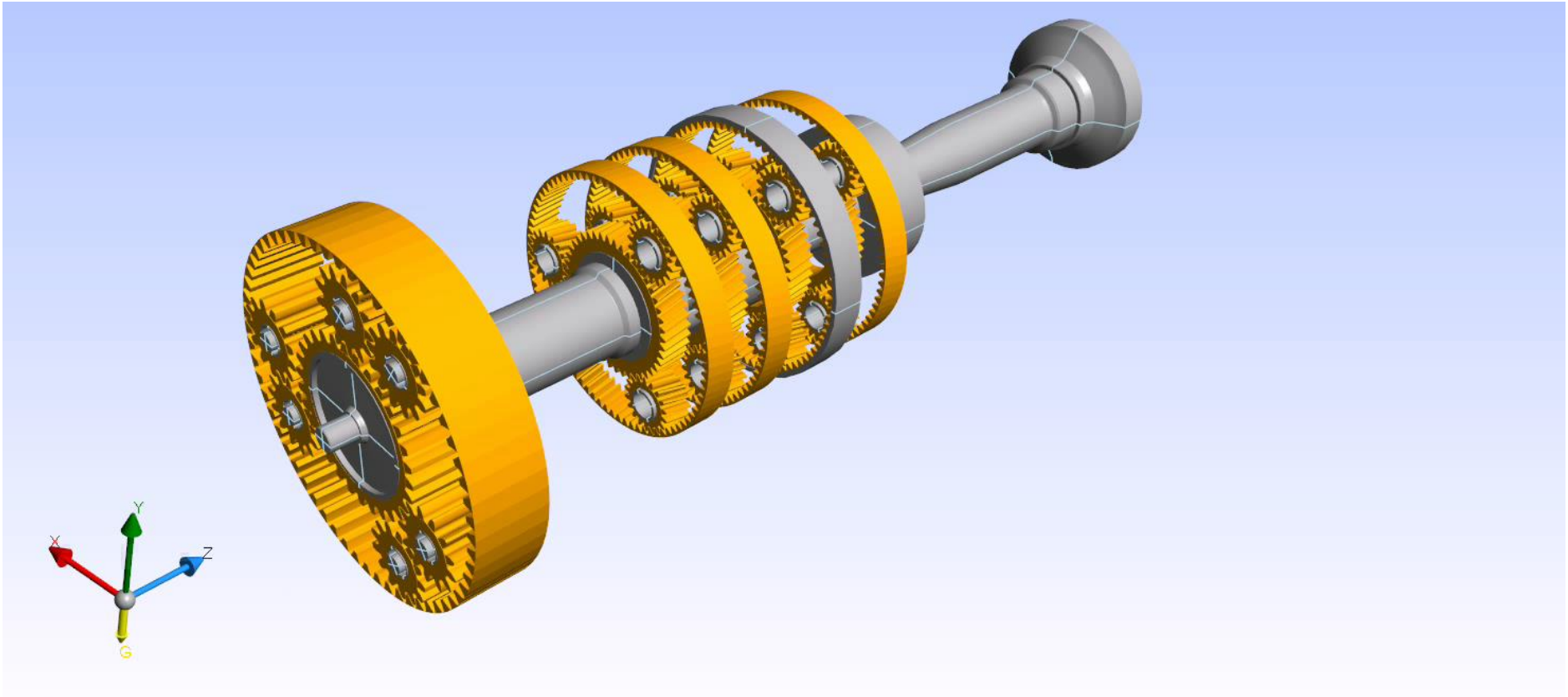
Primary Input				
Option RS(1)-KS(1)-KS(1)-KS(1)-KS(1)				
Feasible				
Gear	**1**	**2**	**3**	**4**
Efficiency [%]	92,0	94,8	97,3	100,0
Power loses [kW]	0,7	0,4	0,2	1,9
Bearing speed [1/min]	4826	4826	4826	5975

→ Load dependent mesh losses considered (defined operation mode)
→ Internal gears: η_{VZ} = 99,5%
→ External gears: η_{VZ} = 98,5%

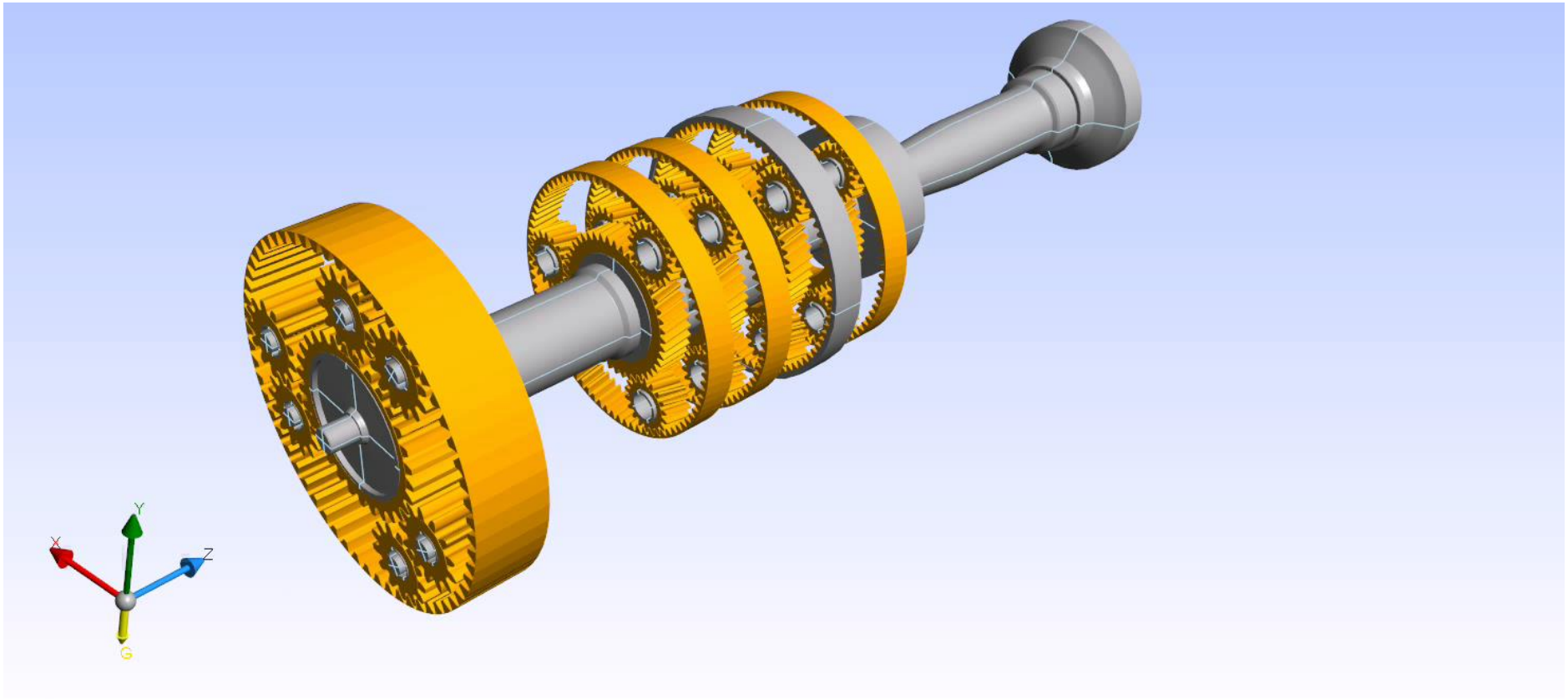
Example
MASTA-Design (rough)



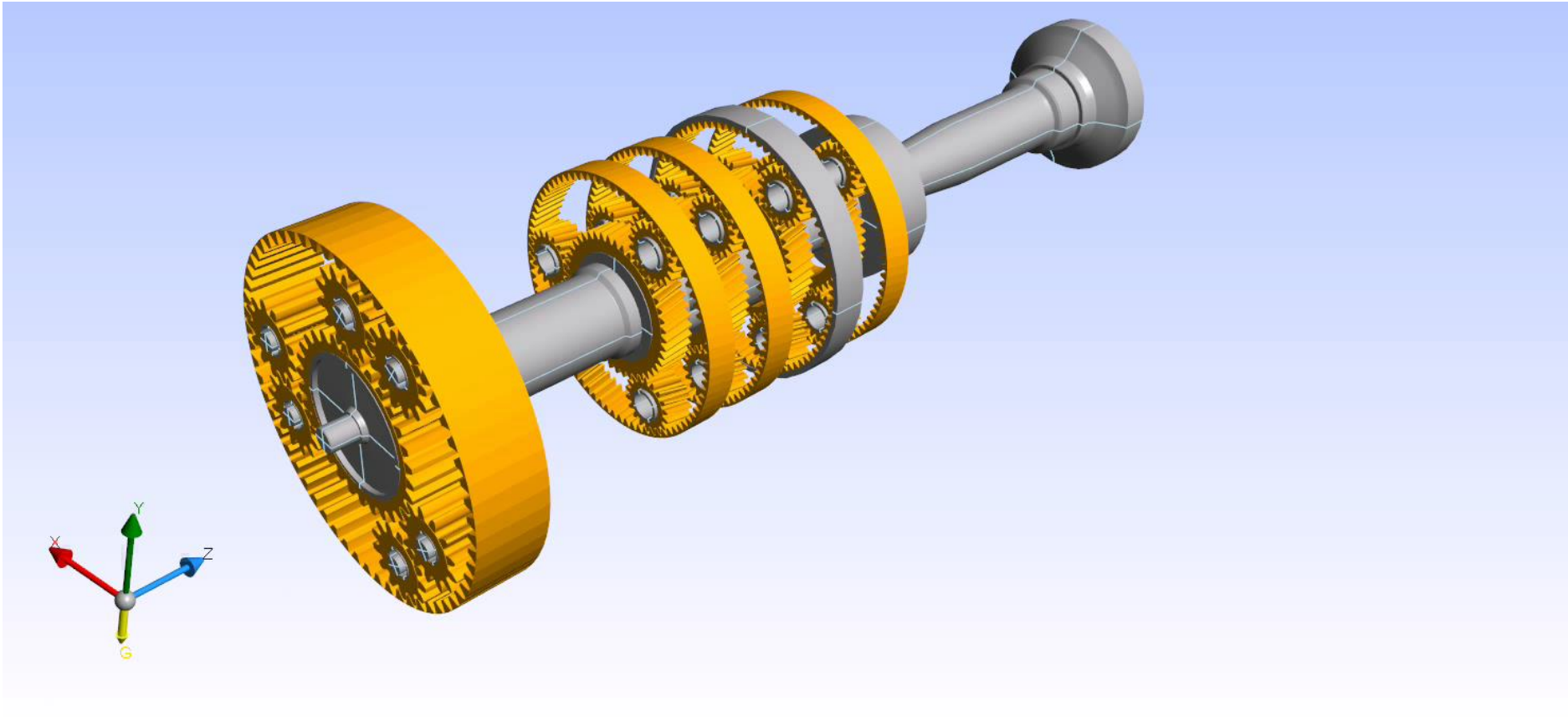
Example
Animation 1st gear



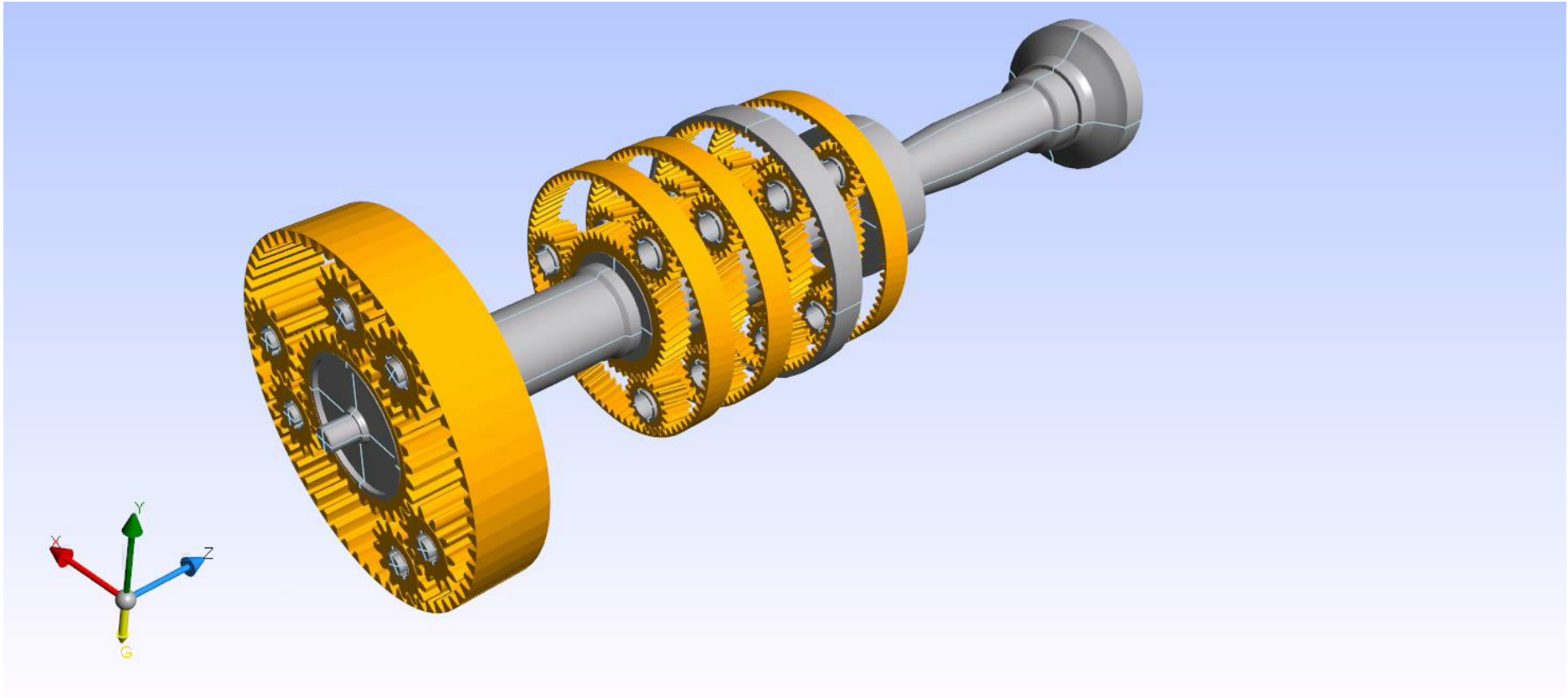
Example
Animation 2nd gear



Example
Animation 3rd gear



Example
Animation Torque Vectoring



Content

Summary

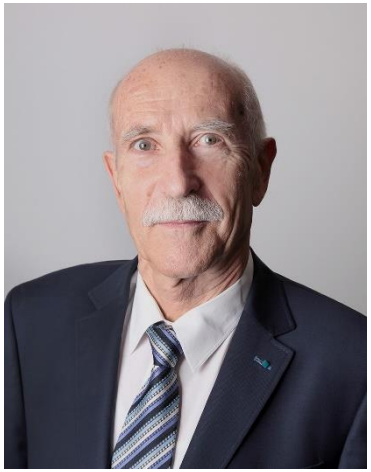
- General principles of torque vectoring (TV) with superimposing units were shown.
- Amplifying planetary gears lead to increased TV-ratios and reduced torques on superimposing gears (→ reduced weight).

- Gear synthesis program “PlanGear” was enabled to calculate torque vectoring structures in combination with hybrid functionalities.

- An example topology generated by PlanGear was explained:
  - Inline arrangement of 5 planetary gears including 1 Ravigneaux gear set.
  - 3 gears for hybrid functionalities over whole speed range of the car.
  - 1 torque vectoring gear for whole speed range.
  - High efficiency in all operating modes.
  - Disc clutches and brakes for fast, reliable and comfortable gear shifts.

Example
Animation Torque Vectoring

Thank you!



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